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INSPIRE
2017

Paper Proceedings

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ISBN: 978-93-5291-610-8

FOREWORD

Both nationally and internationally, India's trajectory of energy consumption, economic development and urban infrastructure growth has incubated several policy debates, business interventions and investment decisions amongst researchers, governments, businesses, multilateral and bilateral banks, respectively.

With stimulating and timely questions, INSPIRE brought together the energy efficiency community for a first of its kind conference with a sharp focus on India's energy efficiency sector, with peer-reviewed research, analytically sound and economically sensible discussions on policies and markets. INSPIRE created a platform for multidimensional evaluation of EE in India by sharing of lessons from extant projects across sectors to presentation of research and analysis for new ideas that lead speedy and constructive actions to help India attain its full energy saving potential.

To turn ideas from INSPIRE into real-world actions, this electronic document includes all of the technical papers presented at the conference. The papers cover the depth and breadth of the EE landscape - from building data frameworks, space cooling, appliance standards, energy services, EE co-benefits, to name a few. The conveners hope that the energy efficiency community - in government, businesses and civil soci-ety organisations - finds this compilation of papers enriching and useful in their technical projects and pol-icy and business decision making in the near and future term.

Bringing out credible research and analysis in public domain has a tremendous role as evidence for effec-tive policy measures and scalable business innovation. Keeping this in mind, the conveners used a double blind peer-review process to curate the papers presented in the conference. Such a state-of-the-art review process has never been used for selecting research papers in conferences in the Indian energy and climate sector before and hence, the review process used at INSPIRE has raised the bar for producing research on pressing policy and market questions. By means of the insights shared in this proceeding, the conveners also hope to bring consistency and clarity in the ambitions of public policy makers, businesses and finan-cial institutions.

Close to 250 abstracts were received in early 2017, from which 66 papers have been published in this electronic document for putting in public domain for researchers, consultants/practitioners and policy makers and business and industry to access and help advance the knowledge in the EE in India. The peer review effort was led by more than 50 technical committee members including nine panel leaders - from academia/research, policy and business and industry segment to provide a well rounded and balanced perspective to the whole process. The technical papers in this proceeding have been organised under three sections - Buildings, Systems and Technologies, Business and Industry and Codes, Standards and Policies - similar to the three panels under which the whole set of technical papers were organised and presented at INSPIRE. Given the papers have been received from multiple authors, there are some inconsistencies in the formatting of this document, although the technical information is correct to the best of the conveners' knowledge.

The conveners are delighted to present this electronic proceeding which captures the research produced for INSPIRE. They hope that this document, while a solid first step for transforming EE adoption in India, unites stakeholders for the journey onwards to actions and solutions that reap the full rewards of energy efficiency in India.

Satish Kumar

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BUILDINGS & APPLIANCES

COMFORT AND ENERGY ASSESSMENT OF LOW-COST PUBLIC HOUSING SCHEME IN ETHIOPIA

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Keywords: Ethiopia, Public housing, Thermal Comfort, Energy performance

ABSTRACT

This paper deals with thermal comfort & energy performance assessment of public housing schemes in various climate zones of Ethiopia, (3–15° N, and 33–48° E). Ethiopia has five major climate zones. Since 2005, the government, through the Ministry of Works and Urban Development (MWUD) is involved in providing public housing for the middle and low-income group in urban areas. Till date nearly 150 thousand houses has been built under the Integrated Housing Development Program (IHDP) scheme as low-cost housing focusing on affordability. The buildings are condominiums ranging from 3 stories to 12 stories high. However, the spatial design and materials specified for construction are consistent across all climate zones. The aim of this paper is to investigate the thermal comfort and energy performance variations of these buildings across the five climate zones of Ethiopia. Four housing design layouts has been considered in this study. Detailed thermal models of these buildings are created using energy plus software tool based on building plans and construction document specifications obtained from MWUD. Thermal comfort and energy simulation are carried out using epw weather data of representative cities in five major climate zones based on the Koppen Geiger classification. The results indicate that there is a significant difference in thermal performance of these buildings at different climates as well as different housing units in the same building. Based on the results obtained, the study identifies possible improvements for better thermal performance and energy efficiency.

INTRODUCTION

Housing shortage is a major challenge in urban areas in Ethiopia. There has been more than 900 thousand houses deficit in 2004 and increasing(Un-Habitat, 2011). Since 2005, the government, through the Ministry of Works and Urban Development (MWUD) is involved in providing public housing for the middle and low-income group in urban areas(Ministry of Works and Urban Development, 2010). Till date nearly 150 thousand houses has been built under the Integrated Housing Development Program (IHDP) scheme as low-cost housing focusing on affordability. The buildings are condominiums ranging from three stories to 12 stories high.

Design & construction irrespective to climatic conditions means either to create uncomfortable indoor environments or to increase the need for maintaining thermal comfort through artificial means (Bodach, Lang and Hamhaber, 2014). Climate responsive architecture therefore is a practice used to make buildings more thermally sound & comfortable while making them less energy intensive.

There are no existent climate and functional performance based building design regulations in Ethiopia. Additionally, the integrated housing development program does not include thermal performance assessment of the public housing. The current study is therefore an attempt to demonstrate the level of thermal comfort these houses offer for their occupants under varied outdoor environmental conditions.

THERMAL COMFORT & ENERGY PERFORMANCE ASSESSMENT

Functional efficiency of buildings is determined by the level of thermal, acoustic, ergonomic & visual comfort they provide for their occupants(Krüger and Zannin, 2004). In naturally ventilated buildings, it is the result of a series of interactions that can be summarised into three broad categories namely, climate-occupant interaction, building-occupant interaction and climate-building interaction(Rajasekar *et al.*, 2015). Hence, ensuring occupant thermal comfort is dependent upon three variables; outdoor climate conditions, building's thermal performance & inhabitants themselves.

According to the Indian standard (SP: 41, 1987), there are three aspects in the thermal design of buildings. Firstly, an evaluation must be made of indoor thermal condition most conducive to comfort, health and safety of the occupants. Secondly, it is necessary to describe optimum outside climatic data that must be taken into account when developing the best design to suit specific procedures. Thirdly physical properties of structural materials which can be effectively utilized to ensure the best possible control of living and working environments. The main factors determining the thermal response of a building are the heat gains or losses through various structural elements, the internal heat loads, and rate of ventilation. The structural heat gains or losses are dependent on certain properties of the elements concerned, for instance heat gain through walls depend upon the colour of the outside surface, the heat storing capacity of the walls and their thermal resistance or insulation property.

(Lin and Deng, 2008) emphasized that, judgment of comfort is a cognitive process involving many inputs influenced by physical, physiological, psychological, and other factors. In general, comfort occurs when body temperatures are held within narrow ranges, skin moisture is low, and the physiological effort of regulation is minimized.

Building thermal performance is aimed to ensure minimum energy consumption and acceptable indoor thermal conditions by regulating thermal transfer through building envelope (Vijayalaxmi, 2010). (OTTV, SP: 41). Additionally, some standards (ASHRAE 90.1, ECBC) include HVAC, Lighting & electricity usage minimum requirements together with building envelope specifications.

Detailed case by case studies were made for specific geographic locations in various countries (Rajasekar *et al.*, 2015), (Rajasekar and Ramachandraiah, 2010), (Dili, Naseer and Varghese, 2010), (Haase and Amato, 2009), (Kuchen and Fisch, 2009), (Nicol 2004), (Oktay, 2002), (Labaki and Kowaltowski, 1998), (Etzion *et al.*, 1997) among others. The aim of these studies were either to investigate the building thermal performance of vernacular architecture in response to their surrounding microclimate or else to study occupant behaviour and adaptive thermal comfort conditions.

OBJECTIVE & METHODS

The main objective of this paper is to analyse thermal comfort & energy performance variations of public housing schemes in various climate zones of Ethiopia. Detailed thermal models of selected buildings are created using energy plus software tool based on building plans and construction document specifications. Analysis and comparison of thermal comfort is performed using various indexes. Ground measurements and occupants demographic profile assessment is yet to be undertaken. For the time being only computer generated simulation is used.

CONTEXTUAL ASSESSMENT

CLIMATE & COMFORT

Maintaining thermal equilibrium between the human body and its surrounding environment is an essential requirement for health and comfort (Givoni, 1976). Analysis of the annual patterns of the main climatic factors affecting human comfort and the thermal performance of buildings is therefore one essential (Givoni, 1992). Certain elements of climate; like daily and hourly temperature, humidity, wind, and sunlight demand careful investigation in attaining climate responsive design (Hyde, 2000).

Traditionally, the three major climate zones in Ethiopia are tropical (Kolla), sub-tropical (Woina dega) & cool (Dega) *(Figure 1)*. Tropical zone is below 1830 meters in elevation and has an average annual temperature of about 27 degree Celsius with annual rainfall about 510 millimetres. The Danakil Depression (Danakil Desert) is about 125 meters below sea level and the hottest region in Ethiopia where the temperature climbs up to 50 degree Celsius. Subtropical zone includes the highlands areas of 1830 - 2440 meters in elevation and has an average annual temperature of about 22 degree Celsius with annual rainfall between 510 and 1530 millimetres. The cool zone is above 2440 meters in elevation with an average annual temperature of about 16 degree Celsius with annual rainfall between 1270 and 1280 millimetres.

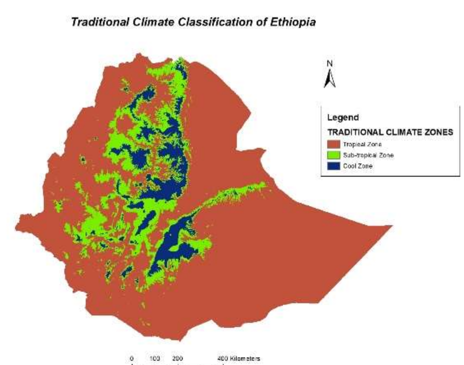

Figure 1: Traditional Climate classification of Ethiopia based on elevation (Source: Author)

According to the Köppen climate classification scheme Ethiopia is divided into five dominant climate zones; oceanic climate, tropical savannah climate, hot semi-arid climate, hot desert climate, subtropical highland oceanic climate and other sub divisions.

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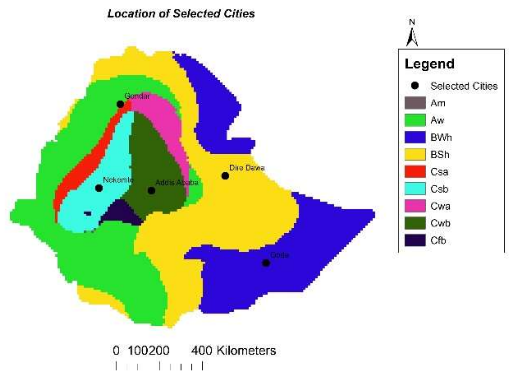

Figure 2: Koppen Geiger Climate Classification of Ethiopia (Source: Adopted from Peel et al, 2007)

Since the country lie on the tropical zone the differences arise from topographic variations. Seasonal changes slightly vary between the different climate zones. Based upon the dominant climate there are four seasons; summer (June, July and August) with Heavy rain fall, Autumn (September, October and November), Winter (December, January and February) is the dry season, & Spring (March, April and May) having occasional showers.

Selected Cities and Their Climate

Five cities are selected for the study, one from each major climate zone according to Koppen Geiger classification. Addis Ababa, Dire Dawa, Gode, Gondar & Nekemte. Monthly temperature and RH differences among the cities are illustrated as follows *(Figure 3 & 4).*

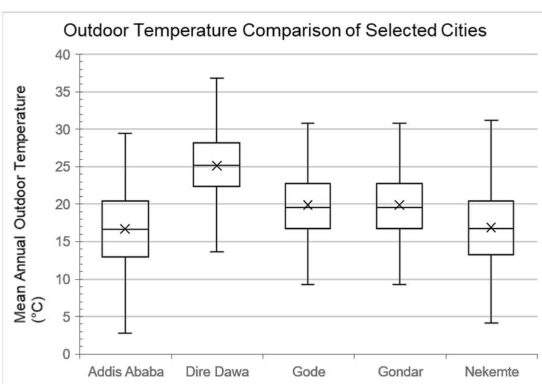

Figure 3: Outdoor temperature comparison

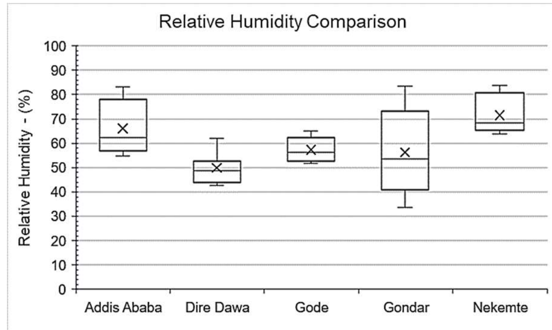

Figure 4: Relative Humidity Comparison

The "comfort zone" is defined as the range of climatic conditions within which the majority of persons would not feel thermal discomfort, either of heat or of cold. A simple adaptive comfort hour comparison done using climate consultant reveals all the selected sites are only comfortable for less than 40% of the time *(Table 1)*.

Table 1: Number of comfort hours based on the adaptive comfort criteria (Output from analysis using climate consultant)

Location	**Adaptive Comfort hours (hrs)**	**Adaptive Comfort hours (%)**	**Summer Comfort Hours (hrs)/ 2208 hrs**	**Winter Comfort Hours (hrs)/ 2208 hrs**
Addis Ababa	1618	18.5	441	294
Dire Dawa	2464	28.1	967	785
Gode	3490	39.8	761	926
Gondar	1842	21	736	441
Nekemte	1583	18.1	467	388

PUBLIC HOUSING (INTEGRATED HOUSING DEVELOPMENT PROGRAM - IHDP)

Selected Building Typologies

A combination of four different condominium flat typologies are used in each condominium block: a studio, 1-bedroom, 2-bedroom, and 3-bedroom unit types. Each unit includes a bathroom, which includes a shower, toilet, hand washbasin, and a separate kitchen. Each unit has water, sewerage, and electricity connections.

Each unit is expected to meet a minimum functional requirement without increasing the floor area which in turn will increase cost. However, in recent years the floor areas of housing units has slightly increased to accommodate the middle and high-income group. The

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general floor area and mix of typologies until 2008 is detailed in *(Table 2)*.

Table 2: Rate of Number of Housing Units In relation to Housing Typologies constructed until 2008 (%) in the IHDP. (Source: Housing Development Program 2006 – 2010 Plan Implementation Report)

No.	Housing Unit Type	Housing Unit Area (M2)	Number of Housing Units In Percent (%)
1	Studio	20 - 25	20-30%
2	One Bedroom	30 - 35	40-50%
3	Two Bedroom	45 - 55	20-30%
4	Three Bedroom	60 - 65	5-10%
5	Commercial spaces	Flexible	10%

There are over 103 project sites in Addis Ababa alone. The typology of condominium blocks in each project site slightly vary on their height as well as housing unit composition. In Bole Gerji site, there are four types of condominium blocks ranging from G+3 to G+6 each composed of modular housing units. I have selected three out of nine condominium-building typologies currently under construction in various locations. The MWUD outsources the task to create neighbourhood layouts using a combination of the different blocks to architecture firms. However, as a rule of thumb they must abide by the prescribed composition percentage of housing unit types per each neighbourhood *(Table 2)*.

Layout Design and Floor area

Individual housing units are designed incorporating basic functional spaces and circulation areas. These units in turn are used as modules to create floor layouts for the whole building. It is common to find similar flats across different building layouts. However, minor changes in area and layout are also implemented to make the modules fit to changes in the building design.

Sample taken from the Addis Ababa Housing Development Project Office is used to illustrate the more recent housing typologies used in the integrated housing development program. Some building typologies include all housing typologies and shops, while others contain only some types of housing typologies.

- Studio Type: Studio type condominiums in the IHDP are single room apartments with separate bathroom and in some cases separate kitchen *(Figure 5)*.
- One bed room type: It has living room, one bed room, a kitchen and bathroom.
- Two bed room type: Two bed rooms and a private balcony accessed from the master bedroom with combined living & dining room, kitchen and bathroom *(Figure 6)*.
- Three bed room type: includes all two bed type features and an additional bed room.

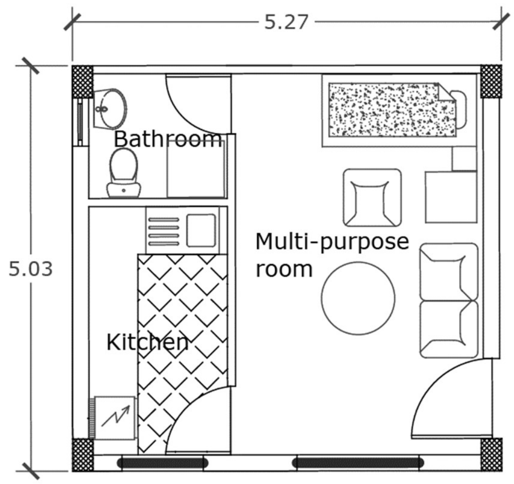

Figure 5: Sample layout of Studio type housing unit

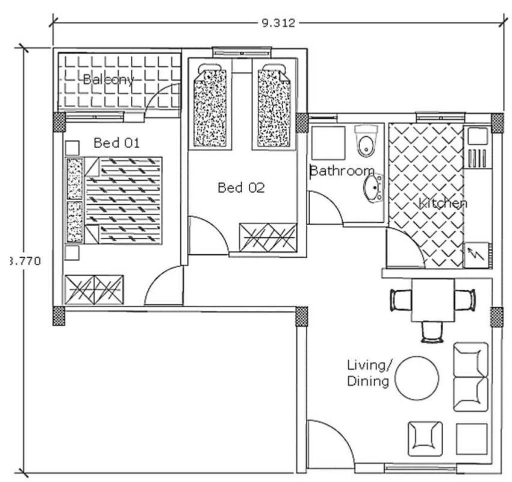

Figure 6: Sample layout of 2Bed room type housing unit

Building materials

As the major aim of the Integrated Housing Development Program (IHDP) is to provide affordable housing for the low income group it is strictly follows the specification of low cost materials introduced by German Technical Co-operation (gtz) & MH Engineering PLC(Un-Habitat, 2011).

Since the study shows similarity regardless of climate differences, thermal comfort and energy efficiency are not taken in to consideration in the prescription of these building materials. The following are the materials used in the building envelope and subsequently used in the simulations.

- Floor: The ground floor is composed of 20 cm thick class C-25 Reinforced concrete applied on top of compacted earth and gravel stone. Unless it is changed by the users afterwards the initial floor finish is a 40mm thick cement screed with cement mortar of ratio 1:3 mix. The structural part of upper floors is made of suspended ribbed slab of total 28cm thick comprising of ribbed blocks rests on pre-cast beams spaced at 62.5 cm c/c and 60mm thick C-25 topping concrete over pre cast unit & slab Hollow Concrete Blocks (HCB) and b/n HCB blocks. *Note: Floor finishes for circulation areas is 20mm terrazzo tiles and for toilets waterproofing materials are used.*
- Walls: External walls are made of Class 'C' 200x200x400mm HCB wall jointed with cement mortar of 1:4 mix ratio finished with three coats of external wall plastering with cement mortar 1:3 mix ratio. Internal Walls are also made from the same material but with a reduced dimension 100x200x400mm HCB. The outer walls have an approximately calculated U-value of 2.853 (w/m2-k) whereas internal partitions have U-value of 2.067 (w/m2-k).
- Roof: Pitched roof is used in all condominium projects made of EGA - 500, 0.5mm thick fixed to SHS purlins with standard hooks and washers. Two coats of anti-rust paint added. Ceiling materials are added after the handover of the building to the households according to their own choice and income. Roof U-value is estimated as 2.93 (w/m2-k)
- Metal & Wood: 28mm LTZ section steel profile frame are used for windows and external doors. 4mm thick good quality ply wood with sides, top and bottom lipped and edged with hard wood is used for internal doors.
- Glazing: all openings are decorated with 4mm thick single layer clear glass joined to frames with putty. U-value of glazing is 5.871 as per ISO 15099/NFRC.

Occupancy

Depending on the average household size in urban areas in Ethiopia, 3.8 people (CSA, 2011) live in each urban house. However, the typology of the condominium determines the number of occupants. Year round 24 hours occupancy is considered for the analysis.

Openings

Window to wall ratio for individual exterior wall elements is averaged at 10-15%. Windows are fully operable and all doors have a fixed rectangular top window. Additionally, exterior doors are partially glazed with figured glass.

Modelling the Houses in Design Builder

Building plans obtained from Ethiopian Housing Agency under the Ministry of Works & Urban Development are used to re-create the building models in design builder software. Envelope properties and building materials are defined based on the actual building specification.

Only occupied spaces are assigned activity schedules and are therefore considered in the simulations. Bathrooms and circulation areas are considered as unoccupied space.

The effect of neighbouring buildings is not considered in the modelling and simulations.

RESULTS

Four types of condominium flats in block Type A2 are compared side by side in Addis Ababa's climate context as well as comparison of a single condominium flat across all the 5 selected cities. In the comparisons, adaptive comfort temperature, inside air temperature (Ta), mean radiant temperature (MRT), and predicted mean vote (PMV) along with total discomfort hours in zones are included. Additionally, heating and cooling demand is also analysed.

Adaptive Comfort Temperature

The term adaptation is interpreted as the gradual diminution of the organism's response to repeated environmental stimulation(de Dear *et al.*, 1998)(Nicol and Humphreys, 2002). Since the buildings are naturally ventilated, adaptive comfort temperature (T_{comf}) is calculated using the formula devised in ASHRAE standard 55-2004. (Ansi/Ashrae, 2004)*(Figure 7).*

$$Tcomf = 0.31Ta,out + 17.8$$

According to (Nicol, 2004) the temperature differential between comfort temperature and outdoor temperature which the building must achieve to remain comfortable indoors must be of 2–3◦c either side of the optimum. But the results in case of Addis Ababa show a difference of 5.6–7.3◦c. The same is also true for Nekemte & Gondar. Only Dire Dawa < 2.5◦c & Gode <3.5 shows a slight overlap between outdoor temperature and adaptive comfort temperature *(Figure 8)*.

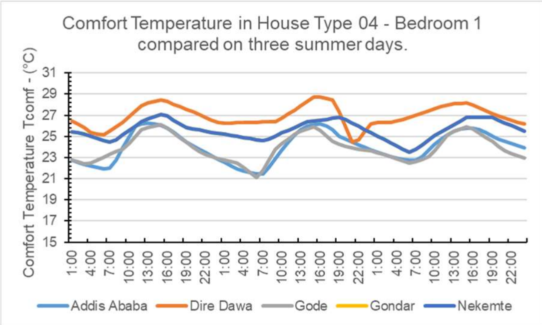

Figure 7: Comparison of comfort temperature Tcomf in House 04, Bedroom 01 at different locations in summer.

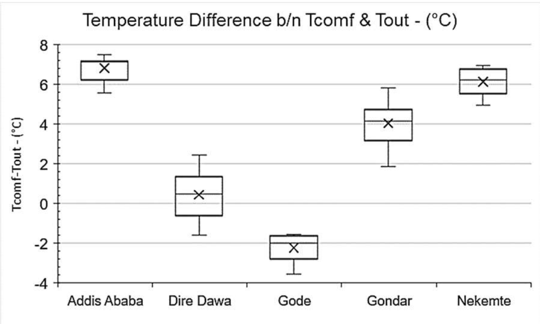

Figure 8: Temperature difference b/n comfort temperature & outdoor temperature (T_{comf}- T_{out}, °c)

Sensible Heating and Cooling

Internal heat gain is the sensible and latent heat emitted within an internal space from any source that is to be removed by air conditioning or ventilation. Annual heating and cooling demand is compared across different climates. As expected, the results show huge variations of heating and cooling demand for the same house typology. Both heating and cooling loads for Addis Ababa and Nekemte in House type 04 are the same, while the same house in Dire Dawa demands 14 times cooling load compared to Addis Ababa. Table (3), demonstrates an annual heat gains and losses of House type 04. Addis Ababa is taken as the base case in the assessment.

Table 3: Sensible heating and cooling loads

City	Sensible Heating - (KW)	Heating load variation (%)	Sensible Cooling - (KW)	Cooling load variation (%)
Addis Ababa	387	100	878	100
Dire Dawa	0	0	12807	1459
Gode	164	42	681	78
Gondar	0.3	0.1	5803	661
Nekemte	387	100	877	100

Predicted Mean Vote (PMV) & Discomfort Hours

An index that predicts the mean value of the votes of a large group of persons on the seven- point thermal sensation scale (Ansi/Ashrae, 2004).

Simulation results of the PMV assessment reflect the ineffectiveness of the building materials and design elements used in this public housing scheme in enhancing thermal comfort for the occupants. At 80% acceptability the results should lie between +1 to -1 PMV, but in this housing typologies the results are spread from +3 to -4 & below PMV in summer and winter conditions *(Figure 9, 10)*.

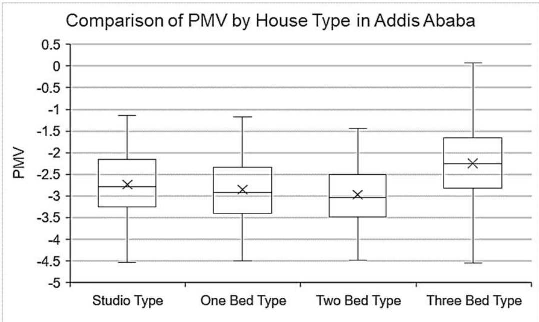

Figure 9: Comparison of PMV by house type in Addis Ababa

Analysis conducted to compare various flats on the same building yield differences up to 0.3 PMV in summer design day and 0.7 at a winter design day in resulting PMV *(Figure 8, 9)*. Calculating PMV using international standards like ISO 7730 fails to present accurate thermal sensation in all climate conditions and naturally ventilated spaces especially prediction of comfort in hot climates (Nicol, 2004). This is also reflected in the present study; while the simulation outputs elaborate the PMV differences and are used

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for comparisons among locations, it also seems to overestimate some values.

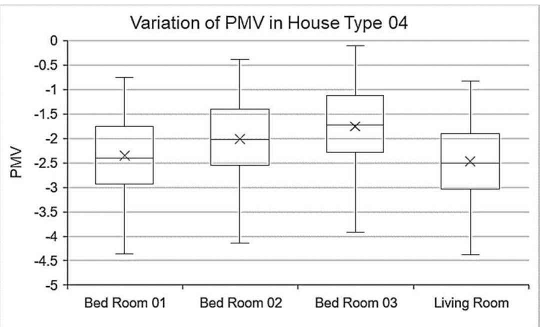

Figure 10: Variations of PMV in house type 04, Addis Ababa

Analysis made in House type 04 (3 Bed Type) reveals significant differences of PMV among some cities. Addis Ababa & Gode stretch from slightly cool-to-cold, while Dire Dawa shows neutral-to-slightly warm. Gondar & Nekemte exhibit almost identical results at neutral-to-cool with a few hours in a year at slightly warm. *(Figure 10)*.

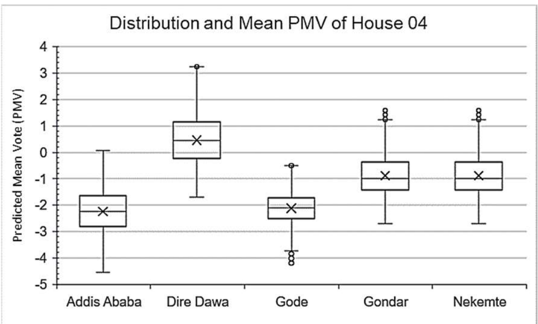

Figure 11: PMV of House Type 04 at various locations

The number of discomfort hours (time not comfortable based on simple ASHRAE 55-2004) also demonstrates the huge difference in which these buildings respond at different environmental conditions. Moreover, zonal comparisons also show large variations in discomfort hours at the same climate for the whole year *(Table 4)*.

Table 4: Time Not Comfortable Based on Simple ASHRAE 55-2004 in House Type 04 (Zone 1, Addis Ababa is used as base case)

City	Room Name	Discomfort hours [hr]	Discomfort hours variation [%]
Addis Ababa	Living Room	3932	100
	Bedroom 1	3478	88
	Bedroom 2	2895	74
	Bedroom 3	2489	63
Dire Dawa	Living Room	3187	81
	Bedroom 1	3710	94
	Bedroom 2	4077.5	104
	Bedroom 3	3971	101

Air Temperature & Mean Radiant Temperature

Mean Radiant Temperature of an environment is defined as that uniform temperature of an imaginary black enclosure that would result in the same heat loss by radiation from the person as the actual enclosure. A study by (Walikewitz *et al.*, 2015) shows that the differences between air temperature (Ta) and mean radiant temperature (Tmrt) are negligible during most periods. However, the study also shows as air temperatures increase and openings are exposed to sunlight, Tmrt exceeds Ta. In the current analysis of Ta and Tmrt using energyplus simulations, the results does not show significant differences between the two variables. The following *(Figure 11)* shows side by side comparison of air temperature and mean radiant temperature in one of the houses.

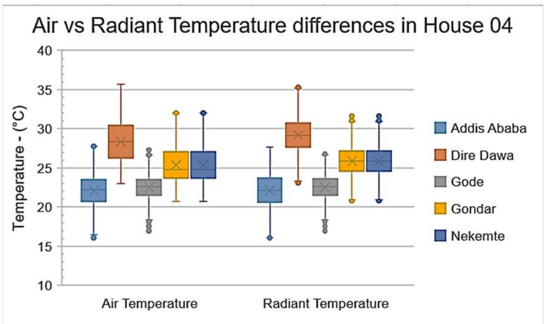

Figure 12: Air temperature and Mean radiant temperature in House type 04

Use of Alternative Building Materials & Construction Techniques

Further research is required to give intensive solutions. However, for a demonstration I used a fiberglass insulation board for both external and internal walls and also changed the window glazing to double. The results strengthen the view that the building materials and techniques implemented in the IHDP neglect thermal comfort requirements. Comparison made on one selected room in Addis Ababa is presented below.

Table 5: Time Not Comfortable Based on Simple ASHRAE 55-2004 in House Type 04 (Living Room)

Scenario	Discomfort Hours (hrs)	Discomfort Hours (%)
Base Case	3932	44.89
Insulated	3718	42.44

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Insulated + Double Glazing	3473	39.64

After the application of fiberglass insulation board on all walls, the number of discomfort hours decreased by approximately 2.44% from the total number of hours (8760 hrs), equivalent to 5.24% decrease from the base case. Additionally, using a double glazing window with air gap shifted the discomfort hours by -2.8%.

CONCLUSION

From the above comparisons we can conclude that climate variations are not taken in to account in the Integrated Housing Development Program (IHDP) of Ethiopia. As a result, thermal comfort in these buildings varies a great deal. Layout and orientation of housing units also exhibits a difference in the comfort or discomfort of the rooms.

The similarity between the outdoor temperature differences between the cities and the pattern of differences on the simulated comfort indexes of PMV show the ineffectiveness of the building envelop and natural ventilation in achieving comfortable indoor environment in the condominium houses. This fact is also evident in the amount of associated heating and cooling load if the houses are to be equipped with mechanical heating and cooling devices.

During the summer in Addis Ababa 441 hours or 20%, Dire Dawa 967 hours or 43.8%, Gode 761 hours or 35.2%, Gondar 736 hours or 34.5% & Nekemte 467 hours or 21.2% of the times the buildings could be made comfortable using adaptive measures. However, since the simulation is done by using ASHRAE 55 – 2004 thermal comfort criteria, further study using actual real-time measurements is essential.

The current trend of same standard building envelops across all the climate regions leads to such variations in indoor thermal comfort. There is a potential to carefully assess this and define it for specific climate zones. Lastly, this study highlights the need of introducing building thermal performance regulations in Ethiopia and subsequently the Integrated Housing Development Program.

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OUTDOOR THERMAL COMFORT ANALYSIS AT A SUSTAINABLE UNIVERSITY CAMPUS

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Keywords: Sustainable campus, outdoor thermal comfort, outdoor spaces, CFD analysis

ABSTRACT

Sustainable campus is a topic that is being of worldwide growing interest. Since mid-1990s the universities which have made the sustainability as a goal in developing their campus are leading the initiative practices to make settlements more sustainable. Designing outdoor spaces that provide a pleasurable thermal comfort experience for users is seen as an important urban design guideline for achieving sustainability goals. The outdoor thermal comfort is a complex issue comprising both climatic and behavioural aspects which affects the use of outdoor spaces and the activities take place in it.

This paper presents findings on outdoor thermal comfort based on field investigations conducted in a sustainable suburban campus, zye in University (OZU) located within the boundaries of the city of stanbul (Turkey). The findings from a survey conducted at fall semester, on a large number of randomly selected people are presented with the measurements of solar radiation, wind speed, temperature and humidity. In addition, the use of computational fluid dynamics (CFD) analysis results validated with the measurements conducted on a windy day has been discussed for further outdoor thermal comfort analysis of the campus which will be done throughout a year.

INTRODUCTION

Being a concept related to various topics, sustainability raised its interest worldwide as so the universities that have made the sustainability a major factor in developing and designing their campuses. When developing a sustainable campus not only buildings and their energy use and waste amount are important, but also a successful design of open spaces should be achieved as well. Moreover, designing outdoor spaces that provide a pleasurable thermal comfort experiences for users is seen as an important urban design guideline for achieving sustainability goals. Due to climate changes and its effect on open areas and users, the importance of outdoor thermal comfort has increased in outdoor spaces which accommodate various activities and improve the liveability of the certain areas used in daily life. In order to determine whether a certain place is pleasurable in terms of thermal comfort, it is necessary to better understand the outdoor thermal comfort itself.

Various bio-meteorological indices have been developed to describe thermal comfort by combining micro-climate and human thermal comfort. The most important of these is steady-state models. These models are based on the assumptions that people who are exposed to environmental factors are able to reach thermal equilibrium in time. The determination of thermal comfort or discomfort is usually made using the "Predicted Mean Vote Index" (PMV). PMV is a 7-point scale-based thermal comfort index (Fanger, 1982) that estimates the average response of a large group of people to thermal conditions. Index is scaled as following: +3=hot, +2=warm, +1=slightly warm, 0=neutral, -1=slightly cool, -2=cool, -3=cold and usually being interpreted by the Predicted Percentage Dissatisfied Index (PPD). With its interpretation, the quantitative prediction of the percentage of thermally dissatisfied people in the environment at each PMV value is possible (Chen and Ng, 2012).

Another example is Physiological Equivalent Temperature (PET) index that calculates temperature index as "degree". It assesses how human temperature is maintained in terms of skin temperature, core temperature and sweat rate (Höppe, 1999).

Outdoor thermal comfort is affected by various parameters that can be classified as (i) human (user) parameters (age, weight, height, clothing and activity level), (ii) climatic parameters (temperature, humidity, solar radiation, wind) and (iii) physical parameters

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(building direction, trees or shading elements, coverage materials etc.).

An ongoing extensive research project is carried out to conduct an outdoor thermal comfort study at a sustainable suburban campus during four seasons. The aim of this paper is to present the findings of outdoor thermal comfort analysis conducted on a weekday at fall season. The case study at Ozyegin University included measurements and questionnaire survey has been conduct during the day in three sessions: morning (8:00-11:00), midday (11:00- 14:00) and afternoon (14:00-17:00) on 20th of October. In the last part of the paper, the CFD analysis of the campus area belonging to a typical
windy day in Istanbul is presented. The capability of CFD in predicting the wind patterns in the campus area is assessed by comparing the numerical results with the measurements. Finally, zones with high wind speed on the campus area are shown and implications for the thermal comfort are discussed.

STUDY AREA - OZYEGIN UNIVERSITY

Located at the periphery of Istanbul, within the borders of the Cekmekoy District, Ozyegin University Campus has been established in 2008 (Figure 1). The Cekmekoy district located in Istanbul's Anatolian site is very close to North Forest of Istanbul. As Istanbul issues with a high population and building density in the urban centres, new universities are usually established at the periphery in order to meet the standards and provide adequate education areas.

University Campus is 28,000 m^2 and offers variety of amenities and facilities for academic development as well as for entertainment. Nowadays, there are 6 faculties, 2 vocational schools, and 3 graduate schools where in total 23 undergraduate and 30 graduate programs are hold. From the total area of 280,000 m^2 campus has 197.317 m^2 of indoor and 14.826 m^2 floor terraces area. Open areas including landscape and walking areas, as well as outdoor sport and picnic areas is 82.993 m^2.

From the very beginning, the university has made being a green campus a main goal of development. For this purpose, the first two buildings have been awarded Leadership in Energy and Environmental Design (LEED) Gold Certificate. Additionally, Academic Building 2 has received LEED Silver Certificate and Academic Building 3 (School of Language-ScoLa) is evaluated as one of the most energy efficient academic buildings in Turkey. According to New Energy Efficiency Practices at Buildings' (NEED4B) ScoLa building is providing energy up to 20% of the average academic building in Turkey. Besides, the solar panels and seven green roofs have been installed through campus buildings.

In the World Universities Sustainability ranking "Green Metric" found by the University of Indonesia Ozyegin University has been ranked 260th (http://greenmetric.ui.ac.id/detailranking2016/?univ=ozyegin.edu.tr). This ranking concept is focused on environmental, economic and equality issues.

Ozyegin University is being only university in Turkey with ISO 14001 Environmental Management System Certificate that is auditing environmental performance of a company.

All these indices are showing that Ozyegin University is making an effort towards sustainability and it is progressing continuously.

Figure1: The location of the university campus in İstanbul

Within the campus, the main alley has been chosen for conducting the study (Figure 2). This area is located between university faculties and student centre, so students are spending the most of their time within this area. During the class breaks student prefer using the fronts of the buildings, due to the limited break duration. While at the periods after class with its entertainment facilities the entrance of student centre attracts more students. This area includes coffee shops, restaurants, one main and two small courtyards as well as landscaped terraces.

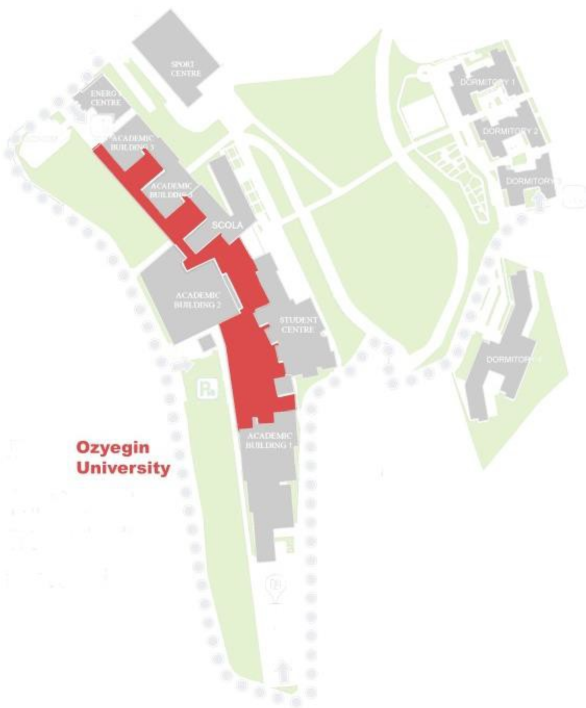

Figure2: Campus and the study area (in red region)

DATA COLLECTION

Data collection has been done in the fall 2016, on 20th of October at three sessions (morning, midday and afternoon) on main promenade. It is consisted of (i) questionnaire surveys and (ii) physical measurements of determined weather parameters conducted at the same time.

Questionnaire Survey:

The questionnaire has been designed in two parts. First part aims to collect information about users' gender, age, clothing, and activity, reason for visiting as well as time of exposure (relation between indoor and outdoor places). These parameters are significant due to the fact that thermal comfort is perceived subjectively, according to interviewee characteristics. For instance, the age affect thermal comfort perception such that elderly people are one of the most vulnerable groups in terms of heat stress (W. Klemm et al, 2015). However, at university campus most of the interviewees were students at the age of 18-22, although there were a number of people at middle age. The activity also plays significant role as it increases the metabolic heat (Herrington and Vitrium, 1977). So, the perception of thermal comfort would not be the same for the person who is sitting with the one who is walking or even doing another higher metabolic level activity such as running or playing.

The time of exposure is important as it can explain relation between indoor and outdoor places. In a study of Tahbaz (2014), conducted in cold climate conditions, thermal shock is emphasized as it may happen to people while changing the environment (indoor-outdoor). It can be stated that similarity in temperatures can help human adapt easier to outdoor conditions as well as exposure of the similar conditions lead to thermal equilibrium during the time.

The second part of the survey has been prepared according to ISO 10551 (1995) and ASHRAEE 55 (2010) standards and criteria. Considering the existing conditions, PMV method has been used in individual perception of thermal comfort conducted with questions about comfort, preference, perception of weather parameters, and satisfaction level of a place where user is spending time.

Meteorological Measurements:

Measurements have been done via three different devices. First of them is portable mini-weather station used to measure radiation, wind speed and direction, humidity and temperature. The radiation probe has an absolute error of less than 10 %. The wind anemometer has an accuracy of □ 0.5 m/s. The wind direction can be measured within □ 5°. The humidity sensor has an accuracy of □ 1.8 % and the temperature sensor has an accuracy of □ 0.3 K. This device has been settled at height of 1.1 m in order to measure general state of the temperature at a certain point. Other two devices are portable CFM (cubic feet per meter) Thermo-Anemometer and humidity meter used to measure wind speed, temperature and humidity at point where the user has been surveyed. The height has been set at 0.6 and 1.1m for sitting and standing subjects as it is the centre of gravity of human body (Johansson et al, 2014). These portable devices measuring the wind speed, air temperature and humidity have been used for measuring conditions at exact place where interviewee exist. In assistance to these devices, every point where interviewee surveyed has been measured and that allowed precisely relation with survey data.

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COLLECTED DATA ANALYSIS

Participant profile and overall evaluation:

122 participants surveyed during the day and 80 % were sitting, 2% lying down, 17% walking and 1% running (Figure 3). As most of the participants were students, 39,2% were in age range below 20 and 44,8% within 21-25 years old. Female- male respondents distribution was 44,8% to 51,2%.

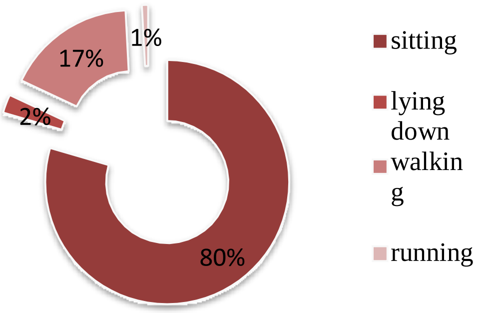

Figure3: Activity of survey respondents shown in percentage

In this study, the time of exposure at survey area as well as relation with indoor-outdoor environment is obtained (Figure 4). Due to the autumn weather conditions the percentage of participants being outside longer than 60 minutes was low. Unlike, participants being outside for less than 10 minutes were 34%. However, the participants that have spent their last 15 minutes indoor were lower (31%) compared to those that have spent outdoor (69%).

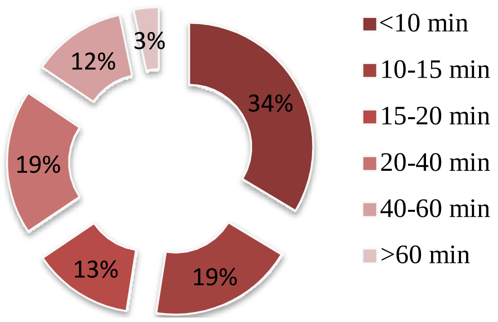

Figure4: Time of exposure shown in percentage

The reason for visiting affects thermal perception in a way that if the reason for visiting is positive (relaxation, eat or drink etc.) the environment is perceived as more comfortable. Vice versa, if reason for visiting is forced activity such as transit, users may not tolerate the uncomfortable environment. In this case, the positive reasons are higher such as enjoying in good environment (12%) or good weather conditions (9%), relaxation (50%) or eat and drink (10%). On the other side the interviewee using the area for studying (7%) or just transit passengers (12%) were minority (Figure 5).

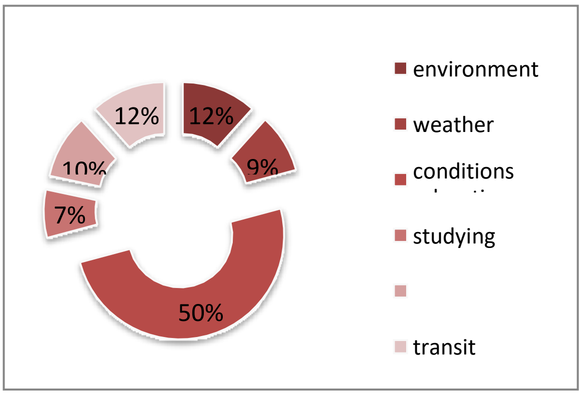

Figure5: Reason for visiting the area

In Figure 6, thermal perception from survey results is presented, where 8% is feeling very cold, 16% cold and the highest percentage of surveys defines their thermal perception as cool (37%). Yet, percentage of those determining their thermal perception as neutral (22%) is meaningful due to the conditions observed.

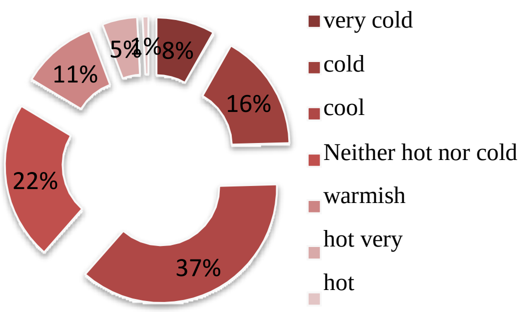

Figure6: Overall thermal perception

Outdoor thermal comfort evaluations for each session:

For each session environmental circumstances and position of interviewee have been abstracted as shown in tables. On Figures 7, 8, and 9 the perception of thermal comfort of users are shown. The positions of interviewee are shown with the use of geographical information systems (GIS) which enable to visualize the place of the participants at surveying time and their thermal perception in a colored scale from red to green. The scale used for interpretation is: +3=hot (shown in red), +2=warm,
+1=slightly warm, 0=neutral, -1=slightly cool, -2=cool, -3=cold (shown in green). Moreover, the measurement results of velocity, humidity, temperature and radiation are included in figures.

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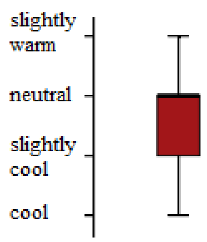
Morning session:

Morning session occurred in period from 8:00-11:00 hours. The number of activities varies, as well as reasons for visiting the place. 43 users have been surveyed. In the open spaces that gets the morning sun radiation from east the temperature is higher than the other zones. U shaped courtyards are colder places until sunset time since the shading effect of surrounding buildings.

In this session, due to the early hours most of users perceived thermal comfort as a neutral (Table 1), although there were exceptions such as hot or cold. The users stating that weather is hot are actually the points where temperature level was high and velocity low (0.03m/sec) (Figure 7).

Table 1: Morning session survey characteristics (number of survey: 43 Time: 8:00-11:00)

OUTDOOR THERMAL CONDITIONS		USER PARAMETERS		THERMAL COMFORT PERCEPTION
Relative humidity %	Min 36.8 Max 49.7 Average 42.0	**Clothing** (clo)	0.3, 0.5, 1, 1.5, 3.0	
Velocity (m/sec)	Min 0.03 Max 2.7 Average 0.47	**Activity**	Sitting, walking, lying, running	
Temperature °C	Min 17.3 Max 22.8 Average 20.7	**Exposure**	<10 min, 10-15 min, 15-20 min, 20-40 min, 40-60 min	
Radiation (W/m^2)	Min 95 Max 682 Average 282.8	**Reason for visiting**	recreation , studying drinking/ eating, transit	

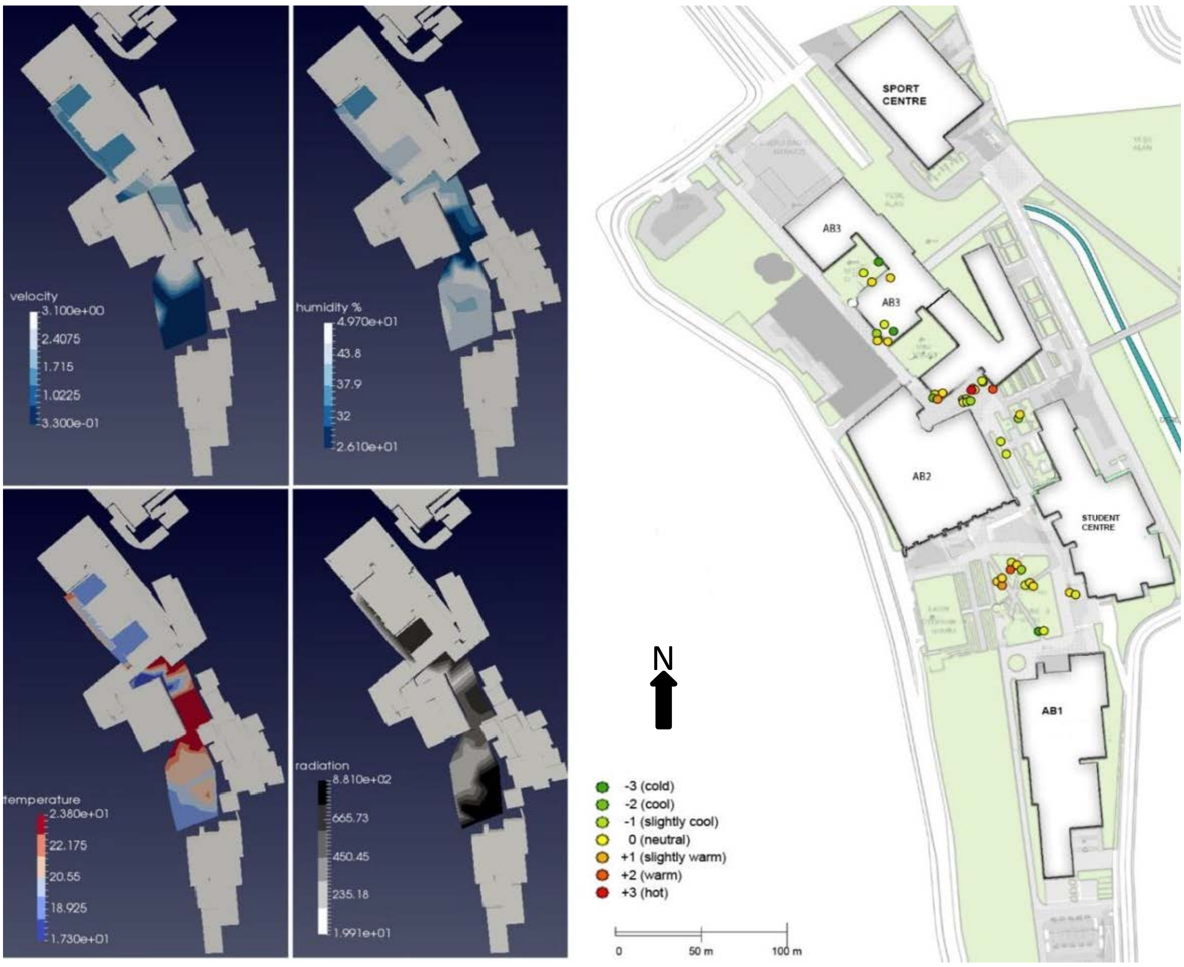


Figure7: Velocity, humidity, temperature and radiation measurement results and perception of outdoor thermal comfort in morning session

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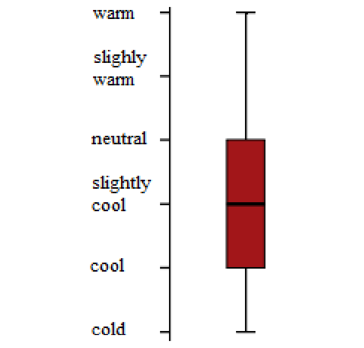
Midday session:

In this session (11:00-14:00), the number of users surveyed is 46. Different from the previous session, as reason for visiting the place pleasurable environment and good weather conditions has been added (Table 2). The average of perceived thermal comfort is slightly cool. Although the temperature did not changed too much, due to the wind effect people experienced the environment as “slightly cool”. The positions of users can be related to the measurement results. At the points of campus where temperature is low, users state the weather as “cold” (Figure 8). Moreover, on the points where radiation is higher the perception of thermal comfort is high as well.

Table 2: Midday session survey characteristics (total number of survey: 46 Time: 11:00-14:00)

OUTDOOR THERMAL CONDITIONS		USER PARAMETERS		THERMAL COMFORT PERCEPTION
Relative humidity %	Min 32.5 Max 44.8 Average 42.0	**Clothing** (clo)	0.5, 1, 1.5, 3.0	
Velocity (m/sec)	Min 0.05 Max 3.72 Average 1.13	**Activity**	Sitting, walking, running	
Temperature °C	Min 18.8 Max 23.2 Average 20.9	**Exposure**	<10 min, 10-15 min, 15-20 min, 20-40 min, 40-60 min	
Radiation (W/m^2)	Min 119 Max 881 Average 236.6	**Reason for visiting**	Recreation, enjoying scenery studying drinking/ eating transit	

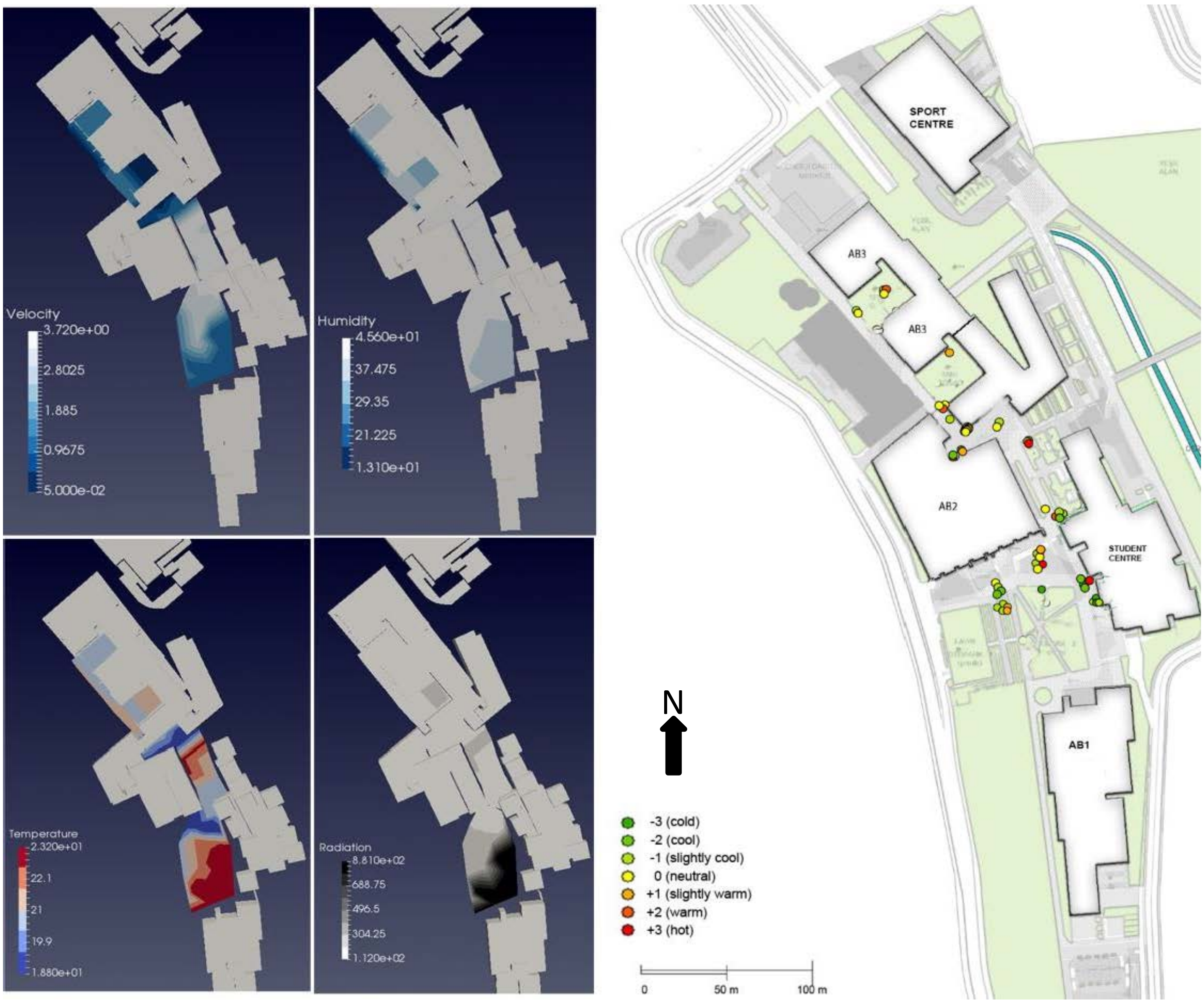
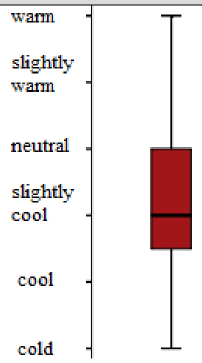


Figure8: Velocity, humidity, temperature and radiation measurement results and perception of outdoor thermal comfort in midday session

Afternoon session:

The period between 14:00-17:00 has been third session of survey conduction. During this session 36 users filled in the surveys. Afternoon session results decreasing temperature, however the average of the users feel slightly cool (Table 3) in some cases hot some of them indicate their thermal comfort perception as "hot". The number of users perceiving thermal comfort cold is observed as well. Users determining weather as "cold" are usually spending time in shade area where solar radiation is low (Figure 9). On the other side, the ones who felt "hot" are spending time in open area under sunrays. Since the buildings not blocking the sun, the open areas get more solar radiation at these hours.

Table 3: Afternoon session survey characteristics (total number of survey: 36 Time: 14:00-17:00)

OUTDOOR THERMAL CONDITIONS		USER PARAMETERS		THERMAL COMFORT PERCEPTION
Relative humidity %	Min 36.6 max 51.8 Average 46.2	**Clothing** (clo)	0.5, 1, 1.5, 3.0	
Velocity (m/sec)	Min 0.18 Max 3.43 Average 0.99	**Activity**	Sitting, walking, lying	
Temperature °C	Min 17.8 Max 23 Average 19.5	**Exposure**	<10min,10-15 min, 15-20 min, 20-40 min, 40-60 min, >60 min	
Radiation (W/m^2)	Min 90 Max 541 Average 232.2	**Reason for visiting**	Recreation , studying drinking/ eating, transit	

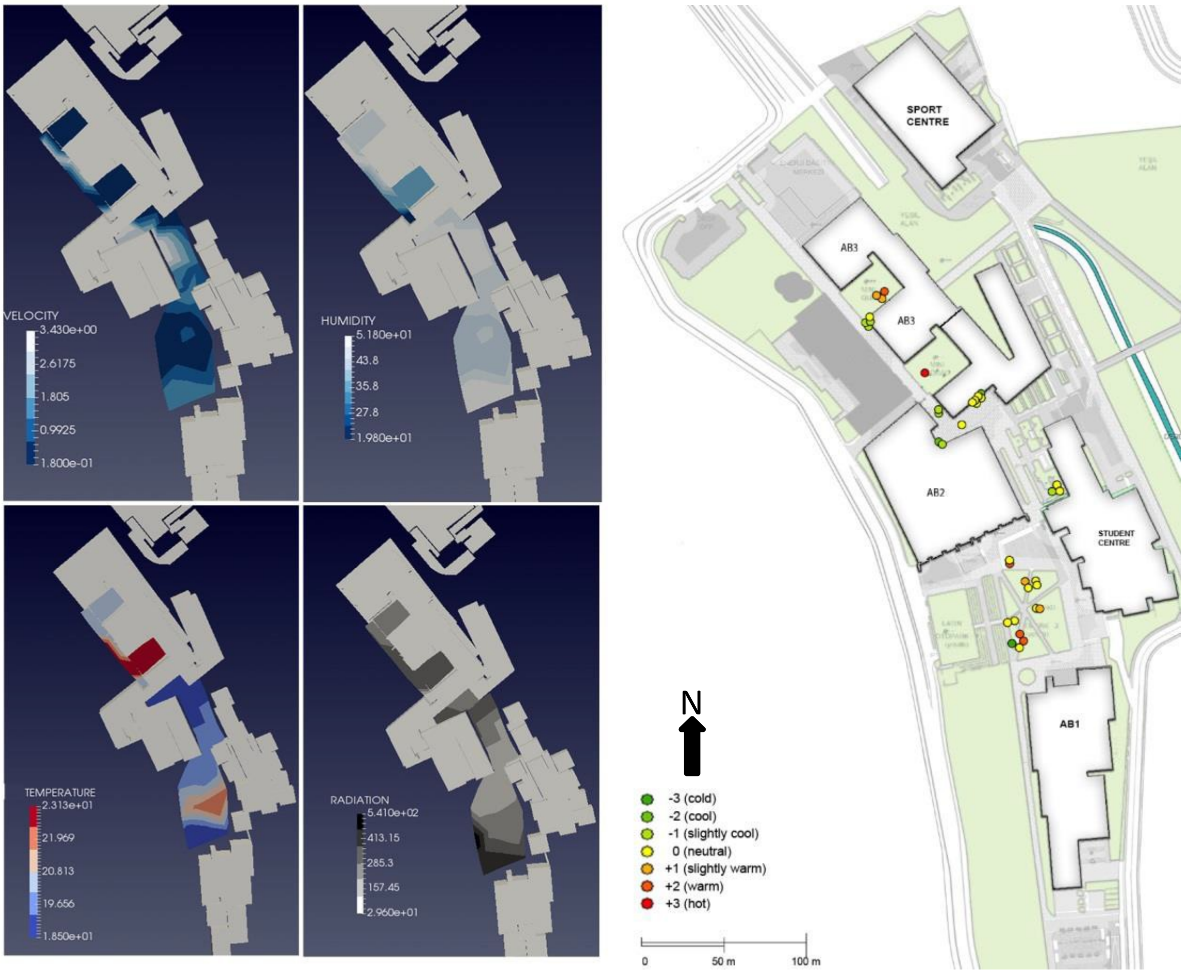


Figure9: Velocity, humidity, temperature and radiation measurement results and perception of outdoor thermal comfort in afternoon session

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CFD ANALYSIS

Wind has a very dominant effect on the comfort level of the pedestrians. Apart from the atmospheric wind conditions, the terrain topography and the positioning of the buildings can also have a major influence on the wind conditions within the campus. This part of study numerically investigates the wind patterns at the Ozyegin University campus with the use of the Star CCM+ CFD software package. The simulations are carried out for a moderate wind speed condition that can influence the comfort of the pedestrians and also that the wind measurement devices can work with acceptable uncertainty levels. The numerical results have been compared with the on-site experimental measurements conducted via a portable meteorological weather station. Measurements are conducted for 5 minutes at each measurement location shown in Figure 10. The "Quad" area is the busiest region for pedestrian traffic at the campus and selected for that purpose. Finally, average wind speed data is obtained to be compared with the simulation results for the validation of the numerical study.

Figure10: Quad area of the campus

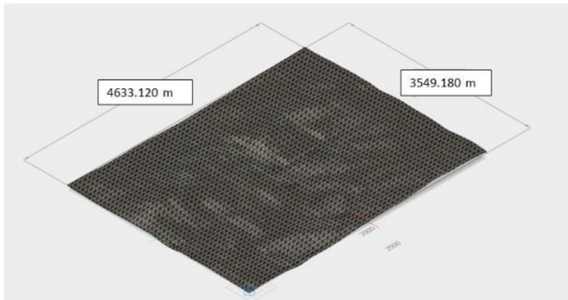
Computational Geometry and Domain:

Figure 11 show the computer drawing of the campus buildings in comparison with the satellite image taken from Google Earth. The surface topography is generated using SRTM data with 90m resolution in both directions. Figure 12 show the extent of the computational domain with the campus buildings positioned at its center.

Computational Grid:

The computational grid has been generated using the automated mesh generation capability of STAR CCM+ which allows a large degree of control over the quality of the grid. The cell size is selected to be around 0.5 m both on the buildings and on the terrain. Prismatic cells surround all the solid surfaces in the wall perpendicular direction ensuring an increased accuracy in the calculations in the vicinity of the buildings. The prism layer extends to 100 m in vertical direction and consists of 30 cells. Outside of the boundary layer, polyhedral cells are utilized. In total, the mesh consists of 8 million cells. Figure 12 shows the volume mesh of the whole computational domain including the terrain and the campus buildings.

Figure11: Top view of the campus and computational grid of the domain



Dimension of the topography

Side view of topography with campus

Figure12: Computational grid of the whole domain

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Boundary Conditions:

At the inlet of the computational domain wind speed and direction have been set to the meteorological data corresponding to the day measurements were conducted. Accordingly, the wind speed set to 10 m/s at 10 m height from the terrain with the wind speed profile dictated by the following formula.

$$( )$$

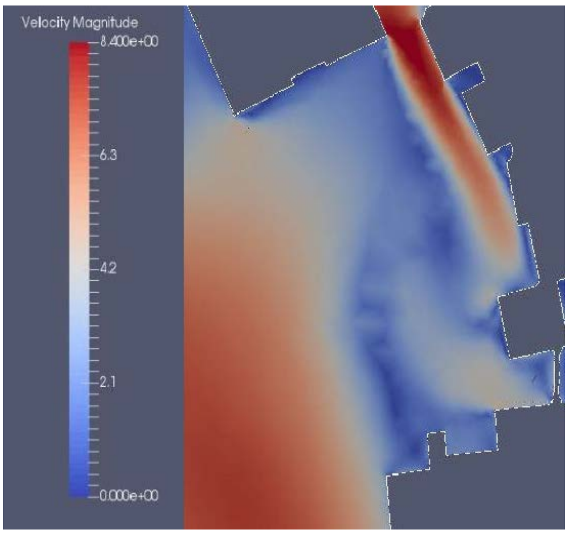
where U is the wind speed at height z, and U_r is the known wind speed at the reference height Z_r.

Additionally, the direction was set to North East, one of the major dominant wind directions for Istanbul. At the outlet, pressure outlet condition is set. At the both sides of the domain, periodic flow condition is applied. The condition for the bottom terrain and the buildings are set as wall with no slip condition while the top wall of the domain is set a wall with slip condition.

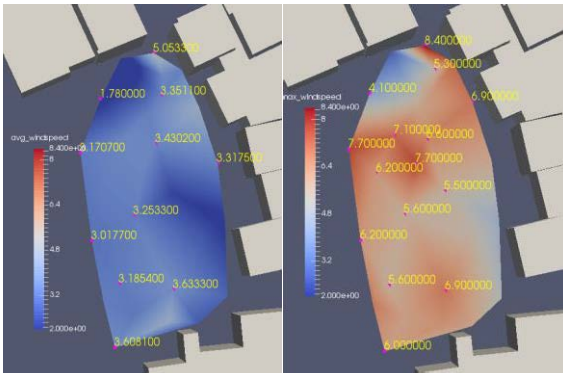
Other Parameters:

Steady, three-dimensional RANS equations are solved using StarCCM+ software. The turbulence is treated via the SST k- turbulence model coupled with an automatic wall function capability. For convergence the residuals for the equations are monitored. The residuals drop to as low as 10^{-6} for momentum equations and 10^{-5} for the continuity.

Validation:



a)



b) *c)*

Figure13: a) Simulated average velocity b) Measured averaged velocity c) Measured max. velocity

In Figure 13 both the simulated and the measured wind speed levels are plotted for the "Quad" area at the university campus. Regarding the measurement the time averaged and maximum wind speed values are separately plotted in the figure. As shown, the predicted wind speed agrees with the measured average wind speed at the center portion of the area. The numerical simulation predicts a considerable rise in the wind speed in the north of the area where two campus buildings approach each other. Even though the measurement points are not dense enough to fully validate the predicted jet like structure, the measurements show the highest values in both the time averaged and in the maximum wind speed in the same area that the simulation predicts. However, compared to the measurements the simulation overpredicts the average wind speed by about 3 m/s at that region. The discrepancy in that region might be due to the limitations of the steady flow assumption that RANS modeling has. Also the inaccuracy in boundary conditions might have played a role in there.

CFD RESULTS

Figure 14 shows the result of the CFD analysis. It is observed from the figure that in the condition of north east wind direction, there are two regions which are mostly affected by the wind: one is at the intersection of Academic Building 2 and Student Center (Point 1) while the other one is at the corner of Scola Building (Point 2)

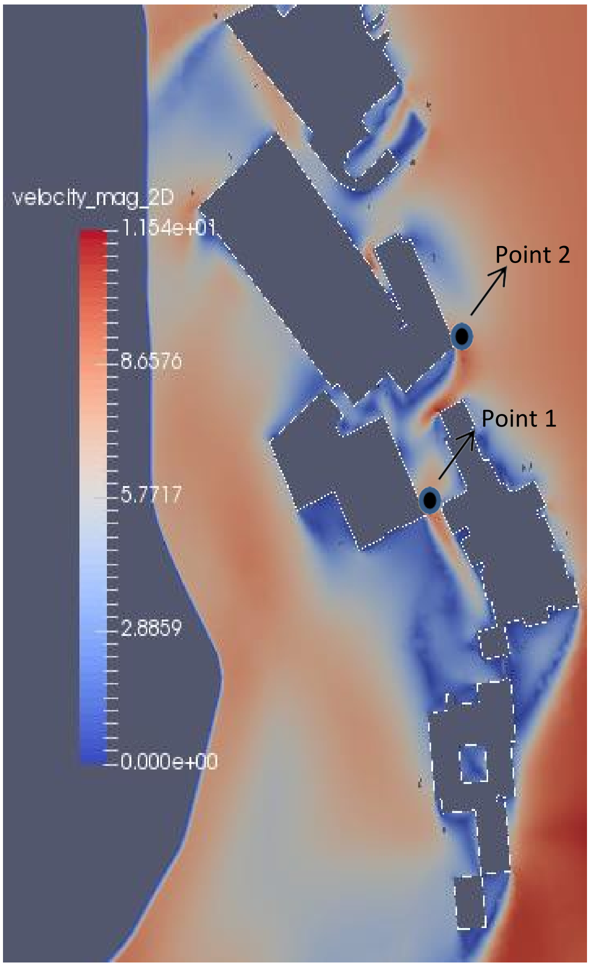


Figure14: CFD results for wind speed

According to the results obtained in fall semester, it can be concluded that the courtyards provide protected outdoor areas from wind effects, on the other hand they are always shady areas during mornings because of surrounding buildings. There are some points that are recorded as windy corners that creates uncomfortable environment for users. With the use of wind barriers it would be possible to control undesired wind effect during windy days. The campus should be observed during a year to make an inference about the outdoor thermal comfort performance of the campus. The studies are keep going for further analysis that would be done in other seasons.

NOMENCLATURE

U = wind speed at height z

U_r = known wind speed at the reference height Z_r

ACKNOWLEDGEMENT

The presented work has been carried out with research project 1115Y225 "Post-occupancy evaluation of outdoor spaces in campus buildings with spatio-temporal mapi ng method" funded by TUBITAK (The Scientific and Technical Research Council of Turkey).

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PASSIVE DESIGN INDICES: QUANTIFICATION OF CLIMATIC POTENTIAL FOR PASSIVE COOLING STRATEGIES

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Keywords: Passive design, Indices, Climate, Weather analysis, Potential

ABSTRACT

The study aims to develop indices to assess the climatic potential of passive cooling strategies. Cooling accounts for 40% to 60% of summer energy demand in metropolitan cities with hot climates & air-conditioner (AC) sales in India are growing at 30% per year (CEM 2014). Recommendations based on current climatic zones may not be appropriate as many microclimatic conditions and variations are found within a few kilometres. The current climate analysis tools do not explore the inter-relationships between climatic parameters. Earlier work showed that it is possible to develop a weather-data-based classification to map the potential of some basic passive design strategies, such as building orientation, layout, plan etc. This study takes that approach forward to establish weather-data-based indices for strategies such as evaporative cooling, comfort ventilation, radiant cooling, earth cooling, and night ventilation. Weather data variables are identified for each strategy. Adaptive thermal comfort models represent the expected indoor comfort conditions. Typical Meteorological Year (TMY) weather data of 59 Indian cities are analysed to develop the indices. Thermal Autonomy and Discomfort Degree Days are the metrics developed to measure the potential of the passive strategies. An Excel processor and a Power BI user interface tool have been developed. These enable the user to compare the potential for strategies within a climate and compare various locations for their climatic potential for a strategy. The quantification of climatic potential for passive cooling strategies can become a key metric in assessing resiliency for climate change.

INTRODUCTION

Buildings consume more than 40% of world's primary energy and have a significant impact on Climate Change. Cooling accounts for 40%-60% of summer peak load in large metropolitan cities with hot climates like Delhi, and air conditioner (AC) sales in India are growing at 30% per year (CEM 2014). Improved energy efficiency can be achieved using low-energy systems and passive design strategies. Identification of appropriate passive design strategies in early design stages thus becomes important to counter increasing energy use. And, understanding the potential for low energy and passive cooling solutions in a location enables the manufacturers and supply chains to market their products more effectively. However, there is a lack of regulation and support for widespread implementation of passive design strategies (Pawar, Mukherjee, and Shankar 2015). Earlier work shows that it is possible to develop a weather data based classification to map the potential of some basic passive design strategies, such as building orientation (Pawar, Mukherjee, and Shankar 2015). Development of such maps first requires developing a methodology for calculating indices that summarize the potential for passive strategies.

These passive design indices can be considered analogous to Cooling Degree Days (CDD). CDD is used to quantify the thermal stress a climate imposes on a building, and provides an index to quantify the relative intensity of use of AC equipment across different climates; similarly, passive design indices can be used to understand the potential and relative intensity of use for low energy cooling methods to provide autonomy from air-conditioning. Literature suggests that most previous work on classifying a climate is based on a quantification of the stress, and passive strategies have been recommended based on the prevalence of certain climatic conditions. These recommendations are not based on the quantified potential of any strategy in a climate i.e. it does not give any indication of the number of hours for which a strategy can be effective to achieve comfort. For example, Givoni (1994), took a conservative approach to define the climatic applicability of various strategies, based on ASHRAE comfort zone. Furthermore, since in many regions, microclimatic conditions vary within a few kilometres, such recommendations based on a regional resolution may not be applicable similarly for specific locations within a climate zone. Therefore, there is a need for indices generated for a location to identify the opportunity and climatic potential of passive strategies. Levitt, Ubbelohde, Loisos, & Brown, (2013) proposed "Thermal Autonomy" as a metric that links occupant comfort to climate, building fabric, and building operation. This metric is framed to avoid energy use and embrace the opportunities in a climate. It measures how well a building harnesses the available ambient energy resources, rather than how much energy its heating and cooling systems will consume. (Chiesa and Grosso 2015) assessed the climatic potential for natural ventilative cooling for 50 reference cities in the Mediterranean region. Their work included climate-dependent evaluation of the Natural Ventilative Cooling potential for different locations using Residual Cooling Degree Hours (CDHres) as a metric. CDHres is defined as the AC- related virtual cooling needed for each location after the application of natural ventilative cooling.

This study develops the calculations to adapt Thermal Autonomy (TA) as a metric that can be used to assess the potential for five passive cooling strategies in a climate and remove the effect of variables that make the building physics calculations specific to arbitrary building conditions. The objective is to calculate the maximum potential available for a strategy in a climate. Similarly, the study also adapts CDHres in to a metric called Discomfort Degree Hours (DDH), by replacing the Balance Point Temperature with the Adaptive Thermal Comfort control set-point. An analysis tool is developed to calculate these metrics. The results presented in this paper use TMY2 weather data for 59 Indian cities.

CURRENTLY AVAILABLE TOOLS FOR CLIMATE ANALYSIS

Commonly available climate analysis tools like Mahoney Tables, Bio-Climatic chart and Climate Consultant give recommendations for passive design strategies, based on the presence of certain climatic conditions. The Mahoney Table is used with monthly data of temperature, relative humidity and rainfall. Diagnosis of thermal comfort is done based on annual mean temperature and monthly mean relative humidity. The tables provide recommendations for building design based on the severity and duration of prevalence of climatic conditions. The Givoni-Milne bioclimatic chart indicates the boundaries for different types of passive design strategies based on the average changes in day's temperature and relative humidity.

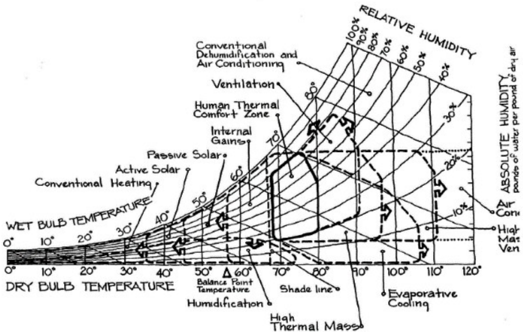

Figure 1: Givoni-Milne bioclimatic chart, 1981; Source:

(Visitsak and Haberl 2010)

It does not use hourly climate conditions and does not account for other climatic variables like wind speed, wet-bulb temperature and cloud cover. The approach is useful to apply passive design strategies based on an understanding of a generic climate profile such as Hot-Dry, but it does not quantify the potential of each strategy over various seasons for a climate. It also does not allow the comparison of multiple locations.

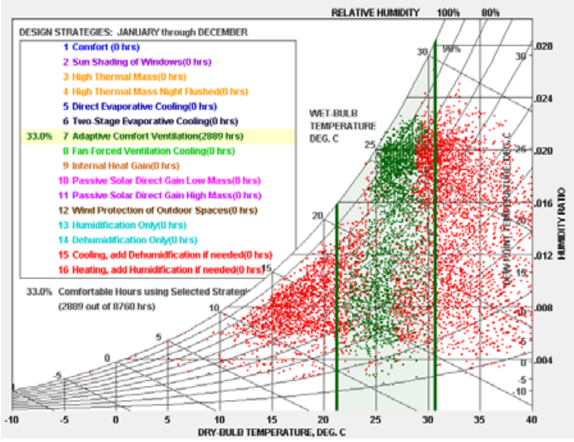

Figure 2: Design strategies for ASHRAE 55-2010 Adaptive comfort model (Source: Climate Consultant 6.0)

The Climate Consultant tool plots the hourly DBT and RH on the psychrometric chart and provides recommendations for a few passive design measures like thermal mass, shading, fan-forced ventilation, and evaporative cooling. Other passive cooling approaches are not included. For the adaptive thermal comfort model, it only recommends comfort ventilation as a measure. The recommendations are based on the RH and DBT values. Other climatic variables are not accounted for. This tool does not quantify the potential of each strategy over various seasons for a climate and it does not allow the comparison of multiple locations.

Walsh, Cóstola, & Labaki, (2017) concluded that climate zones for building energy efficiency programs are most often developed to support performance-based or prescriptive-based requirements. Therefore, these approaches lack consideration for passive design approaches and show little sensitivity for the related climatic variables. The quantification of climatic potential for passive cooling strategies can become a key metric in assessing resiliency for climate change.

METHODOLOGY

Identification of strategies and climate variables

Literature was reviewed to identify relevant climatic variables, heat sinks and physics for 5 passive cooling strategies (Evaporative Cooling, Comfort Ventilation, Night Ventilation, Ground Cooling and Radiant Cooling).

Evaporative cooling is the transformation of sensible heat into latent heat by introducing water molecules in to the air stream. The non-saturated air reduces its temperature when sensible heat transforms into latent heat to evaporate water. If the process takes place in ideal adiabatic conditions, the dry bulb air temperature decreases as humidity increases.

Comfort ventilation is the flow of outdoor air through the building to provide a direct physiological cooling effect by increasing the rate of sweat evaporation from the wet skin. It can be applied when indoor comfort can be experienced at the outdoor air temperature with acceptable air speed.

Night ventilation is the cooling of the structural mass of the building by convection by allowing natural ventilation at night. For this to be effective, the building should be closed during daytime to prevent the interior from being heated by the warmer outdoor air.

Ground cooling is the use of earth-contact to control the building heat losses. It can be achieved by direct contact through earth sheltering or earth coupling. This strategy is effective when the ambient air temperature is sufficiently higher than the earth temperature.

Radiative cooling is the rejection of building heat to the night sky through radiative heat transfer. It is effective in clear sky conditions that provide exposure to low sky temperature.

Table 1: Climatic Variables associated with strategies

STRATEGY	SINK	CLIMATIC VARIABLE	SINK OPPORTUNITY
Evaporative Cooling	Air	DBT & RH	WBD
Comfort Ventilation	Air	DBT & Wind Speed	T_{in} - T_{out}
Night Ventilation	Air	DBT	Diurnal Variation
Radiative Cooling	Sky	DBT, T_{dp} & Cloud cover	Difference between DBT & T_{sky}
Ground cooling	Earth	T_{ground} & DBT	Difference between T_{ground} & DBT

Source: (Givoni 1994; Cook 1989; Alvarez and Molina 2003)

Key steps to quantify Passive Cooling Design strategies

1. Identifying heat sink for a strategy
2. Identifying key climatic variable for the strategy
3. Identifying building physics which relates them to climate variables
4. Calculating the stress and opportunity
5. Quantifying the climatic potential with TA and DDH.

Findings of steps 1 and 2 are summarized in Table 1.

Passive Design Indices

In this study **Stress** is defined as the distance (in degrees) between the ambient condition and the expected comfort temperature for an hour. **Opportunity** is defined as the availability of cooling potential in a heat sink (in degrees), to achieve desired comfort temperature for an hour.

The potential of a strategy is determined based on its ability to provide required comfort temperature using the heat sink in the climate and is quantified using two indices, TA and DDH. We remove the confounding variables such as building use characteristics, building system characteristics for implementation of a strategy and assume the overall system efficiency at 100%; this enables us to calculate the maximum potential available for a strategy in a climate, and frees the building physics from keeping the calculations relevant to only a specific building or design condition. The results are to be applied to the climate and not to the performance of a specific building. If the objective is to measure the TA or the DDH for a given building or design, the same overall approach can be used by reintroducing the building system and use characteristics.

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We use the upper limit indoor operative temperature of an adaptive thermal comfort model; Indian Model for Adaptive (thermal) Comfort model (IMAC) as the base point to calculate thermal stress.

TA is the ability to achieve comfort in a climate without the use of active systems. It is achieved for an hour when Stress is less than the Opportunity as defined in Table 2. The number of hours in a year for which TA is achieved divided by the total (8760) hours to get annual TA as a percentage value.

For a given hour, TA = 1 if Stress < Opportunity, otherwise TA = 0

DDH indicates the residual cooling required to achieve comfort after the application of a passive cooling strategy. For a given hour when TA is not achieved, it is calculated as the difference between Stress and Opportunity (in ºC) which indicates the residual cooling required. The sum of this residual cooling for all the hours in a year gives the total annual DDH.

For a given hour when TA = 0, DDH = Stress – Opportunity

For example, in-case of evaporative cooling, when the DBT is 37 °C, WBT is 35.44 °C and expected thermal comfort temperature (T_c) is 30.57 °C:

- the stress is (DBT -T_c) 6.43 °C,
- the opportunity is (DBT – WBT) 1.56 °C,
- Stress > Opportunity and hence TA =0 and,
- DDH is (Stress – Opportunity) 4.86 °C.

Table 2: Equations for Stress and Opportunity

STRATEGY	STRESS	OPPORTUNITY
Evaporative Cooling	(DBT – Tc, when DBT> Tc)	DBT – WBT
Comfort Ventilation	(T_{in} – T_c)	T_{in} – [1]
Night Ventilation	((DBT- T_c), during daytime if DBT > T_c)	((DBT- T_c), during night when DBT < T_c)
Radiative Cooling	T_{stag} – T_c	T_{stag} - DBT @ Night
Ground cooling	DBT – T_c	DBT – T_{ground}, when DBT>T_{ground}

In Table 2: T_{Stag} is the lowest possible temperature a radiator surface can achieve theoretically; T_{ground} is the ground temperature at a depth of 0.5m from the surface.

Tool

A simple graphic user interface tool is developed with user selection of the city, the passive strategy, and the desired thermal comfort model. The tool has the capability to show comparative results for different strategies and cities. Currently, the tool processes TA and DDH for TMY data for 59 Indian cities. The results are summarized at monthly and annual levels. The tool can also be used to understand the variation in the potential of a strategy across different cities, and to understand the potential for different strategies for an individual location.

The software used is Ms Excel™, Ms Power BI™ and VBA™. The TMY weather file for each city is loaded into an Excel template, and the climate variables relevant to the physics of each strategy (shown in Table 2) are filtered. The calculations are processed in Excel for all the cities and the thermal comfort models, and the results are transferred into an Excel database. MS Power BI™ is used for the visualisation of these results data. The user can compare the potential of strategies with the flexibility to choose the cities, strategies and the thermal comfort models.

The tool allows architects and designers in their early design stage to evaluate the climatic potential for different passive cooling strategies, and for policy makers to evaluate the effectiveness of a strategy across various locations in India.

RESULTS

Comparison of Potential for all 5 Strategies for 1 City (Annual Summary)

In Figure 3, annual summary of TA and DDH is displayed for all the strategies for the selected city and selected thermal comfort condition. For IMAC MM Neutral Temperature, New Delhi (Composite Climate as per NBC) evaporative cooling has the highest potential followed by ground cooling, radiant cooling and night ventilation. Comfort ventilation has the lowest potential over a year.

Also, TA for comfort ventilation is 10% less than night ventilation but the DDH for comfort ventilation

[1] 2.319 v_{air} + 0.4816 (°C), It is the air temperature decrease perceived by a person as the effect of air movement (v_{air}). Source: (Chiesa and Grosso 2015)

is increasing by 2.5 times that of night ventilation. Therefore, night ventilation has more potential in decreasing the active cooling demand to achieve thermal comfort. Similarly, ground cooling has TA of 62.8% (5.1% more TA than radiant cooling), however, ground cooling has 7013 less DDH than radiant cooling. Though both have almost similar TAs but ground cooling will be more effective in reducing the active cooling demand.

Comparison of Potential for all 5 Strategies for 1 City (Monthly Summary)

Figure 4 shows the monthly summary and provides a visualization of the variation over the year. The overlapping periods of applicability for the strategies can also be seen. For e.g. in the months of December, January and February all the strategies work well, however evaporative cooling, night ventilation and ground cooling showing highest applicability. In this figure, though evaporative cooling has highest potential in New Delhi, it is less applicable for the months of June to September. Also in the month of June & July, evaporative cooling is the only strategy which will help to reduce DDH. Comfort ventilation only works for the months of December, January and February whereas night ventilation works only during November, December, January and February. Comfort ventilation, night ventilation doesn't work at all in the months of June and July and ground cooling and radiant cooling shows very less potential in those months.

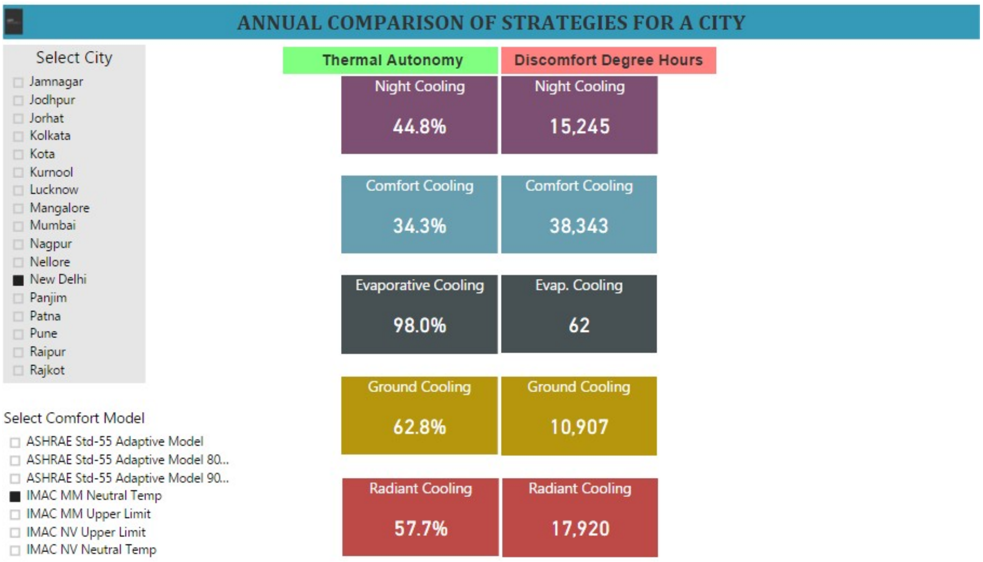

Figure 3: Annual comparison of 5 strategies for one city

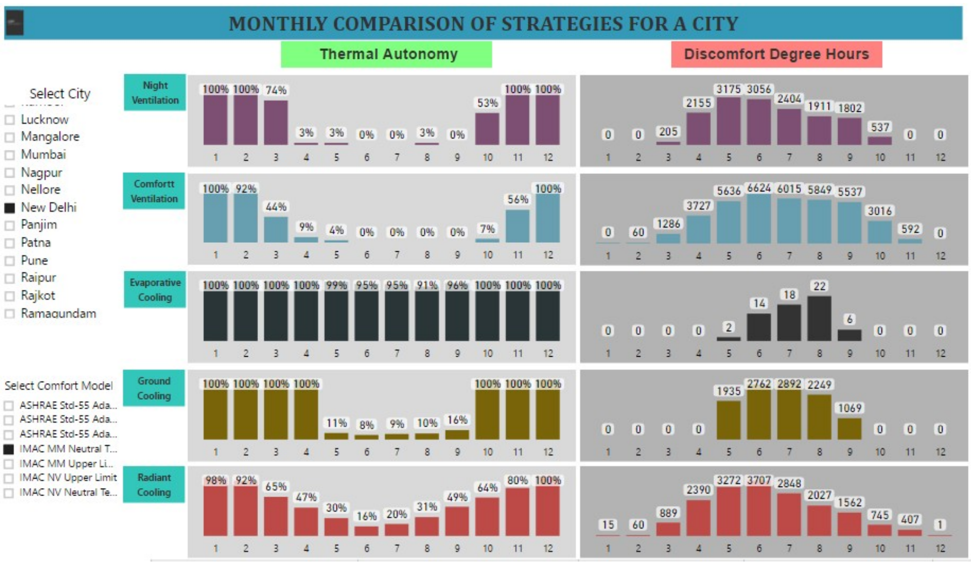

Figure 4: Monthly comparison of 5 strategies for one city

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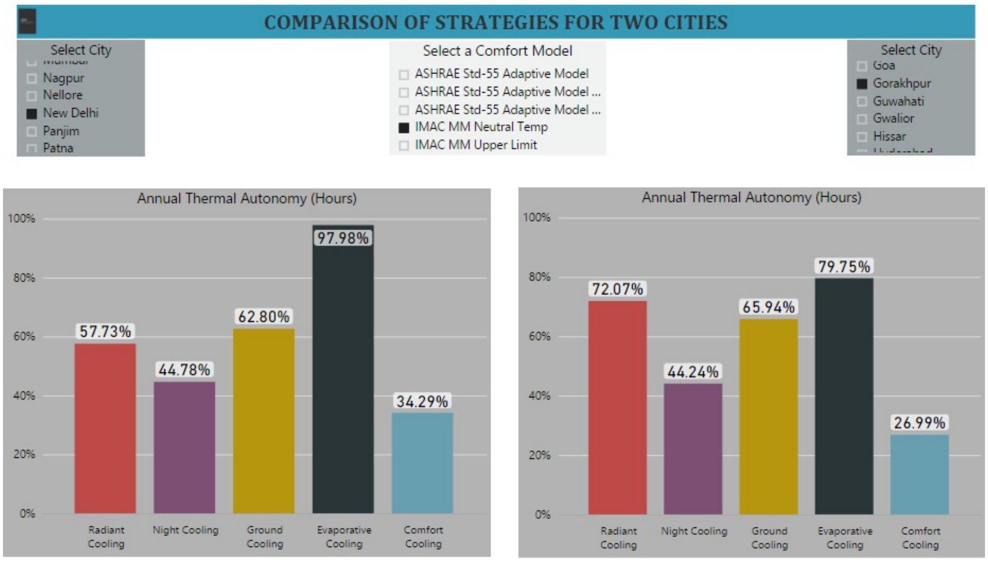

Figure 5: Comparison of TA of 5 strategies for two cities

Comparison of Potential for all 5 Strategies between 2 Cities

Figure 5 shows the annual TA comparison of all strategies for any two selected cities in same climatic zone. Here, New Delhi and Gorakhpur (Uttar Pradesh) was selected. Both these cities are in Composite Climate Zone as per NBC, 2005. In this, both cities show same potential for night ventilation (44%). New Delhi shows a higher TA for evaporative cooling (98%) whereas Gorakhpur shows a TA of 80% for evaporative cooling. Radiant cooling is the second-best strategy for Gorakhpur followed by ground cooling but in case of New Delhi, ground cooling shows higher potential than radiant cooling. Except for night ventilation all strategies show different TA for the two cities in composite climate zone. Night ventilation has 44.78% and 44.24% TA for New Delhi and Gorakhpur respectively. A similar comparison is also done for DDH.

Comparison of Cities for a Strategy

In Figure 6, a strategy and a thermal comfort condition are selected. Multiple cities can be selected for comparison. The spider graph on left shows the TA and bar graph on the right shows the DDH for Kota, Surat, Ahmedabad, Allahabad, Jaisalmer, New Delhi, Jaipur & Jodhpur. In this case, a significant variation in DDH can be seen for comfort ventilation across the selected cities.

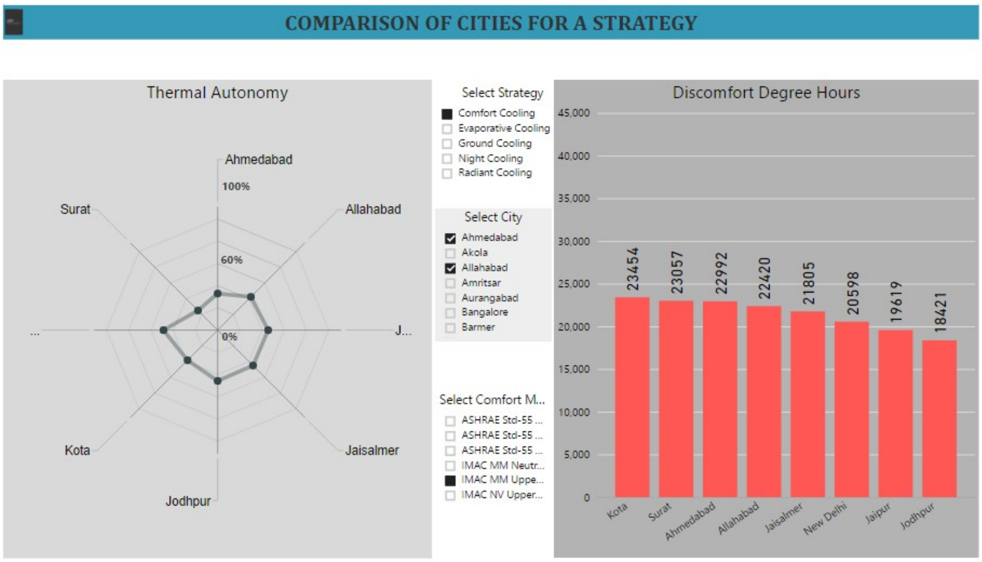

Figure 6: Comparison of Cities for a strategy

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Figure 7: Comparison of 59 Indian Cities (Ranked) for a strategy

Comparison of all cities (ranked) for a strategy

In Figure 7, the user selects a comfort model and a strategy. The ranked comparison of annual TA for all the 59 Indian cities are shown for the selected strategy. In this Shillong shows highest TA with 93%. Majority of the cities shows a TA between 20-40%. Cities like Chennai, Mangalore, Mumbai, Tiruchirappalli shows TA less than 10%. A similar comparison has also been done for DDH. The ranking is not same for DDH and TA, therefore one needs to consider both indices for a better understanding of the climatic potential.

CONCLUSION

This study uses Discomfort Degree Hours and thermal Autonomy as two indices that can quantify the climatic potential for passive cooling strategies.

This methodology and tool developed allow comparison of cities for their potential for each strategy. They also allow the comparison of strategies and cities at monthly and annual level. The results give an idea of the effectiveness of the strategies in terms of Thermal Autonomy, and resultant intensity of use of AC in terms of Discomfort Degree Hours. The tool is indented to help the user identify the best strategy for a climate and the months when it is most effective. Users can also compare the effectiveness of a strategy for distinct locations and rank performance. This methodology can be used developing a TA and DDH map for each strategy for cities of India. While some preliminary validation of the tool suggests that it shows expected trends, additional validation is needed before the methodology and its results can be used in design or policy-making.

NOMENCLATURE

CDD = Cooling Degree Days
HDD = Heating Degree Days
CDH = Cooling Degree Hours
WBD = Wet Bulb Depression
(°C) *NBC* = National
Building Code

TMY = Typical Meteorological
Year *DBT* = Dry Bulb
Temperature (°C) *DDH* =
Discomfort Degree Hours *TA* Thermal =
Autonomy

RH = Relative Humidity

AC = Air-Conditioning

T_{dp} = Dew-Point Temperature
(°C) T_{ground} = Ground
Temperature (°C) T_{stag} = Stagnation
Temperature (°C) T_{in} = Indoor Temperature (°
C)

T_{out} = Outdoor Temperature (°C)

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Tc = Indoor Comfort Temperature (°C)

ACKNOWLEDGEMENT

This research was supported by the Centre for Advanced Research in Building Science and Energy, CEPT University, under research grant project titled 'Centre for Solar Passive Architecture and Green Buildings' 2012-17, by Ministry of New and Renewable Energy, Government of India.

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CASE STUDY OF AN ENERGY EFFICIENT COMMERCIAL BUILDING: VALIDATING DESIGN INTENT & ENERGY SIMULATION RESULTS WITH MONITORED PERFORMANCE DATA

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Keywords: Energy Monitoring Methodology, Simulated vs measured performance, Energy efficient public building

ABASTRACT

In India, adoption of ECBC and energy-efficient building design measures in commercial buildings has remained limited due to various reasons. One of the reasons is the non-availability of good case studies of energy efficient buildings based on performance data. Such case studies are needed for convincing both government agencies (responsible for ECBC implementation) and builders and building design teams about the advantages of energy-efficient buildings. Monitoring of energy performance of buildings is a challenge due to non-installation or non- functioning energy information system (EIS) in majority of the buildings.

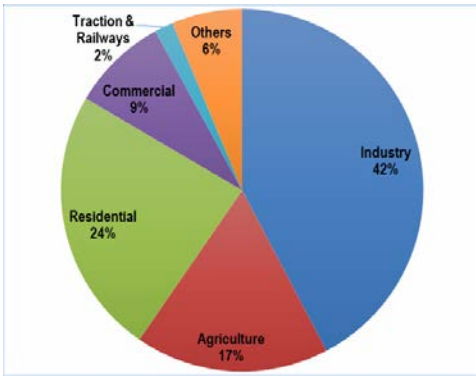
The paper presents case study of an energy efficient day-use public office building in composite climate (Jaipur). The paper provides details about:

a) Energy efficiency measures adopted in the building.
b) Results of the building energy simulation during the building design.
c) Methodology and results of the performance monitoring of the fully functional building for one-year period.
d) Results of checking compliance with ECBC

Energy efficiency measures (EEMs) for this building includes use of insulation in external walls & roof, optimized window-to-wall ratio, efficient glazing, high efficiency water cooled chiller, T5 & LED lighting and rooftop solar photovoltaic system. Since the building does not have an EIS, a monitoring methodology was developed. This consisted of (i) two-weeks detailed energy monitoring twice a year, in winter and summer season; (ii) analysis of monthly energy bills for a year; and (iii) a calibrated energy simulation model. Results show 53% of electricity is used for HVAC annually, while 31% of electricity is used for office equipment and 6% for artificial lighting. The difference in simulated performance (EPI: 53 kWh/m^2.y) and measured performance (EPI: 43 kWh/m^2.y) is explained.

INTRODUCTION

India as an emerging market economy is witnessing a significant increase in energy consumption. The total installed capacity for electricity generation in the country was ~350 GW (as on 31.03.2016), and has increased at a compound annual growth rate (CAGR) of 8.52% in last decade (Energy Statistics, 2017). Total installed capacity is estimated to increase to ~1145 GW by 2047 (IESS, 2015) under 'Determined Effort Scenario' (i.e. level of effort which is deemed most achievable by the implementation of current policies and programmes of the government).



Buildings are the second largest consumer of electricity in India after industries (Figure 1). Overall, buildings sector accounts for 33% (24% residential & 9% commercial) of the electricity consumption (Energy Statistics, 2017).

Figure 1: Electricity Consumption in India (sector-wise)Projections under different scenarios (Figure 2), show that the electricity consumption for the residential sector is expected to increase 6-13 times from 2012- 2047 and 7-11 times for the commercial sector in the same time frame (IESS, 2015). This increase of electricity

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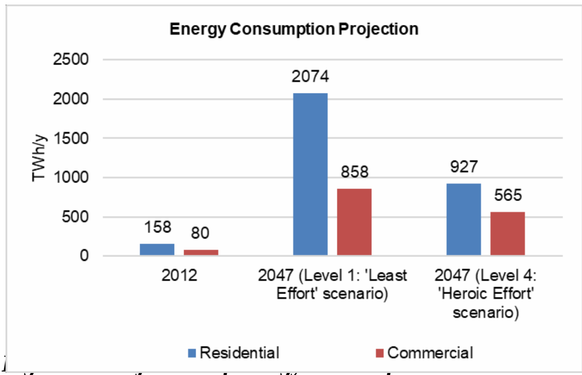
consumption in buildings is primarily attributed to the increase in building stock with residential sector built-up area expected to increase by ~4 times, while commercial sector by ~13 times, during 2012 to 2047 (Figure 3) (IESS, 2015), expansion of electrification in rural areas as well as to the increased intensity of electricity consumption in urban buildings, mainly due to rapid growth of air conditioning.



(Level 4) and worst (Level 1) scenario

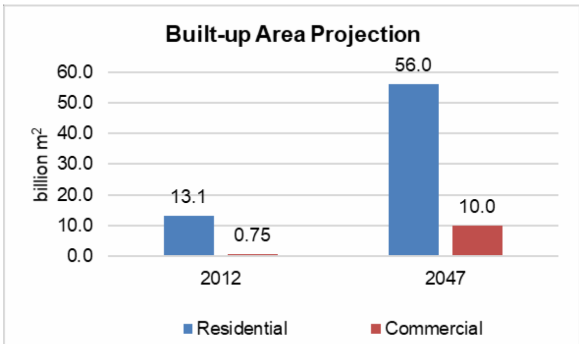


Figure 3: Projection of built-up area

The difference between the "Least Effort Scenario" (i.e. projections assuming past trends continue) & "Heroic Effort Scenario" (i.e. heightened efficiency numbers, leading up to the physically best attainable in due course) (Figure 2) shows that there is a large potential of reducing the overall energy consumption in building by ~50% by the year 2047.

Regulatory efforts in India have focused on commercial building energy efficiency. The Bureau of Energy Efficiency (BEE) developed Energy Conservation Building Code (ECBC) in 2007 to address energy efficiency in new and large commercial / institutional buildings. However, ECBC adoption is voluntary and becomes mandatory in the state after notification by respective state government. As of now, 10 states have notified ECBC and established ECBC cells in 5 states; but actual implementation of the code has remained challenging.

Mandatory building energy efficiency codes like ECBC are considered essential for mainstreaming building energy efficiency in new buildings in emerging economies. Further, it has been noted that world-wide the building energy efficiency codes have better acceptance in the cold climate regions as compared to warm climate regions (Liu et.al. 2010). There are several challenges in the implementation of building energy efficiency codes in the emerging economies and a multi-pronged approach is needed for successful implementation.

Development of good quality case studies of energy-efficient commercial buildings is one of the key components of this multi-pronged strategy, particularly for countries like India which falls in warm climate region. Most of the existing case studies on energy efficient commercial buildings in India are based on building energy simulation results and not on actual monitored energy performance of the building. Due to this reason, there is a lack of confidence and a certain degree of distrust amongst the builders/developers and building designers about the effectiveness of ECBC, building energy efficiency design measures and the results of building energy simulations.

This paper presents a case study of a commercial building. The paper provides details about:

a) Energy efficiency measures adopted in the building.
b) Results of the building energy simulation during the building design.
c) Methodology and results of the performance monitoring of the fully functional building for one-year period.
d) Results of checking compliance with ECBC

Building Design

About the building: The building (Figure 4 and Figure 5) is the head office of the Rajasthan Forest Department, situated in Jaipur (composite climate).

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Figure 4: Aranya Bhawan

Key details of this building are:

- Built-up area: ~10,000 m^2 (excluding basement parking and service area)
- Number of floors: Five (G+4) + one basement level for parking and services
- Number of users: 344
- Types of spaces: Offices, museum, library, auditorium, guest rooms
- Building has three wings with the floor plans as shown below.

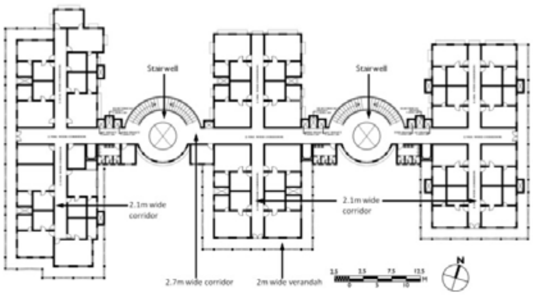

Figure 5: Ground floor plan of the building

- Project timeline & key steps
  - A design workshop for energy-efficient design with key project team members was organised at the design stage in December 2012. This workshop resulted in identification & selection of energy efficiency measures (EEMs) as well as building energy simulation to quantify energy savings.
  - Construction of the building was carried out from 2013 – March 2015.
  - The building was inaugurated in March 2015 and fully occupied by April 2015. Energy monitoring of the building was done in 2015-2016.

Energy efficiency measures & renewable energy system implemented: During the design workshop, the main emphasis was on reducing heat gains, improving day lighting, energy efficient lighting and cooling systems and integration of renewable energy. Following EEMs were agreed upon and implemented during construction stage. The EEMs include:

- Roof insulation (Figure 6): Roof of this building is insulated with 40 mm polyurethane foam (PUF) resulting a U-value of 0.6 W/m^2.K. Also, light coloured terrazzo tiles at top was incorporated to have high reflectivity.

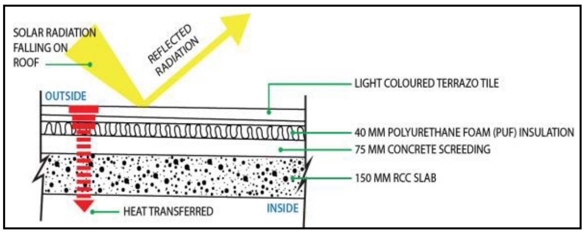

Figure 6: Roof insulation details

- Wall insulation (Figure 7): External wall constructed as cavity wall filled with insulation. A 50 mm extruded polystyrene (XPS) insulation was used, resulting a U-value of 0.5 W/m^2.K (without taking account thermal bridging).

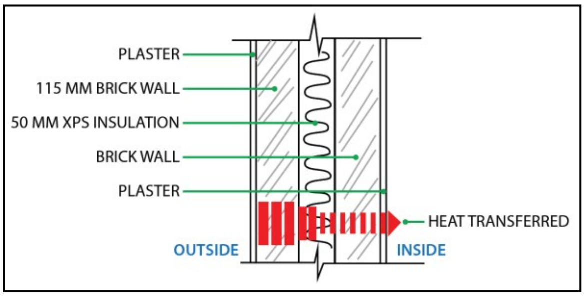

Figure 7: Wall insulation details

- Efficient glazing (Figure 8): Double glazed unit (6-12-6 mm) with U-value: 1.8 W/m^2.K, SHGC: 0.24 & VLT: 36% was used to reduce heat gains and get enough daylight. Relatively shallow floor plate (15 m deep) of the building helped in daylighting.

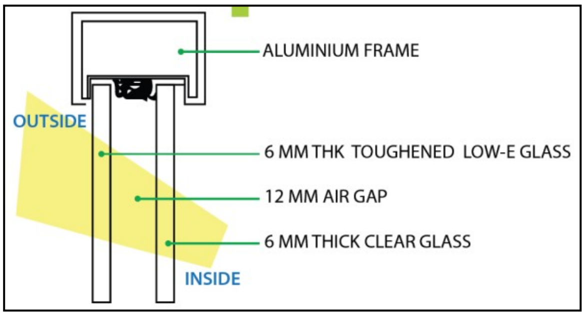

Figure 8: Glazing details

- Energy efficient lighting: LEDs and T5 were used to achieve a lighting power density (LPD) of ~6 W/m^2.

- Energy efficient cooling system: A centralised high efficiency water-cooled chiller (COP: 5.8) was implemented for air-conditioning the building. Given the water scarcity in Jaipur, a sewage treatment plant (capacity: 15 m^3/d) was installed and treated waste water is used for the cooling towers.
- Solar photovoltaic (SPV) system: A 45kW_p grid-connected roof-top SPV system (Figure 9) with net metering is installed to meet part of the building energy requirement. It should be noted that the contribution of solar PV system has not been included in the EPI calculations during energy simulations.

Figure 9: SPV system at the rooftop

The energy simulation of the building was carried out using DesignBuilder software to quantify the benefits of the integration of EEMs. The key results of the energy simulation were:

- Reduction in cooling system size: The cooling system size was reduced from 230 TR (before the design workshop) to 165 TR (after the integration of EEMs), which is a 28% reduction in the cooling system size (Figure 10).

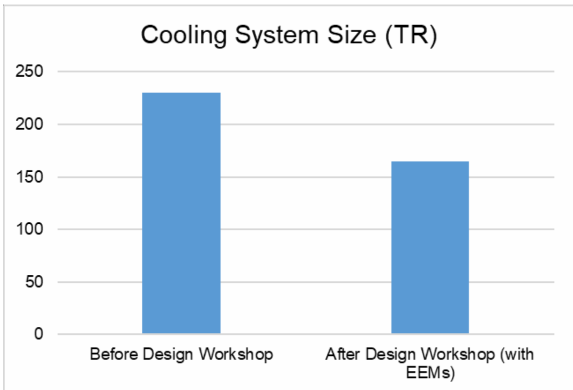

Figure 10: Reduction in cooling system size with EEMs

- Reduction in energy consumption: The energy performance index (EPI) was reduced from 77 kWh/m^2.y to 53 kWh/m^2.y (31% reduction) after considering EEMs in energy simulation (Figure 11). This does not include the energy generated from SPV system.

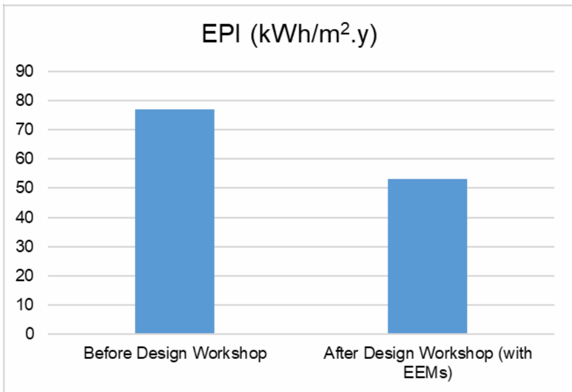

Figure 11: Reduction in EPI size with EEMs (SPV contribution not included)

ENERGY MONITORING

Energy monitoring of the building was done to understand the actual energy performance of the building and to compare it with the estimated energy performance through energy simulation. As the building does not have an EIS, the methodology for energy monitoring involved.

Collection of Electricity Bill

Monthly electricity bills for a period of one year (May 2015 to April 2016) were collected. Using this data monthly and annual EPI of the building was calculated. The billing data was also cross-checked with the data from the log book maintained by the building operation team on the hours of usage of HVAC system and periodic readings of the electricity meter.

Seasonal Energy Monitoring

The objective of the detailed seasonal energy monitoring was (1) to get break-up of energy consumption for different end-uses (e.g. HVAC, lighting, equipment, etc.), and (2) to identify further energy saving opportunities by measuring the performance of different systems (e.g. chillers, pumps, fans, lighting fixtures etc.).

Detailed energy monitoring for two weeks in winter and two weeks in summer was done. Winter monitoring was done for a duration of two weeks in January 2016. During this period, the HVAC system was not operational. Except HVAC system data, all measurements were done. In addition, data on building usage such as number of people, occupancy schedule, schedule of operation for lighting and other systems was gathered. Summer monitoring was for a duration of two weeks in May 2016. During summer, all the measurements were done as the HVAC system was fully operational.

Prior to actual energy monitoring, a detailed monitoring plan was prepared. Architectural drawings, HVAC schematic and electrical schematic was studied in detail to prepare a draft monitoring plan (Figure 12). A visit to the building was done to exactly identify the different measurement points, instruments needed, measurement frequency and other details to be collected.

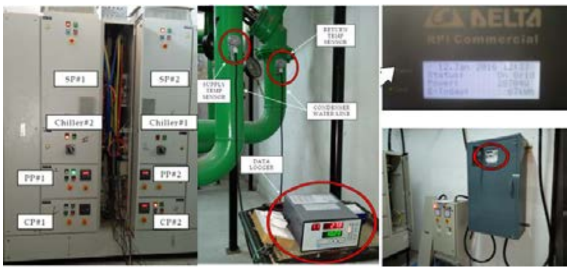

Figure 12: Identification of monitoring points

Monitoring plan for building included three levels of data monitoring and collection

Level 1: Continuous data logging with an interval of 15 min. or less: Energy loggers were installed at electricity distribution panel to continuous log the HVAC and non-HVAC loads. In addition, data logging was done for HVAC system components which included power for each operational chillers, condenser water flow, condenser water in and out temperature, power for air handling units, ambient air temperature and relative humidity. This data was used to calculate the HVAC energy break-up in AHU and Chiller plant and to calculate the chiller coefficient of performance (COP).

Level 2: Spot measurement of parameters (2 times per day: 1100-1230 hrs, 1430-1630 hrs): The key aim of this task was to find an approximate energy break-up of non-HVAC loads which included lighting (office spaces, corridor & exterior), office equipment, STP & miscellaneous (lift, water pump, basement ventilation fan, etc.). Measurement points on multiple electricity distribution panel were identified for the same.

Spot measurements of electrical power was done for primary chilled water pump, secondary chilled water pump, condenser pump and cooling tower fan to get further break-up of chiller plant energy consumption.

Spot measurements were also made for indoor lighting levels and artificial lighting power to understand the daylight penetration in spaces and lighting energy.

Level 3: Data collection (from hourly panel reading, through records or through interaction): Energy generated from SPV system, from DG set was collected to get energy supply from these systems.

Figure 13: Photographs during the monitoring

Table 1 shows the list of instruments used during the monitoring, its make and measured parameter.

Table 1: List of instruments used during monitoring

Sr. No	Name of Instruments	Make	Measurement
1	Single CT power meter	MECO	Snap shot power measurement
2	Three CT power analyzer	ORACLE	Power Data Logging
3	Three CT power analyzer	Krykard	Power Data Logging
4	Swing Psychrometer	JRM	DBT & WBT
5	Lux meter	TES 1332 A	Illumination levels
6	Surface contact type temperature sensor	Libratherm	Measurement of surface temperature on condenser water header
7	Head mount temperature sensor	Libratherm	Measurement of water temperature through thermowell
8	8 Channel Temperature Logger	Libratherm	Logging of water temperature readings
9	8 Channel Temperature Logger + %RH logger	Libratherm	Logging of Ambient Temperature + water temperature + %RH
10	Ambient temperature + %RH sensor	Libratherm	Ambient Temperature + %RH
11	Ultrasonic Water Flow meter	Essiflo	Data logging of Water flow through main header of condenser
12	Infrared temperature gun	Testo	Measurement of Envelope temperature

Calibrated Energy Simulation Model

Based on the information gathered, detailed specification of equipment and performance measurement of systems; an energy simulation model (using VisualDOE) was prepared. Calibration of simulation model was done:

- Against the monthly energy bills to match the monthly energy consumption
- Against the energy consumption of different end-uses (lighting, equipment, HVAC, etc.) for the detailed monitoring period i.e. two weeks of January and two weeks of May

The objective of this model was: (1) to calculate the break-up of energy consumption for different end-uses round the year as the detailed monitoring was done only for a total of four weeks duration and (2) to calculate the energy saving through the additional measures identified during the monitoring period.

ECBC Compliance

'Whole building performance method' was followed for ECBC compliance check. This requires preparation of energy simulation model for two cases

(1) ECBC Prescriptive and (2) As Designed. All the simulation inputs, (e.g. wall U-value, roof U-value, fenestration SHGC, VLT & U-value, lighting power density, HVAC system COP, etc.) for 'ECBC Prescriptive' case, were taken as defined in ECBC. For the 'As Designed' case, all the simulation inputs were taken as designed capacity and design specification. Inputs on building operation (e.g. thermostat setpoints, schedules, internal gains, occupant loads, etc.) were kept same for both cases. In addition, all the mandatory requirements were checked for ECBC compliance.

Actual energy performance of building may not match to the 'As Designed' case due difference in user behaviour and difference in actual performance of various systems.

RESULTS AND DISCUSSIONS

Comparison of energy performance (Simulation vs actual)

The simulated EPI during the charrette (December 2012) was 53 kWh/m^2.y as compared to the actual EPI (monitored data for May-15 to Apr-16) of 43 kWh/m^2.y. Figure 14 shows the comparison of monthly EPI for these two cases.

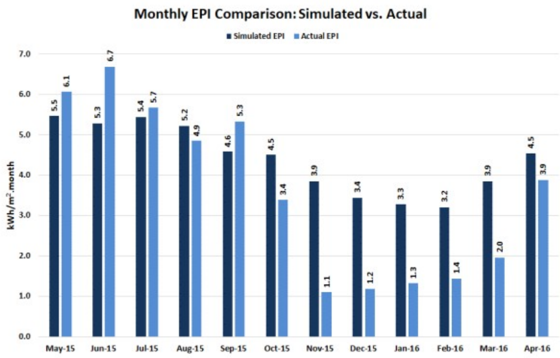

Figure 14: Simulated and actual monthly EPI

Key reasons for these differences are:

- The simulation was done using the ISHRAE weather data file which gives the hourly data for a year with long term measured data. Weather conditions for the monitoring period may have differences as compared to the data considered in the energy simulation.
- During monitoring it was observed that the HVAC remained OFF during the period November - Mid March, while in simulation, the HVAC system was considered operational during this period.
- The artificial lighting energy consumed in winter (Nov-Feb) was also less than that estimated in the charrette due to better use of daylight.
- During the simulation, only weekends (Saturday & Sunday) were considered as holidays, whereas in actual there were 20-30 additional holidays.

All the findings of energy monitoring (actual schedule for occupancy, lighting, equipment, HVAC system performance) were used to prepare a 'calibrated energy simulation model' as explained in subsequent sections.

Energy supply and consumption

Figure 15 gives the break-up of energy supply from grid & SPV system. DG set was hardly used during this period and thus does not feature here. SPV system of 25 kW$_p$ capacity was installed in October-2015 and subsequently the installed capacity was increased to 45 kW$_p$ in January-2016 and later net metering was done in April-2016. Therefore, during May-15 to April-2016, only ~6% of energy was supplied through SPV system and ~94% was drawn through the grid. However, is it estimated that contribution of energy from SPV system would increase to ~20% (considering the present energy consumption and energy generation from 45 kWp system for a year).

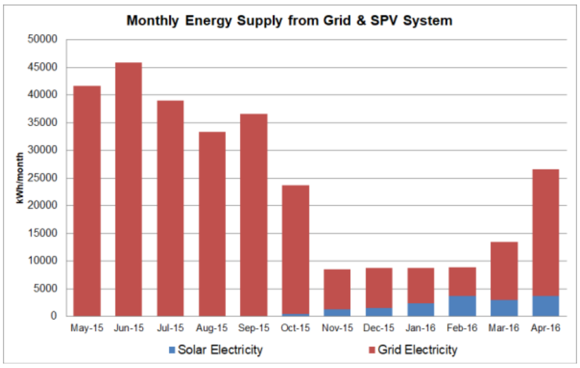

Figure 15: Energy supply break-up

Figure 16 & Figure 17 gives the annual and monthly break-up of energy consumption for different end- uses, respectively.

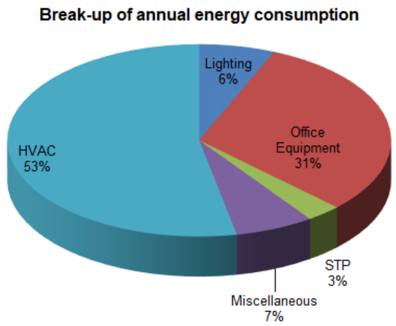

Figure 16: Break-up of annual energy consumption

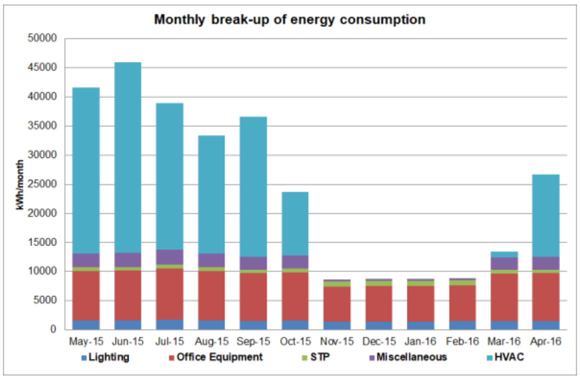

Figure 17: Break-up of energy consumption (Monthly)

Annually, HVAC consumes maximum energy and accounts for 53% of the electricity consumed. Office equipment consumes 31% of the annual electricity with artificial lighting consuming 6%. November- 2015 to mid of March-2016, the HVAC system remained off. Total monthly consumption peaks in June due to peak energy consumption by the HVAC system.

Seasonal energy break-up

Figure 18 and Figure 19 show the break-up of energy consumption during the winter (Nov-Feb) and summer (Mar-Oct) months, respectively. During the winter office equipment consume maximum (69%) amount of energy while in summer HVAC accounts for maximum (60%) energy consumption.

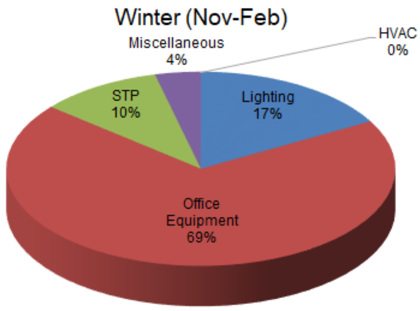

Figure 18: Break-up of energy consumption in winter

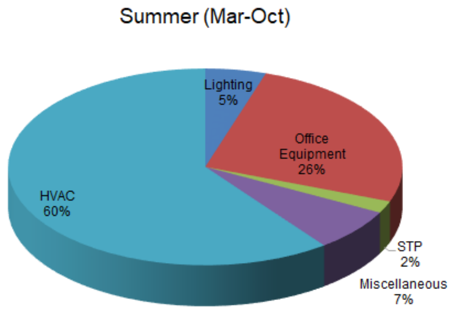

Figure 19: Break-up of energy consumption in summer

HVAC system performance

Figure 20 shows the measured COP of two operational chillers day-wise. The average COP of Chiller#1 was 7.4, while for Chiller#2 it was 5.5. Although cooling water temperature delivered to Chiller#2 was same as Chiller#1; but the "Condenser Approach" was found to be 4.5°C; as compared to the "Condenser Approach" of 2°C for Chiller#1. Due to this higher "Condenser Approach" for Chiller#2, the condensing pressure of refrigerant was higher as compared to that of Chiller#1 and therefore, performance of Chiller#2 was found to be low.

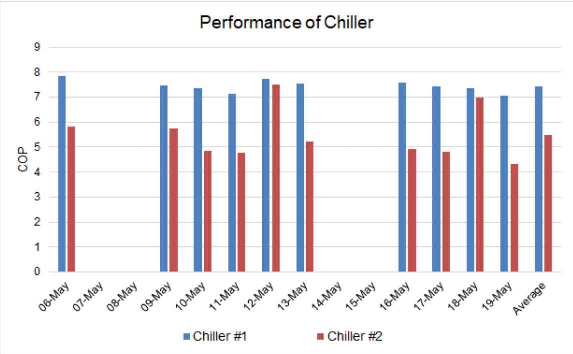

Figure 20: Measured chiller performance

Figure 21 shows the COP of overall HVAC plant (including chiller, pumps & cooling tower) for the monitoring period. It varied from 3.6 to 4.6 during the monitoring period and the average COP was calculated as 4.1.

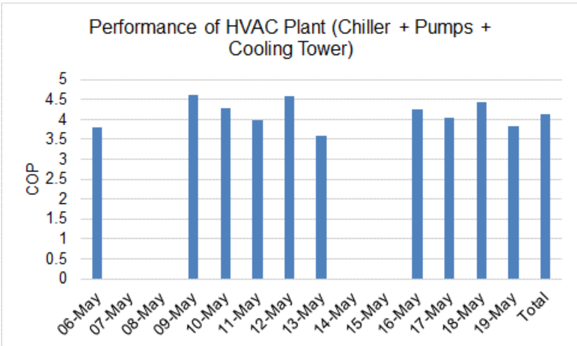

Figure 21: HVAC plant performance

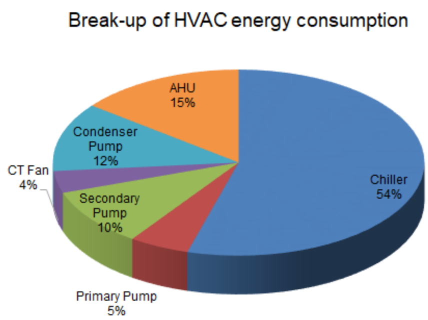

Figure 22: Break-up of HVAC energy consumption

Figure 22 shows the break-up of HVAC energy consumption. Chillers account for the 54% of HVAC energy while AHU consume 15% of it.

Daylighting measurement

Figure 23 shows the sample spaces (total 9 spaces) for which daylight measurement (lux levels) was done. The measurement was done once during winter and summer monitoring.

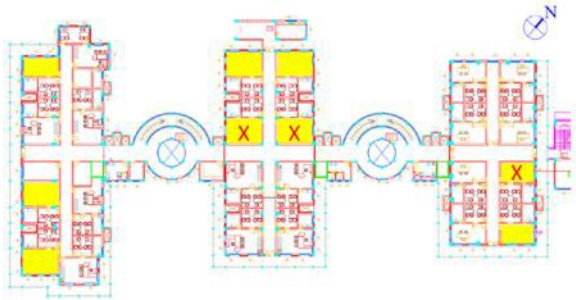

Figure 23: Sample spaces for daylight measurement

Out of these 9 spaces, 3 spaces (marked as 'X') had average daylight of ~30 lux and required artificial lighting. This was mainly due shading by adjacent staircase block. Other 6 spaces had average daylight of ~300 lux and did not require any artificial lighting.

Further Energy Saving Opportunities

Energy monitoring identified few additional measures which can further help in energy saving. The saving potential of these additional measures is estimated through energy simulation (by adding these measures in the 'calibrated energy simulation model'). These measures are:

- Reduction of contract demand from 500 kVA to 400 kVA as the recorded demand did not exceed 300 kVA.
- Improve condenser approach for under-performing chiller by cleaning the condenser tubes and maintaining water quality.
- Improve cooling tower efficiency.
- Replace condenser water pumps & primary chilled water pump with revised capacity (pressure & flow).

Energy savings through these additional measures is estimated to be ~10,000 kWh/y.

ECBC Compliance Analysis Results

Following the 'whole building performance method', energy simulation was done for 'ECBC Prescriptive' case and 'As Designed' case to check whether the design of the building is ECBC compliant or not. Figure 24 shows that the energy consumption of 'As Designed' case is ~20% less as compared to 'ECBC Prescriptive' case; confirming that the building is an ECBC compliant building.

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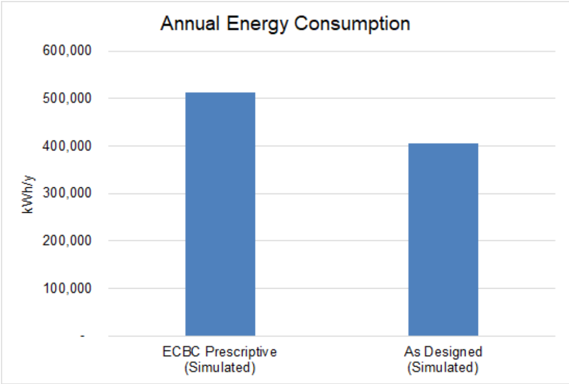

Figure 24: Energy consumption results for ECBC compliance

BEE also has a star rating programme for existing buildings based on one energy consumption (EPI) data for a complete year. For day-use office building in composite climate (e.g. Jaipur), a building with an EPI < 90 kWh/m^2.y, gets a five-star (maximum) rating. With an EPI of 43 kWh/m^2.y, The building easily qualifies for five-star rating under BEE's star rating programme.

Cost Benefit Analysis

Cost of construction before design workshop was estimated to be Rs 300 million, while the actual cost of construction after implementing all EEMs (except SPV system) was Rs 306 million. The increase in capital cost was only 2% while energy saving estimated to be 44%; thereby resulting in a payback period of 2.5-3.0 years.

CONCLUSION

Good quality case studies based on monitored energy performance are needed for mainstreaming ECBC in the country. The paper presents case study of an office building at Jaipur and cover:

a) Energy efficiency measures adopted in the building.
b) Results of the building energy simulation during the building design.
c) Methodology and results of the performance monitoring of the fully functional building for one-year period.
d) Results of checking compliance with ECBC

Energy efficiency measures (EEMs) for this building includes use of insulation in external walls & roof, optimized window-to-wall ratio, efficient glazing, high efficiency water cooled screw chiller, T5 &LED lighting and rooftop solar photovoltaic system. Since the building does not have an EIS, a monitoring methodology was developed. This consisted of (i) two-weeks detailed energy monitoring twice a year, in winter and summer season; (ii) analysis of monthly energy bills for a year; and (iii) a calibrated energy simulation model. Results show 53% of electricity is used for HVAC annually, while 31% of electricity is used for office equipment and 6% for artificial lighting. The difference in simulated performance (EPI: 53 kWh/m^2.y) and measured performance (EPI: 43 kWh/m^2.y) is explained.

The case study shows that for building without an EIS, using a customised energy monitoring methodology, one can get quite good understanding of energy performance of building, break-up of energy for end- uses and performance of systems; also identify possibilities of further improvement in energy performance.

There is a need to have many such case studies. This would help in motivating builders / developers and other building sector professional to adopt energy efficiency measures in their projects, having more ECBC compliant buildings.

ACKNOWLEDGEMENT

The authors of this paper would like to thank Indo-Swiss Building Energy Efficiency Project (BEEP) under which the technical support was provided to Aranya Bhawan project team for design & implementation of energy efficiency measures as well as funding was provided to carry out the energy monitoring work. The authors would also like to thank Energetic Consulting Pvt. Ltd. for conducting the energy monitoring; Rajasthan State Road Development Cooperation (RSRDC) for implementing the EEMs and Forest Department of Rajasthan to support as building owner.

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EMBODIED ENERGY & OPERATIONAL ENERGY (FOR LIFTS & PUMPS) OF DIFFERENT DESIGN CONFIGURATIONS OF AFFORDABLE HOUSING

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Keywords: Embodied energy, Buildings, Affordable housing, Housing for All

ABSTRACT

India is witnessing a rapid increase in the residential building floor space. As per one of the projections of NITI Aayog, the residential floor space is estimated to grow from 16 billion m^2 to 56 billion m^2, from 2017- 2047. The increase in residential floor space will have significant impact on energy demand of the country, because of increase in operational energy (OE) and embodied energy (EE). Government of India's Housing for All 2022 programme focuses on meeting the housing demand of economically weaker sections of the society. The programme targets construction of 20 million affordable houses in urban areas in less than 6 years.

The paper presents EE calculations based on actual material consumption data for 9 affordable housing projects being implemented by the Rajkot Municipal Corporation, Gujarat. The analysis shows that EE for the projects varies from 2500 MJ/ m^2 to 3700 MJ/m^2. EE is primarily affected by the choice of the construction technology and building materials, as well as by the building height. The buildings in this analysis vary in height from 4 to 11 stories; the construction technology covers monolithic concrete construction and concrete framework with a variety of masonry infill (burnt clay bricks, AAC blocks, flyash bricks). The paper shows that around 30-40% reduction in EE is possible through design improvements and building material choices in affordable housing projects. The paper also shows that OE for water pumping and lifts increases by 3 to 4 times as we go from low-rise to high rise buildings.

INTRODUCTION

India is rapidly urbanising. The current 30% urban population in India is expected to increase to 50% by 2050, adding 441 million to the urban population (UN DESA, 2014).

Population increase, economic development and urbanisation are resulting in increased demand for constructed built-up area. This will have significant impact on the country's resources. It is estimated that during the period 2012– 47, building stock will increase from 14 billion m^2 to 66 billion m^2 (NITI Aayog, 2015) the majority of which will be residential buildings. The residential building stock is expected to see a four-fold increase from 13.1 billion to 56 billion m^2 of floor space (NITI Aayog, 2015).

The Pradhan Mantri Awas Yojana (PMAY)- Housing for All (Urban) is Government of India's flagship programme to fulfil the housing demand / housing shortage for the urban poor. This mission target is 20 million affordable houses between 2015-2022, which will be provided central financial assistance / subsidies through the states / UTs with different implementing mechanisms. The targeted construction is almost 11% of the predicted urban residential built-up area, which will house 20-30% of the urban population in 2022 (NITI Aayog, 2015). Given the magnitude and scale of affordable housing to be built, it provides an opportunity to explore the potential of low-carbon and resource-efficient construction.

This paper looks at the type of construction for affordable housing that will be low-carbon and resource-efficient, considering two factors: construction technology / building envelope materials, and building height. The case studies are projects being executed by the Rajkot Municipal Corporation (RMC) in the state of Gujarat. The paper analyses the effect of these factors on the embodied energy (EE) and operational energy (OE). While both factors have an impact on the EE of a building, their impact on OE is in two ways:

- Impact of construction technology / building envelope materials on energy used to provide thermal comfort for the occupants; and

Impact of building height on energy used for water pumping and operation of lifts.

A comprehensive analysis of these factors on EE and OE can inform on the type of building massing and construction type that would be low-carbon and resource-efficient. This paper limits its analysis to EE and OE for water pumping and lifts. Analysis on OE for thermal comfort is excluded from this paper, as its scale and complexity warrants separate analysis and documentation.

Affordable Housing

Affordable housing is generally defined in terms of "(i) multiples of household income; (ii) size of the tenement; and (iii) in case of rented accommodation, in terms of percentage of household income." (High Level Task Force on Affordable Housing for All, December 2008). The third point could also be extended to include "percentage of household income for home loan EMIs." It goes without saying that such housing should be provided with basic civic and infrastructure services.

The Ministry of Housing and Urban Poverty Alleviation (MoHUPA) notes both income and size criteria to define affordable housing. This usually includes the Economically Weaker Section (EWS) and Lower Income Group (LIG) Category. For PMAY, affordability is also extended to the Middle- Income Group (MIG) under only one of its implementation mechanisms. The definition of affordable housing for PMAY (January 2017) is:

Table 1: Definition of affordable housing under PMAY

	ANNUAL INCOME	**SIZE OF DWELLING UNIT (DU)**
EWS	Up to Rs.3 lakhs	Up to 30 m^2
LIG	Between Rs 3 lakhs to 6 lakhs	Up to 60 m^2
MIG I	Between Rs 6 lakhs to 12 lakhs	Up to 90 m^2
MIG II	Between Rs 12 lakhs to 18 lakhs	Up to 120 m^2

Embodied Energy (EE)

There have been different definitions of embodied energy. One of the more comprehensive definitions of embodied energy is that it "comprises of the energy consumed during the extraction and processing of raw materials, transportation of the original raw materials, manufacturing of building materials and components and energy use for various processes during the construction and demolition of the building" (Cited in Dixit, Fernandez-Solis, Lavy, Culp, 2014).

Embodied energy in a building has two primary components, direct energy and indirect energy (Cited in Dixit, Fernandez-Solis, Lavy, Culp, 2014).

- Direct energy: Total energy consumed in onsite and offsite operations, such as construction, prefabrication, assembly, transportation and administration etc.
- Indirect energy: Energy consumed in manufacturing the building materials, in renovation, refurbishment and demolition processes of the buildings etc. Thus, it can be further subdivided into the following:
  - Initial embodied energy: Energy consumed during the production of materials and components, which includes raw material procurement, building material manufacturing and finished product delivery (transportation) to the construction site.
  - Recurrent embodied energy: Energy used in various maintenance and refurbishment processes during the useful life of a building.
  - Demolition energy: Energy expended in the processes of a building's deconstruction and disposal of building materials.

Operational Energy (OE)

Operational energy can be defined as the amount of energy consumed to satisfy the demand for

- Thermal comfort, i.e. heating, cooling and ventilation,
- Visual comfort, i.e., lighting, and running other equipment and appliances for common and individual amenities.

Scope and limits of the paper

The contents of this paper form part of a study on the potential of addressing the issue of low-carbon and resource-efficient construction for affordable housing (EWS and LIG segments). The original study also looked at quality of life, efficiency of space utilisation etc. apart from the energy required in affordable housing. Nine (9) completed and on-going affordable housing projects executed by the Rajkot Municipal Corporation (RMC) were taken as the examples for this study.

The EE analysis is done using the initial embodied energy (excluding transportation to the construction site) of the main construction components: cement,

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steel and walling material, as they contribute the most to the embodied energy of a building, especially that of affordable housing. The results of the analysis are constrained by the availability of the data on material quantities for building projects of different heights and different material. For e.g. for the same material, examples of different building heights were not available, and vice versa. Also, the material quantities for the few on-going projects are estimated rather than the final quantities.

Apart from the effect of material and building height on embodied energy, this paper will also look at their effect on OE for running the common equipment for water pumping and lifts. This is affected by the building height, but not so much by the building materials.

METHODOLOGY

Embodied Energy Analysis

For this study, information about 9 affordable housing projects, built and on-going, executed by RMC was collected. Details of these projects are given in **Table 2**. The size and design of individual dwelling unit within each project is the same. The criteria for selection was to cover the range of multi-family multi- storey affordable housing being constructed in Rajkot, in different building height and envelope material combinations. For e.g.:

a) In terms of height i.e. low-rise (Ground (G)+3 storeys / Stilt (S)+4 storeys; mid-rise (S+7 storeys); and high-rise (above S+8 storeys)
b) In terms of construction material / technology: RCC framed structure with burnt clay bricks; RCC framed construction with Autoclaved Aerated Concrete (AAC) blocks; and monolithic concrete (MASCON) construction.

The Bills of Quantities (BOQs) of these 9 projects were collected, from which the quantities of the larger building items were taken, viz.

- Cement concrete used in Reinforced Cement Concrete work (RCC) for the building structure viz, foundations and footings, columns, plinth beams, beams, lintels, overhangs (if any), staircases, lift walls.
- Steel used in RCC
- Cement mortar used in walling material
- Cement plaster required on walls and ceilings
- Walling material

From these item quantities, the quantities of the three major materials, i.e., cement, steel and walling material (bricks or AAC) was calculated. Cement quantity was calculated based on the mix ratios. Quantities of other materials used in cement concrete,
i.e. coarse aggregate and fine aggregate / sand was also calculated. The EE of these materials were then calculated based on the EE values given in **Table 3** to get the total embodied energy for the project (of the major materials). This value was then divided by the total built-up area of the project (A) to arrive at the *"embodied energy per m^2"* for each of the projects.

The embodied energy of each project is calculated using the following formula:

$$EE_{building}\text{, (MJ/m}^2\text{)} = \frac{(EE_{ce} + EE_{br} + EE_{st} + EE_{AAC} + \cdots)}{A} \quad (1)$$

Table 2: Details of affordable housing projects studied

PROJECT NO.	TYPE OF HOUSING	SITE AREA (M^2)	BUILT-UP AREA, A (M^2)	NO. OF STOREYS	NO. OF DU'S	BUILT-UP AREA OF EACH DU (M^2)	CARPET AREA OF EACH DU (M^2)	CONSTRUCTION TYPE	BUILT-UP AREA-TO-CARPET AREA RATIO
Project 1	EWS	8086.0	11227.03	G+3	304	31.69	26.59	RCC framed structure + bricks	1.38
Project 2	EWS	2888.0	5314.68	G+3	120	41.45	30.74	RCC framed structure + bricks	1.44

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Project 3	EWS	42391.3	53519.20	G+3	1512	31.75	27.61	MASCON	1.28
Project 4	EWS	2091.6	4788.94	S+4	89	33.39	27.56	RCC framed structure + AAC	1.95
Project 5	LIG	8820.0	21388.40	S+7	280	56.07	47.71	RCC framed structure + bricks	1.60
Project 6	EWS	3678.2	8570.83	S+7	168	34.31	28.00	RCC framed structure + AAC	1.82
Project 7	EWS	17593	57408.02	S+7	1176	35.03	27.09	RCC framed structure + AAC	1.80
Project 8	LIG	1637.7	5650.27	S+10	100	40.86	33.19	RCC framed structure + AAC	1.70
Project 9	EWS	4732.0	17344.32	S+11	352	35.03	27.09	RCC framed structure + AAC	1.82

Operational Energy Analysis

Water pumping energy. The OE for water pumping per dwelling unit (DU) was calculated for the building projects using the following formula:

$$E_p = \frac{c \times b \times H_1}{3.6 \times p \times 10^6 \times \eta} \times 365 \qquad (2)$$

Lift energy. To calculate the OE for lifts, Gear-less PMD and VVVF non-regen type lift is considered (most commonly used lift in all mid-rise and high-rise projects now)

OE for lifts per DU per year (E_l) is the sum of the "lift running energy (E_{lr}) per DU per year" and "lift

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Table 3: Embodied energy values of building materials

S.NO.	BUILDING MATERIAL	EMBODIED ENERGY (MJ /KG)	SOURCE
1	Cement (EE_{ce})	3.99	N.A.Madlool et al., Renewable and Sustainable Energy Reviews 15, (2011)
2	Steel (EE_{st})	34.24	K.I.Praseeda et al, Energy and Buidlings 85, (2015)
3	Burnt Clay Brick, (EE_{br})	1.80	GKSPL analysis, (bricks produced in clamps in Saurashtra)
4	AAC blocks (EE_{AAC})	1.85	GKSPL analysis, (2016)
5	Coarse aggregate	0.22	Auroville Earth Institute, (2013)
6	Fine aggregate/ sand	0.02	

standby energy (E_{ls}) per DU per year."

$$(E_{lr} + E_{ls}) \times 365 = E_b \quad (3)$$

Where,

$$E_{lr} = \frac{SEC \times L \times D}{1000} \quad (4)$$

$$E_{ls} = \frac{T_s \times P_s \times N}{1000} \quad (5)$$

Where,

$SEC = \left(\frac{P_m \times 1000}{L \times v \times 3600}\right) \times \frac{1}{\eta_l}$	(6)
$D = d_t \times b \times n_t$	(7)
$T_s = 24 \left(\frac{D \times 2}{v} \times \frac{1}{3600} \times \frac{1}{N}\right)$	(8)

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RESULTS

Effect of Building Materials and Height on EE

Figure 1 shows the embodied energy per unit built-up area of the affordable housing projects, including the EE share of cement, steel, walling material (burnt clay brick / AAC blocks) and others (coarse aggregate, fine aggregate and, in 1 project, gypsum plaster). One of the projects (Project 4) was excluded from the analysis: as it was located near the river bed, raft footing had to be constructed, thus using more RCC and leading to wide deviation in embodied energy results. The analysis shows that:

- The structural materials (steel and cement) and the masonry materials (brick and AAC) form the two main components of building EE.
- In low-rise masonry construction (Projects 1 and 2), steel and cement contribute ~70% of the building EE. As we go higher, this share increases to 80-85% for mid-rise (Projects 5,6 & 7) and ~ 90% for high-rise buildings (Projects 8 & 9.
- In the case of monolithic concrete, steel and cement account for almost 95% of the embodied energy, even for a low-rise building (Project 3).
- Masonry materials contribute between 10% (for high-rise) to 30% (for low-rise) of the building EE.
- Use of AAC blocks instead of burnt clay brick can reduce embodied energy of the building by around 20%. This happens on account of the lighter density of AAC: it reduces the embodied energy of the walling component, and also reduces the quantity of steel and cement to be used in the RCC structure. However, enough evidence is not present among the different building height categories in the current study to quantify and strengthen this.

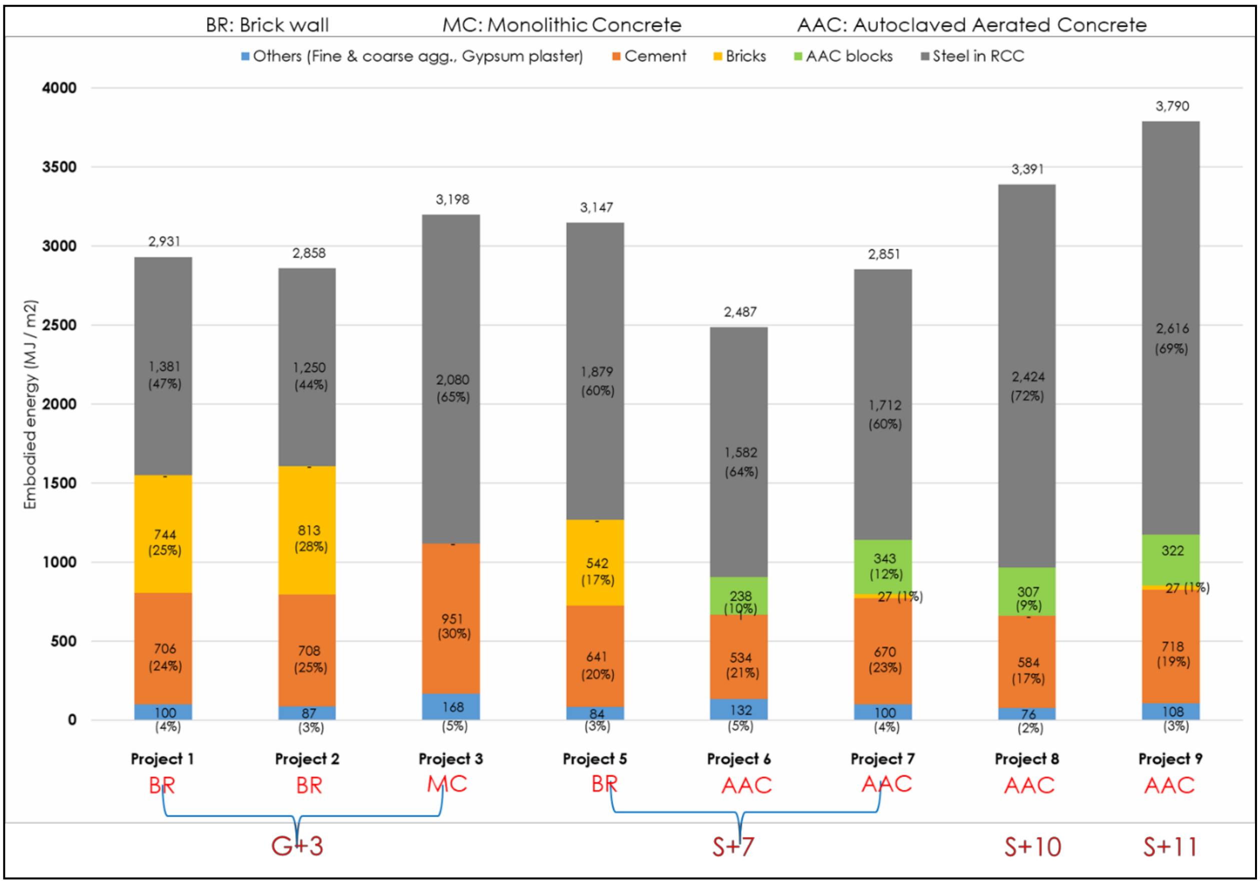

Figure 1: Comparison of Embodied Energy of 8 affordable housing projects

Given the same walling material, with an increase in building height from mid-rise to high-rise, EE is seen to increase by 20% - 50%. As buildings get taller, greater quantities of steel and cement is required in RCC, resulting in greater EE. This can be seen in **Figure 1**, where Projects 6, 7, 8 & 9 have AAC blocks as the walling material. The former two are mid-rise and the latter two are high-rise buildings. This result was not extended to the low-rise buildings as there was no low-rise building with AAC as walling material.

Effect of Building Materials and Height on OE

Energy for water-pumping and operation of lifts is proportional to the number of floors of the building or

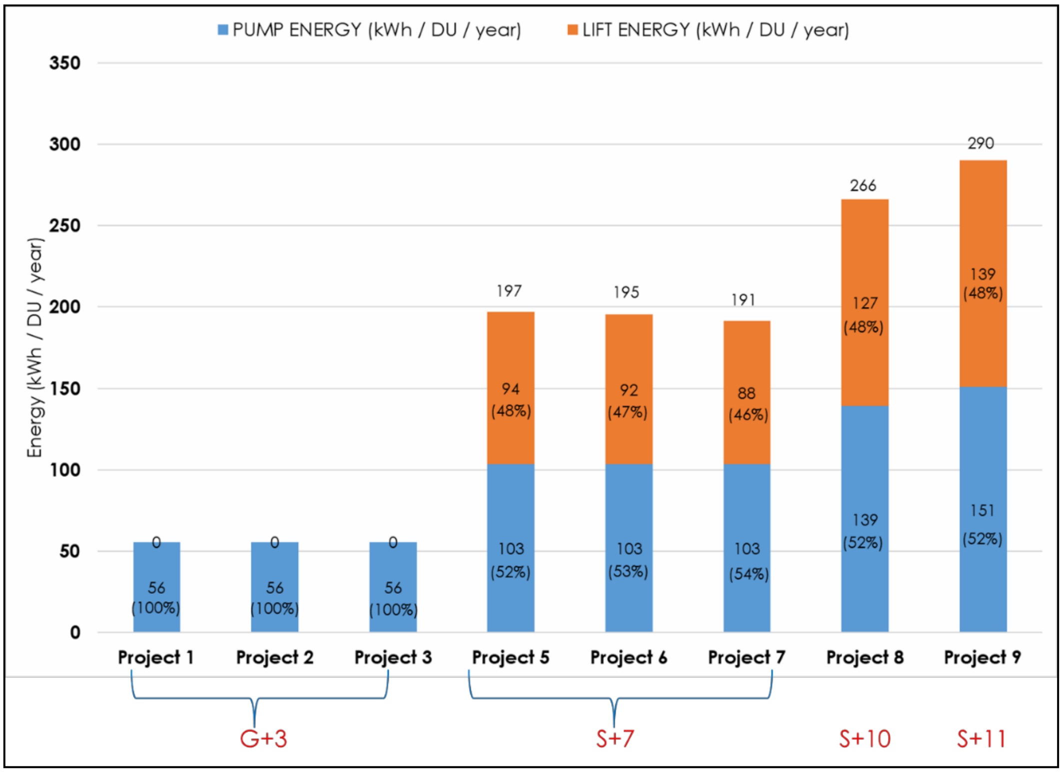

Figure 2: Comparison of Operational Energy (for pumps & lifts) per DU per year

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building height. **Figure 2** shows the OE (water pump & lift energy) per unit built-up area of the affordable housing projects. Building construction materials has no impact on this. The analysis shows that:

- There is a 3 to 4 time increase in common service energy consumption (pump + lift) as we go from low-rise to high rise.
- Low-rise buildings use the least amount of OE. They use 45-60% less energy than mid-rise and high-rise buildings for water pumping; and they do not require lifts for vertical transport.
- A 35-55% increase in lift energy is seen as we go from mid-rise to high-rise buildings.

CONCLUSIONS

The analysis shows that the embodied energy for the projects varies from 2500 MJ/ m^2 to 3700 MJ/m^2, affected by the choice of the construction technology and building materials, as well as by the building height. Steel and cement are the largest contributors to embodied energy. Low-rise construction + efficient structural design + low embodied walling materials e.g. AAC; can help in reducing embodied energy by 30-40% compared to a business-as-usual high-rise construction.

Analysis of the OE used for water pumping and lift energy shows an increase of 3 to 4 times as we go from low-rise to high rise.

The results in the paper present a case for future stock of affordable housing to be built as low-rise development from the point-of-view of both EE and OE. It can also be argued that the clientele of this type of housing will also have a better quality of life and less hassle of society management in a low-rise high- density development. Using low EE materials like AAC also helps maintain better thermal comfort inside these homes by reducing solar heat gains inside- monolithic concrete construction being the worst in this regard. This aspect is also important as the people living in these homes, in most cases, will not be able to afford air-conditioning.

The analysis results need to be corroborated forlarger number of affordable housing projects in different climate zones and contexts. Doing this can inform future policy on the design of affordable housing.

NOMENCLATURE

$EE_{building}$ = Total embodied energy of a building, MJ/m^2

E_{ce} = Total embodied energy of cement used in a building, MJ/building

E_{br} = Total embodied energy of brick used in a building, MJ/building

E_{st} = Total embodied energy of steel used in a building, MJ/building

E_{AAC}= Total embodied energy of AAC blocks used in a building, MJ/building

Ep = Pumping energy per DU in kWh / year

a = Water requirement per DU (assuming 1000 Litre/DU/ day)

g = Gravitational acceleration (9.8 m/s2)

H = Total head in m (Static head + Frictional losses which is assumed to be 20% of static head), and

ηp = Pump efficiency (assumed to be 30%)

L = Nominal load of the lift, kg

Pm= Lift motor rating = 5.6 kW

v = Lift speed = 1 m/s

Ps= Lift stand-by power = 24 W

nt= Number of lift trips per DU per day = 10

ηl = Lift efficiency = 70% (including motor efficiency, drive efficiency and other mechanical losses)

b = Number of flats in the project

N = Number of lifts in the project

dt = Average distance travelled per lift trip, (this is assumed to be half the height of the building)

SEC = specific energy consumption of the lift (in Wh/m.kg)

D = Total distance travelled by the lifts in the project per day (in m)

Ts = Lift stand-by time (in hours / day)

ACKNOWLEDGEMENT

The authors would like to thank the Swiss Agency for Development and Cooperation (SDC) for funding the study and the Rajkot Municipal Corporation (RMC) for the project information.

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ENERGY EFFICIENT BUILDING ENVELOPE & VENTILATION STRATEGIES FOR MULTI-STOREY RESIDENTIAL BUILDINGS IN INDIA

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ABSTRACT

India is witnessing a rapid increase in the residential building floor space. A survey of electricity use in middle class multi-family housing shows that electricity use for cooling and ventilation accounts for 30-60% of the annual electricity consumption. Thus, the new residential building stock should be designed to maximize thermal comfort, and to minimize energy requirement for cooling and ventilation.

This paper is based on research on energy use in dwellings and energy modelling of typical spaces in dwellings. The paper presents key strategies for designing energy efficient multi-storey residential buildings:

1. Strategies to reduce solar heat gains through the building envelope by proper sizing and shading of windows (external fixed and/or movable), insulation of roof and walls.
2. Strategies to improve ventilation, when desired, inside flats through window design and assisted ventilation.

The paper presents the results of integrating energy-efficient envelope and ventilation strategies in sample bedrooms of 3 multi-storey residential projects located at Indore (composite climate), Chennai (warm and humid climate) and Rajkot (composite climate). The experience from these 3 projects shows that a reduction in peak operative temperatures in a range of 4 - 7°C is possible by implementing these strategies.

INTRODUCTION

Globally, buildings use about 40% of energy, and in the process, emit approximately 1/3rd of GHG emissions (UNEP, SBCI). In India, buildings account for 1 3rd of the electricity consumption, second only after industries. Of this residential buildings and commercial buildings account for 23% and 8%, respectively, of the total electricity consumption in year 2014-15.

Projection done by NITI Aayog under different scenarios shows that the electricity consumption for the residential sector is expected to increase 6-13 times from 2012-2047. This increase of electricity consumption in residential buildings is primarily attributed to the increase in building stock, with residential sector built-up area expected to increase by ~4 times, during 2012 to 2047; expansion of electrification in rural areas as well as to the increased intensity of electricity consumption in urban buildings, mainly due to rapid growth of air conditioning.

A survey of electricity use in middle class multi- family housing show that the measured mean Energy Performance Index (EPI) for sample residential flats of 2-3 bedrooms in composite (National Capital Region) and warm and humid (Chennai) climate for the year 2009 are calculated as 48 kWh/m^2/annum and 43 kWh/m^2/annum respectively (BEEP, 2014; BEEP, 2016). The surveyed flats operated on mixed mode cooling, with most of the flats owning one or two room air-conditioners. It was found that energy consumption for comfort cooling varied from 1/3rd to 2/3rd of the total annual energy consumption, based on number of occupants and the number of air- conditioners. The study also indicated that in some of the flats having greater air-conditioner use, the EPI was more than 70 kWh/m^2/annum. The survey results were used to develop design guidelines for energy- efficient multi-storey housing. The guidelines put significant emphasis in designing an appropriate building envelope to reduce solar heat gains and improving natural ventilation potential to achieve thermal comfort and reduce energy use for comfort cooling in residential buildings.

Heat gains from the envelope play the most significant role in influencing thermal comfort and consequently energy efficiency in residential buildings. Residential buildings have large exposed façade area to built-up area ratio, resulting in the space cooling loads dominated by heat gains from the envelope. The penetration of air-conditioners in

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residential buildings is negligible, meaning the envelope characteristics are vital in maintaining thermal comfort. The paper presents the results of integrating energy-efficient envelope and ventilation strategies in 3 multi-storey residential projects located at Indore (composite climate), Chennai (warm and humid climate) and Rajkot (composite climate). The results of building energy simulations studies to understand the impact of these measures are presented. The simulations were carried out during design workshops conducted to recommend practical strategies for improving thermal comfort and reduce energy required for cooling and ventilation in these building projects.

METHODOLOGY

The methodology stated here follows that adopted during a 3-4 day design workshop carried out for 3 residential projects. The main purpose of the design workshops was to provide design recommendations for improving thermal comfort and energy efficiency, specific to the requirements and constraints of the project. Given the nature and duration of the design workshop, only a few practical design strategies were simulated and analysed.

1. Selection of sample bedrooms: As the design workshop takes place over a short duration, it is important to select the critical spaces for simulation instead of the whole building, or in case of residential projects, multiple building blocks. In residences, bedrooms are the most used spaces, with maximum occupancy in evenings and nights. These are also the spaces were air-conditioners are most likely to be installed. Thus sample bedrooms were selected in all 3 projects to analyse the impacts of the design recommendations. The sample bedrooms were selected based on their orientation to account for different levels of solar and wind exposure.
2. Simulating the base case: Energy models of the sample bedrooms were developed in DesignBuilder software. Inputs of the existing design are entered, viz, details of the building envelope and internal loads. These are non- conditioned spaces, as in residences air- conditioning is a matter of the residents' choice. The simulation is carried out to predict the peak operative temperature in the bedroom on a typical summer week or day. These inputs for the base case are shown in **Table 1** and **Table**
3. Simulation of the proposed envelope and ventilation strategies: Envelope and ventilation strategies are applied on the worst of the sample bedrooms of the base case, i.e., the bedroom with the highest peak operative temperature. Simulation predicts the peak operative temperature of the same summer week or day as the base case, after applying these strategies.

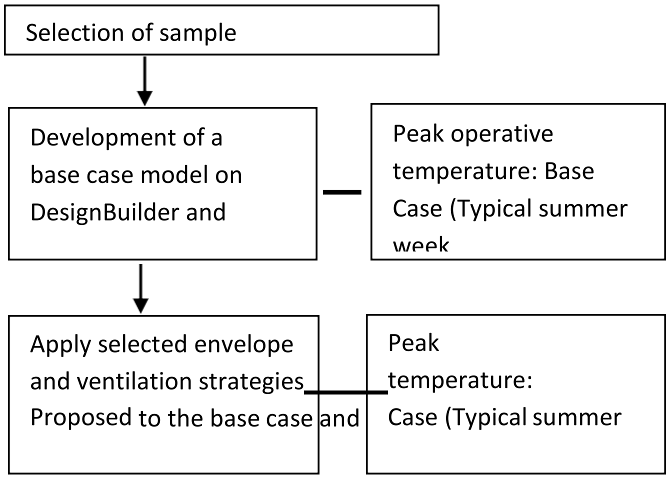

Figure 1: Flow chart showing the methodology

Table 1: Details of internal loads

Parameter	Value	Unit	Schedules
Occupancy	2	persons/ bedroom	Weekdays: 2 persons (21:00 to 7:00) Weekends: 2 persons (23:00 to 7:00) & (14:00 to 17:00)
Lighting	30 W T-5 light (1 no.)		18:00 to 23:00
Equipment	--		None

RESULTS

Project 1, Indore

This Middle-Income-Group (MIG) housing project is consists of 1743 units in 13 towers varying in height from "Stilt (S)+10" to S+14 storeys in height.

Base case simulation results: The base case simulation was carried out for 4 bedrooms of 4 flats in different orientations (**Figure 2**).

1. Bedroom with north façade exposed with window
2. Bedroom with south façade exposed with window
3. Corner Bedroom with south and west façade exposed with window on the south façade
4. Bedroom with south and west façade exposed with window and glass door on west façade

Table 2: Building envelope inputs for the 3 residential projects

	Project 1, Indore	Project 2, Chennai	Project 3, Rajkot
External wall	230 mm burnt brick with 15 mm plaster on both sides	200 mm fly ash brick with 12 mm plaster on both sides	230 mm Autoclaved Aerated Concrete (AAC) block with plaster
External wall (U value)	2.00 W/ m^2.K	1.90 W/ m^2.K	0.70 W/ m^2.K
Floor & ceiling	Considered adiabatic for intermediate floors		
Roof (U value)	3.70 W/ m^2.K	3.70 W/ m^2.K	2.70 W/ m^2.K
Glazing: 6 mm single clear glass U-factor Solar Heat Gain Co-efficient (SHGC) Visual Light Transmittance (VLT)	 5.80 W/ m^2.K 0.81 0.88	 5.80 W/ m^2.K 0.81 0.88	 5.80 W/ m^2.K 0.81 0.88
Window size	1 sliding window or window +door in 1 bedroom • Window: 1800mm x 1585mm • Window and glass door: 1900mm x 2285mm	2 sliding windows in 1 bedroom • W1: 2150mm x 1200mm • W2: 600mm x 1200mm	1 sliding window in 1 bedroom • 1450mm x 1220mm
Window-to-Wall Ratio (WWR) of sample bedroom	• Bedroom with window: 29% • Bedroom with window and glass door: 43%	15%	20%
Window operation	• 50% openable • Window opens when inside temperature outside temperature by 1°C	• 50% openable • Window opens when inside temperature outside temperature by 2°C	• 50% openable • Window opens when inside temperature outside temperature

Figure 2: Site plan of Project 1, Indore. The 4 bedrooms selected for simulation are marked

Energy simulation was carried out in all four bedrooms to calculate peak operative temperature inside the flats on a typical summer day. This was done for an intermediate floor as well as the top floor.

- On the intermediate floor, there was a temperature difference of around 5°C between the coolest bedroom (~34°C Bedrooms 1 & 2) and the hottest bedroom (38.4°C in Bedroom 4).
- The top floor bedrooms had higher inside temperatures than the corresponding bedrooms on the intermediate floor. Temperature difference between the coolest and hottest bedrooms (37.9°C and 40.4°C in Bedrooms 1 and 4 respectively) of the top floor is around 2.5°C (**Figure 3**).
- On the intermediate floors, the walls and windows contribute most of the heat gains, depending upon the orientation. On the top floor, the heat gain from the roof is most dominant.

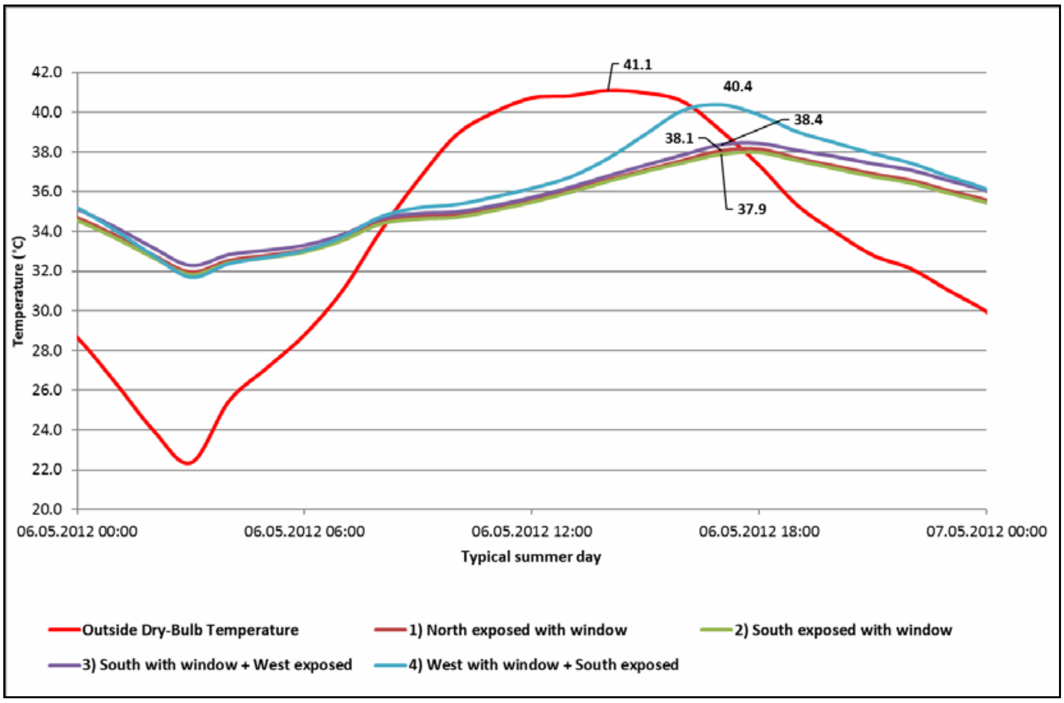

Figure 3: Peak operative temperatures for the base case on a typical summer day on the top floor (Project 1, Indore)

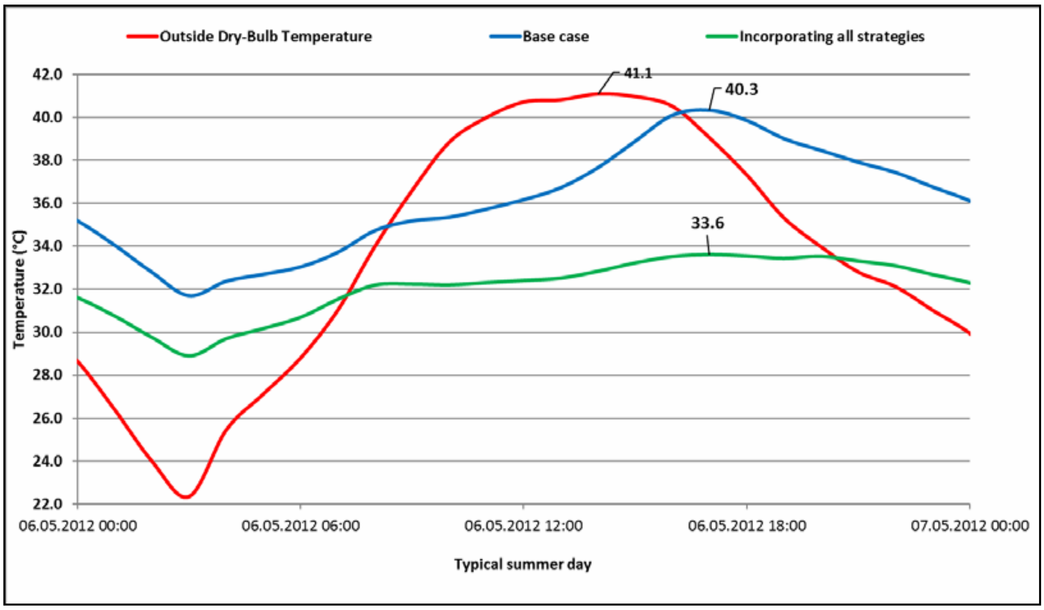

Figure 4: Peak operative temperature of Bedroom 4 on the top floor on a typical summer day- in the base case & after incorporating the strategies (Project 1, Indore

Proposed strategies: The following strategies were proposed:

- Reduce WWR to 20-30 %
- External movable shading on windows
- 200mm thick AAC blocks for walls instead of burnt brick
- 100mm XPS insulation on the roof

These strategies were simulated for the worst of the sample bedrooms, i.e. Bedroom 4 (Bedroom with south and west façade exposed with window / glass door on west façade) on the top floor. It was seen that, with the above strategies, the inside temperature can be reduced by ~7°C (**Figure 4**), bringing the peak operative temperature from 40.4°C to ~33°C. If air-conditioned, the cooling load of this bedroom will be reduced to 1/3rd from that in the base case.

Project 2, Chennai

This project consisted of 874 units (2 and 3 BHK) distributed in nine towers, predominantly facing the east and west (**Figure 5**). The towers vary in height between 14 and 17 storeys. This project had a "sky-deck" above the top floor, effectively covering the roof.

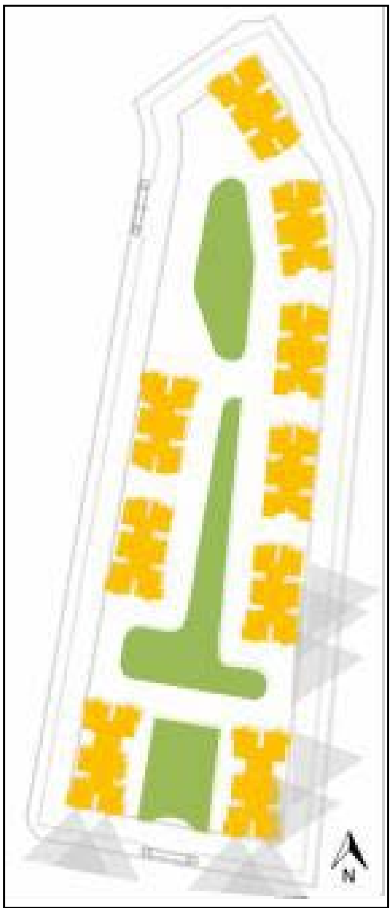

Figure 5: Site plan of Project 2, Chennai

Base case simulation results: The east-facing bedroom was considered for simulation as it was found to have higher day-time temperature. Two cases were simulated for this bedroom: when wind was available i.e. a wind-facing flat (taking wind speed as per climate file) and when wind was not available, i.e., the lee ward facing flat (wind speed 0 m/s).

This was done as Chennai is in the warm-humid climate, where the wind plays a role in maintaining thermal comfort.

- Peak operative temperature in the bedroom reach 37.8°C on a typical summer day, for flats on the windward side (**Figure 6**).
- For flats on the leeward side (wind speed 0 m/s), the peak operative temperature calculated on a typical summer day is 38.2°C.
- Most of the heat gains were occurring through the glazed windows, which faced east – west.

Proposed strategies: The following strategies were proposed:

- Shade the windows well with external movable shading and overhangs; and
- Replace the sliding windows with casement windows to improve ventilation.

The analysis shows that external movable shading has the most prominent effect in reducing inside peak temperatures and thus improving thermal comfort. While fixed shading reduces inside temperatures by 1.5°C, external movable shading reduces it by 4.2°C (**Figure 7**). Even for leeward flats, with no wind speed, peak internal temperature is reduced by about 4°C by external movable shading.

The improvement in thermal comfort due to this is also seen over the year. The number of hours in a year when the operative temperature was below 30°C is improved from 65% in the base case to 95% for wind-ward flats; and from 40% to 74% for the leeward flats.

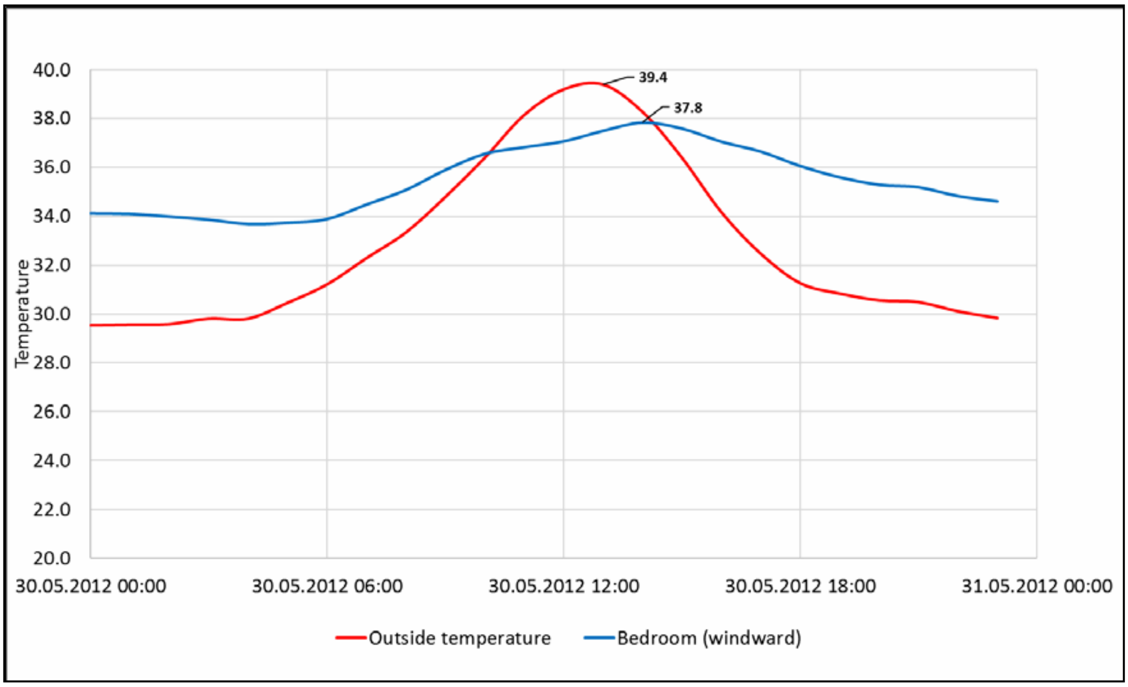

Figure 6: Peak operative temperatures for the base case on a typical summer day in a windward facing bedroom (Project 2, Chennai)

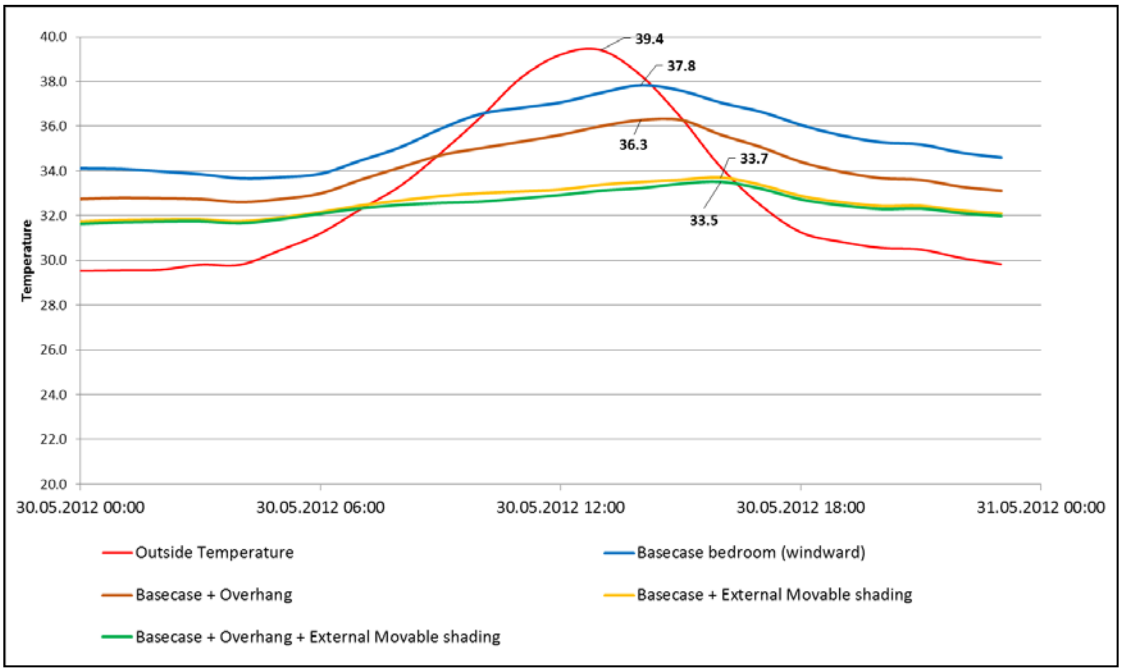

Figure 7: Peak operative temperature of a wind-ward bedroom on a typical summer day- in the base case and with different external shading (Project 2, Chennai)

Project 3, Rajkot

This affordable housing project consisted of 1176 dwelling units with the built-up area of each flat around 30 m^2. These flats were designed in 11 towers of 7 storeys with stilt parking (S+7).

Base case simulation results: The base case simulation was carried out for 4 bedrooms of 4 flats in different orientations (**Figure 8**).

- On the intermediate floors, bedrooms facing north and south are coolest in summer (**Figure 9**). There is a difference of around 3.5°C between the south

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facing bedroom (peak operative temperature 34.7°C) and the west facing bedroom (peak operative temperature 38.3°C).

- On the top floor, a similar temperature difference is found between the bedrooms facing north and south and those facing east and west, with the annual peak temperature ranging between 38°C to 41°C.
- The operative temperature inside the sample bedrooms remain below 30°C for 25% - 40% of annual hours.
- Highest heat gains occur through the glazed windows.

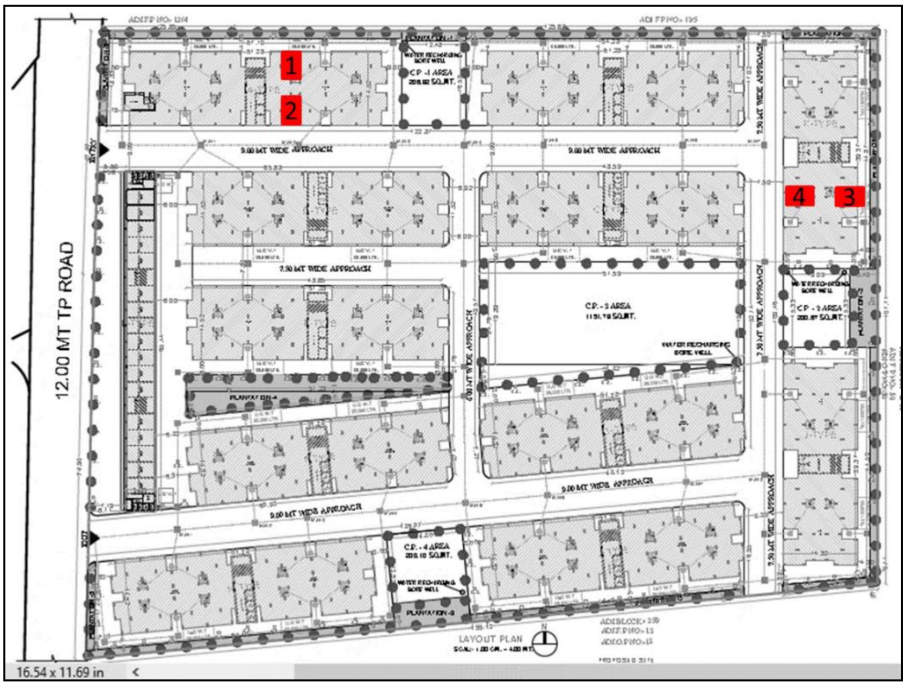

Figure 8: Site plan of Project 3, Rajkot. The bedrooms selected for simulation are marked

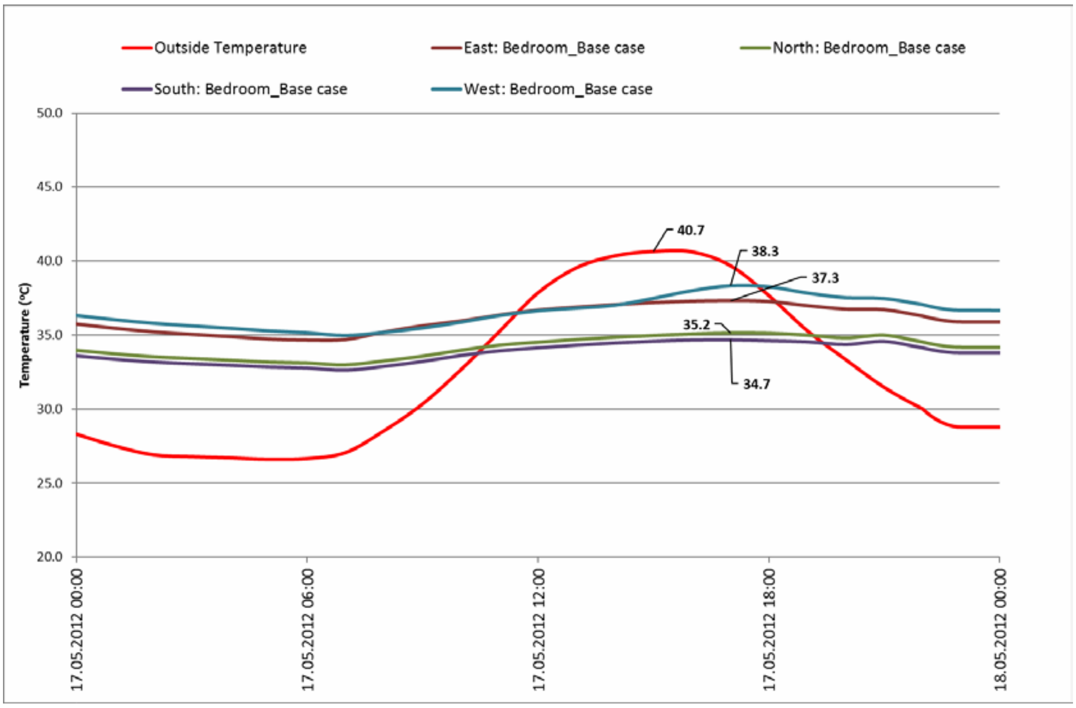

Figure 9: Peak operative temperatures for the base case on a typical summer day on an intermediate floor (Project 3, Rajkot)

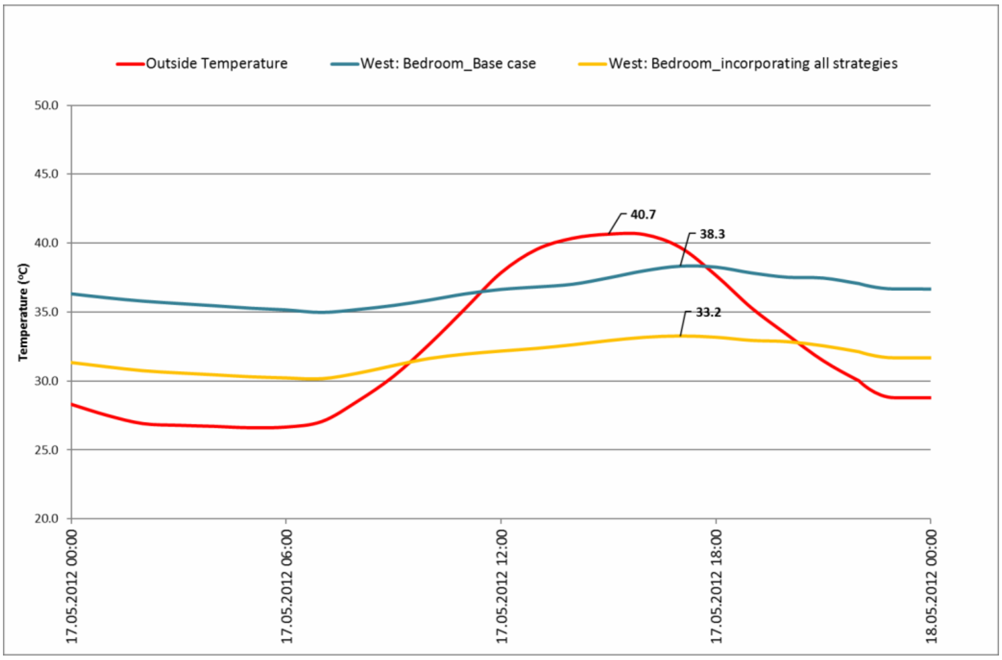

Figure 10: Peak operative temperature of a west-facing bedroom on an intermediate floor in a typical summer day- in the base case and with all strategies (Project 3, Rajkot)

Proposed strategies: The following strategies were proposed:

- External movable shading on windows or opaque window shutters with 20% glazing for daylight
- Casement windows instead of sliding windows for better ventilation
- Assisted ventilation through central shaft when ambient temperature is cooler than inside temperature
- 40 mm polyurethane foam (PUF) insulation on the roof

Using the envelope measures of shading and casement windows, the inside peak operative temperature on the intermediate floor is found to reduce by 4°C over the base case. Adding assisted ventilation through a central shaft reduces the peak temperature by another 1-2°C. This is shown in **Figure 10**.

On the top floor, these measures were found to reduce the peak temperature by 4-5°C. Adding roof insulation would reduce the peak temperature further by ~3°C.

The number of hours in a year when the operative temperature was below 30°C is improved from 25% in the base case to 72%.

CONCLUSIONS

The experience from these 3 projects shows that a reduction in peak operative temperatures in a range of 4 - 7°C is possible by implementing a few key envelope and ventilation strategies.

- Reducing window-to-wall ratio where required;
- Providing fixed shading: Fixed horizontal shading for the south and north façade can reduce direct solar radiation from entering the building from these facades. However, fixed shades are not effective in cutting the diffuse solar radiation which can form a large part of the total solar radiation given the high level of particulate matter and dust in several Indian cities.
- External movable shading: External movable shades are the most effective in cutting of solar gains from windows. They are particularly recommended on the west and east facades. Using external movable shading allows less than 15% of the solar heat falling on the window inside. The use of such systems on windows facing east and west can reduce the solar heat gains by 60%–80%.
- Roof insulation: A large reduction in heat gains is possible for the top floor with roof insulation.
- Wall insulation: Wall insulation works best in regions when the diurnal temperature range is high like in Indore and Rajkot, but not in Chennai.
- Casement windows (100% openable) instead of sliding windows (50% openable) for better natural ventilation potential
- Provision for cross ventilation in the room or through the flat

- Natural or assisted ventilation through the central shaft of the buildings to induce air flow in buildings.

The analysis done during the development of the design guidelines, and the simulation results from the 3 projects highlights the importance of reducing heat gains through the building envelope and improving natural ventilation as being central for improving thermal comfort and energy efficiency in multi-storey residential buildings in most of the Indian climates.

It is to be noted that several countries, e,g, Singapore has codes on envelope thermal performance of buildings . The Singapore code defines a Residential Envelope Transmittance Value (RETV), which takes into consideration the three basic components of heat gain through the external walls and windows of a building i.e. a) heat conduction through opaque walls,
b) heat conduction through glass windows, and c) solar radiation through glass windows. These three components of heat input are averaged over the whole envelope area of the building to give an RETV that represents the thermal performance of the whole envelope. For the purpose of energy conservation, the maximum permissible RETV has been set at 25 W/m^2.

At a broader policy level, it is necessary to develop similar codes to be included in the building bye-laws and national building code. This is necessary to make the new residential building stock in India adhere to minimum levels of thermal comfort and energy efficiency.

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GENERATING NEGAWATTS THROUGH CURRICULA CHANGE IN ARCHITECTURE COLLEGES IN INDIA

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Keywords: Sustainable Cooling, Architecture Academia, Engineering Academia, Curricula Integration

ABSTRACT

If the Energy Conservation Building Code (ECBC) were enforced by law across all Indian states today, the workforce in place would be unable to implement it. The potential economic benefits from progressive policy making would not challenge the status quo. This statement is based on a rigorous scrutiny made by cBalance on academic curricula in India's top 55 architecture colleges, which found less than 25% of colleges offering courses that embed energy efficiency or sustainable design knowledge to some point into the student's critical thinking and design skill set. Amongst these, only 3 to 4 out of 72 courses over the bachelor's degree course require the student to think and work on the environmental impact of their designs. So what is typically left out ? Heat load reduction techniques such as building orientation; appropriate building materials; shading devices and window-wall ratios allowing daylight but reducing load on ACs; natural ventilation methods; etc. In effect, 5% of India's Architecture Colleges curricula is related to the environmental impact of buildings. We estimate that every year, India's 423 Architecture Colleges graduate 17,000 students with deficient skills. We explore long-term approaches piloted in 30 architecture colleges by the Indo-Swiss Fairconditioning Program. Fairconditioning transforms architecture curricula, beyond merely adding elective Environmental Architecture courses.

INTRODUCTION

Background

The wrath of global warming is now evident to all on a daily basis. We need to act right away to reduce the unsustainable build-up of greenhouse gas emissions, through a series of international, societal, and personal transitions.

India is the fastest-growing major economy in the world. It is the fourth largest greenhouse gas emitter, accounting for 5.8 percent of global emissions. India's emissions increased by 67.1 percent between 1990 and 2012 and are projected to grow 85 percent by 2030 under a business as usual scenario [1].

As one of the major steps towards climate change mitigation, India ratified the Paris Agreement in December 2015, committing to reduce its carbon emissions intensity per unit GDP from 33% to 35% below 2005 by 2030. This is now in preparation to be implemented as a nationally adopted goal. It is further estimated that India's building sector is expected to grow 4 to 5 times its current size [2], thereby increasing the energy demand and emissions. The cooling sector would be one of the main drivers of energy demand. Electricity consumption amongst commercial buildings in India is growing 11-12% annually [3]. The share of air conditioning in commercial building energy consumption in 2012 is 23% and is expected to grow to 55% by 2030. The amount of Window and Split ACs in operation in India is expected to grow from 32 million in 2015 to 225 million by 2035, which could emit approximately 338 MT CO_2e (approx. 12% of India's total 2010 emissions) by the year 2030 [4]. Furthermore, the production of Energy required to run conventional ACs installed in Indian commercial and residential buildings are expected to require 1010 additional power plants by 2030. The amount of energy (and related GHG emissions) necessary to cool Indian building interiors in the years ahead will depend on how they are designed and built today, and in the coming years, on which technology is used for cooling the residual heat load, as well as on how occupants operate their cooling equipment. Considerable amounts of energy demand and GHG emissions could be avoided while maintaining comfortable interior temperatures, provided adequate technologies, know-how, information and behaviour are transmitted and aimed at the key

[1] developed by Centre for Advanced Research in Building Science and Energy (CARBSE) at CEPT University in India

stakeholders. Hence, while there is considerable know-how related to indoor comfort conditioning and energy efficient building design in India, the rate of uptake of these approaches remains extremely marginal. Reduced uptake of efficient cooling technologies compounded by a rapid expansion of built spaces in India with a lack of attention to bioclimatic architecture locks-in the current useless and toxic surge in energy consumption. Additionally, out of 2,888 architecture students graduating each year from India's top 55 architecture colleges, less than 25% of these colleges offer courses that embed energy efficiency or sustainable design knowledge into student's critical thinking and design skill set[5]. Of these 25% colleges, only 3 to 4 courses out of the 72 courses over the bachelor's degree course require the student to think of the environmental impact of their designs (including orientation of the building; using building materials that provide better insulation; appropriate shading devices and ratio of window to wall area that allows daylight to enter without exacerbating the load on the air conditioner; natural ventilation methods; etc.). Less than 5% of the curricula of India's architecture colleges offer basic knowledge on sustainable design and the environmental impact of the buildings they will design. Out of the 423 registered Architecture colleges, a total of 17,000 students graduate with deficient skills.

Furthermore, professors across architecture and engineering colleges are left to grapple with a dearth of high-quality teaching aids: physical scale- models and virtual (animations etc.). Even the professors that have realized the lacunae are faced with insurmountable administrative complacency from decision making executives in colleges and academic regulatory bodies. There are no punitive consequences, financial incentives, and peer-pressure amongst colleges to transform curricula. Moreover, the Energy Conservation Building Code (ECBC) and the Bureau of Energy Efficiency (BEE) Commercial Building Energy Performance Benchmarking Programme have established the concept of 'Benchmark Energy Performance Index' values (kWh/m2/year) for various building usages and climatic conditions. However, these concepts have not yet transformed the Indian building energy consumption scenario due to a lack of awareness, skilled-capacity and insufficient emphasis on increasing uptake of these codes. This diminished skilled-capacity can only be addressed by updating the existing architecture curricula. Today, most architecture and engineering students lack comprehension towards fundamental concepts of building physics; psychrometry; comfort cooling techniques & technologies; and localized, contextualized models of adaptive thermal comfort;

such as the India Model for Adaptive (Thermal) Comfort (IMAC)[1] which provides a progressive alternative to the hegemony of the ASHRAE-55 which has perpetuated a problematic culture of sealed air-conditioned buildings that has permeated the mainstream of building and HVAC design thinking in India. However, even if ECBC becomes mandatory, presently, there isn't enough workforce that will be able to adequately handle its implementation. The only way to address the aforementioned concerns is to work upstream, by building capacity within India's architecture and engineering colleges, those that teach Refrigeration & Air Conditioning (RAC) design. What is needed is to focus on horizontal and vertical integration, where relevant subjects are infused, subtly so that the changes made are unnoticed, thematically expanding the breadth of knowledge imparted from a current two-dimensional focus of '*space*' and '*structure*', to a three-dimensional realm. Sustainability thus becomes an equal third-axis that shapes the building design process. The intervention described in this paper takes many vital cues, derives impetus and reaffirmation from clear recommendations articulated in an exhaustive study conducted under the USAID ECO-3 Project related to Architectural Curriculum Enhancement for Promoting Sustainable Built Environment in India[2]. The paper validated the merit of the following areas of further work: Technical course content development/ enhancement, Skills enhancement/continuous learning for faculty members, Integration of theory/elective courses with design studios, and Infrastructure improvement (laboratories and library). As is evident from the subsequent dissection of the effort currently underway, this program moves towards institutionalizing these structural reforms in academic institutions engaged in shaping architecture pedagogy in India. While there are many elements of the intervention described herein that can be directly correlated to recommendations made by this seminal study conducted in 2010, its metaphysical underpinnings are rather distinctly different. Unlike the general 'capacity, material

[2] Sanyogita Manu, Anurag Bajpai, Satish Kumar, Shruti Narayan, and Ankur Tulsyan, International Resources Group, Rajan Rawal, CEPT University, Sudha Setty, Alliance to Save Energy

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support, and content' reform focus of the precedent study, this program draws upon the elemental idea that sustainability in the built form is not a missing 'component' in the pedagogy, it is the missing third pillar, along with space and structure, which ought to be part of the ontological preoccupation of the practice of architecture. It is, as postulated by this program, a form of reasoning, a invisible lens through which the built form must be critically viewed, which needs to be reinstated in a manner that is so intricately enmeshed with the core of its pedagogy that it cannot be cognitively separated without unravelling it entirely.

Programme Overview

Co-devised by Noe21 (Geneva) and cBalance Solutions Hub (Pune), the Fairconditioning project aims to help countries in tropical regions address their cooling demand with the highest level of energy efficiency and lowest carbon emissions. June 2013 marked the beginning of this program, with the Pilot phase focusing on phasing-out air conditioners using synthetic (fluorinated) refrigerants having very high global warming potential and phasing-in energy efficient ACs that use natural refrigerants (propane), having close to zero global warming potential.

Fairconditioning is now a Building-Cooling Demand-Side-Management (DSM) education, capacity building, and pilot implementation programme. It focuses to achieve behaviour change amongst occupants of conditioned indoor spaces reduce building heat loads and reduce energy and GHG intensity of artificial cooling systems. The program aims to do this by improving energy-efficiency (EE) in the continuing building boom, integrating the most energy efficient-technologies to address cooling load in buildings, and, influencing corporate consumer behaviour.

The academic leg of Fairconditioning, object of this article, aims to deeply integrate sustainability and EE into architecture curricula. This is achieved through a series of training, re-training, troubleshooting and course-correcting session which commence with Training of Trainers (ToT) workshop for architecture professors. The academic project has been specifically designed to enhance action-oriented understanding of sustainable cooling technologies and efficient building design centred around ECBC and other relevant sustainable design building guidelines to facilitate a two-way process of learning.

These semester-long pilot engagement sessions enhance pedagogy knowledge and skills amongst architecture professors, facilitate activity-based learning processes amongst students, as well as prepare for the subsequent (Fairconditioning phase 2) seamless syllabus integration of sustainability and energy efficiency into official University- defined curricula.

The academic project deliberately avoids creation of '*additive*' curricula content (i.e. separate courses) for architecture colleges and instead works in an '*integrative*' manner. ToT workshops seek to inform the entire five-year educational curricula spanning architectural theory, design and technical subjects.

The project's' first phase (2014 to 2016), trained 96 professors from 28 architecture colleges across 6 cities (Delhi/NCR, Mumbai, Bengaluru, Pune, Chennai, and Jaipur).

DIAGNOSIS

Phase 1 implementation with 28 colleges have led to a refined diagnosis of persistent lacunae that the program (in Phase 2 implementation, now underway from February 2017 onwards) addresses in its most evolved form (2017). This is what we learned :

Deficient Tech-Support

Technical training '*tech support*' for architecture professors post ToT workshop is required for Climatology, i.e.: Psychrometrics, Refrigeration Cycle; Sustainable Cooling Technologies such as Direct/Indirect Evaporative Cooling, Structure/Radiant Cooling, Solar Vapor Absorption; Comparative Life-Cycle GHG Emissions Assessment of Passive Design and Sustainable Cooling Technologies.

Feedback from attending professors suggested that more time should be spent on sustainable cooling technologies, current best practices in sustainable architecture, rethinking pedagogy, and building physics concepts, possibly extending the workshop from a 3-day format to a 4 or 5 day workshop

They also pointed to the lack of high-quality teaching aids (physical) and virtual animations

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etc.), needed to convey building physics concepts and electro-mechanical processes of active cooling systems.

Administrative-Complacency

No punitive consequences, incentives, or pressures – financial (taxation or increased revenue incentives), social (peers), market (competitors), or professional (regulatory bodies) in the academic ecosystem ensuring curricula is upgraded to integrate passive design and sustainable cooling across the spectrum of learning/teaching opportunities.

Administrative and intellectual complacency towards augmenting the existing syllabi to integrate concepts of energy efficiency through sustainable cooling technologies/methodologies and building design in parent educational institutions of participating professors despite MoU's being signed and approved by senior management of educational institutions.

Dis-interest amongst non-participating professors as a result from inadequate participation by colleges, in most cases does not translate to uptake of curricula integration.

Tepid (National Institute of Advanced Studies in Architecture, NIASA), or inconsistent (Council of Architecture, COA) response from national capacity building and regulatory bodies in the context of training program certification, outreach support and mainstreaming. Diffuse, hierarchical nature in conjunction with significant flux of executive body members harms long-term engagement and delivery upon promises made.

Siloed Education

Siloes of sustainable cooling knowledge libraries, well-documented performance-based case studies, capabilities and project opportunities in all 6 cities where the Program operates: tenuous or absent networks amongst Architecture and Engineering Academic Institutions, between practitioner's (Sustainable Design Architects and Sustainable HVAC Suppliers, Designers, Consultants) and professors/students.

Narrative Transformation

Formal surveying, roundtables and feedback from preliminary workshops by Fairconditioning staff underscored that sustainability, environmentally responsible architecture, and energy efficiency related knowledge, where it is taught, is largely seen as a 'dry technical subject' by students. It is a secondary, at best a tertiary concern in their design philosophy and praxis. Knowledge available through prescribed 'texts' for these subjects is seen as inorganic, uninspiring content. Content that must be plugged into one's intellectual repository of facts, figures, techniques, and mechanical operations leading to objective answers during exams in one out of four colleges where such courses are even offered.

It is also tacitly understood by students and professors that real-world practice of commerce-driven architecture for a paying 'client' requires only structural and fire-safety norms to be strictly obeyed, their violations considered to be deeply unethical and illegal. Climate change and energy- scarcity impacts of buildings they design (either for design studios or as professionals) comprise, at best, a final 'layer' of unrelated mechanically assembled systems that will 'make' their original design sustainable. A building can be converted to a 'green' rated building through a series of final 'polishing' steps to address only a few of the most acute impacts after their root causes have been inadvertently integrated in the core design itself.

INTERVENTION

The program's core philosophy is manifested in its communication tone and practice of embodying sustainability. These measures are enacted by staff during events to show how integrity can meet indoor comfort management: avoiding high-carbon travel options such as air travel and preferring to travel by railways instead; avoiding use of ACs and preferring natural or low-energy forced ventilation; setting room ACs at 24-26 degrees to address thermal comfort efficiently). This is a vital strategic tool used to convey the importance of viewing sustainability and environmental responsibilities as 'non-cosmetic values' and empathically rejecting the parochial notion of it being merely a 'value added service' or 'Unique Selling Point (USP)' for a project.

Training Content Development

While the current architecture syllabi lacks the opportunity to challenge conventional methods of cooling our built space and explore energy efficient cooling methods and technologies that are already mature, the unavailability of high-quality teaching aids (physical) and virtual (animations etc.) to convey building physics concepts and electro-mechanical processes of active cooling systems makes it even worse for the energy efficiency case.

Fairconditioning collaborated with several stakeholders to devise training content capable of building trainer capacity as well as integrate within existing architecture curricula. Training modules encompass fundamentals of building physics such as: heat transfer; psychrometry; adaptive thermal comfort including The India Model for Adaptive Comfort Study (IMAC); passive cooling design strategies; climate analysis; solar geometry; and sustainable cooling technologies/techniques such as Structure Cooling, Radiant Cooling, Evaporative Cooling, and Natural Refrigerants.

These training modules have constantly evolved during the course of the programme. Until their most recent form, the technical concepts were devoid of internal integration where, relevant teaching aids used to explain the concept were discussed after the module. However, all technical modules are now integrated with activities for deep-sensitisation, best practices in integrating sustainability within curricula, and teaching aids that encompass physical scale models for climatology and building physics, software tools, animation videos, testing and evaluation aids, etc.

The training content further seeks to rethink the existing pedagogy methods and challenges the status-quo by introducing (re-introduce in certain cases) Kolb's experiential learning cycle and Bloom's Taxonomy of learning domains along with the proposed adapted learning system.

Capacity Building and Pilot Scale Application

To this end, Fairconditioning developed a wholesome program to integrate *Building Physics, Passive Design, and Sustainable Cooling Technology*' into undergraduate architecture curricula. The program's interventions at collegiate level commence with securing explicit management buy-in to translate successes of the 1-semester pilot into transformation of the entire syllabus (while adhering to the rubrics of the university prescribed curricula) across all humanities, technical, and design studio courses comprising the 5 year undergraduate program to be aligned with principles and praxis of energy efficient building design that integrates sustainable cooling systems.

This intervention manifests in the form of a kick- off 4-day deep-dive workshop conducted for the entire faculty of a given semester chosen for the pilot (5th semester in most cases). These capacity building workshops include extensive training sessions that empower, guide, and provide technical actionable-knowledge to professors to seamlessly deliver and subsequently be empowered to embed syllabus-content related to sustainable cooling strategies across courses. Seven core themes are developed: climatology, building materials, building technologies, structural design, and building services.

The training for professors that starts with extensive training on fundamentals of building physics. Technology fundamentals and their working along with their real-world applications and benefits are further explored during the sessions.

Finally, technical training sessions formulate into '*syllabus renaissance*' sessions on day 4 of the workshops, where working groups develop deployable sustainability infused lesson plans towards the pilot integration across a humanities, a design, and a technical subject of the chosen semester.

Sustainability infused curricula

The project seeks to execute and implement a horizontal '*Deep Curricula Integration*' in partner Architecture Colleges that have already been part of the capacity building ToT workshops.

The deep-dive workshops are a precursor to a semester-long series of micro-engagements centred around weekly curricula-integration planning and review meeting/calls with college faculty to further enable them with additional technical and pedagogy technique support immediately prior to the specific learning session (lecture, studio etc.) in the upcoming week(s). Fairconditioning will monitor and evaluate the pilot integration for the 3 aforementioned courses (1 technical, 1 humanities and 1 studio). Given the lacunae that exists in architecture education, Fairconditioning plans to continue its efforts beyond just building capacity, by providing resources and material that could potentially help achieve the pilot integration. A College Resource Kit is being devised, that would include (not limited to):

Sustainability Handbook - A repository of sustainability & EE fundamentals that should be delivered through a combination of recommended methods, tools and systems of learning (associative, experiential, etc.).

Training content delivered during workshops are made freely available through Fairconditioning's website.

Other useful teaching/learning resources that can be used by professors to better explain concepts and fundamentals (videos, software's, articles, journals, Case studies, etc.)

A concept's textbook that elucidates upon topics such as: 1) *Climate Change, Ozone Depletion and Cooling Systems*; 2) *Energy Efficiency, Thermal Comfort and Cooling Systems*; 3) *Sustainable Cooling Technologies (End-of-Pipe Solutions)*

Scaled models & animations, which includes:

Along with providing existing animations on conventional cooling methodologies that enable students to deconstruct the de-merits of using air as a refrigerant, the project is developing self-explanatory animation videos for the 4 sustainable cooling animations: Structure Cooling, Radiant Cooling, Solar VAM, and Evaporative Cooling. These videos can be used in all colleges to mainstream sustainable ways of cooling built space.

Physical model prototypes of sustainable cooling technologies and building physics concepts enabling deep understanding.

A Do It Yourself (DIY) kit that is a comprehensive step-by-step booklet/manual that supports along with building, the usage of these tools and clearly lists the proposed experiments (wherever applicable) and learnings that can be implemented by professors during lectures.

A question bank for professors that can be used to assess students and to provoke critical thinking towards concepts of climatology.

Massive Open Online Course (MOOC) - Fairconditioning in collaboration with Environmental Design Solutions, an organisation based out of Delhi, that looks at reducing GHG emissions across the building sector in India, developed a 9-module online course that helps establish a thorough foundation in scientific and technical concepts that are related to Building Physics, Passive Design Strategies and Sustainable Cooling Technologies. It has benefited professors by acting as a platform to re-learn fundamental concepts, motivating and encouraging them to teach these concepts to the students in a simpler, yet effective manner. Moreover, it is a prerequisite since the ToT workshop intensely focuses on imparting pedagogy related training through the technical and design concepts discussed in the MOOC. Going forward, this MOOC will be distributed with architecture students

Along with implementing a regular monitoring framework, a specific framework evaluating baseline '*capacity*' amongst the test group and control groups has been developed; the framework builds on prior work already undertaken in other academic institutions across the globe, thus avoiding re-invention of '*capacity measurement*' methodologies for surveying wherever possible.

Ecosystem Integration

Realising that there exists no platform to exchange valuable knowledge on EE amongst academics, HVAC practitioners, architects, students, etc. Fairconditioning is developing a Sustainable Cooling related '*Talent and Knowledge*' technology and human-engagement platform. This '*Freemarket*' platform, online but not only online, will intensify ecosystem interactions and breed organic connectivity amongst the sustainable cooling ecosystem and enhance quality of architecture education. The platform further aims to act as a forum & support group on sustainable cooling technology issues, environmental science and building technologies. Once developed, it will further seek to promote research towards improved pedagogy, creative activities that seek to engage students and improve learning, etc. Information pertaining to maintenance, site installations, specific technology info, MOOCs, lecture videos, wiki and research papers will other features of the '*Freemarket*'.

Fragmented 'ecosystems' need much more impetus, reinvigorating, and trust-building between competing actors. This is why the program does not merely rely upon relatively 'passive' methods such as online platforms. Creating local, human-scale links between the most promising professors in engineering and architecture colleges of a city (i.e.

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bridges spanning the architecture-engineering gap) as well as amongst their peers (professors from 'competing' institutions in their respective fields) is a deliberate strategy that is being experimented with. Its formal manifestations are: a) roundtables (2 per year in each city) that are anticipated to catalyse knowledge and experience-exchange between professors; anticipated to translate into human-level bonds and subsequent intensified use of the online platform to continue their informal association; b) formal arrangements, articulated through MoUs, between Mechanical Engineering (RAC course) and Architecture Design Studio to formally establish joint 3rd-year design projects. These involve detailed passive and sustainable active cooling system design for a large scale commercial, institutional or residential building project.

The project further aims to create a local sustainable-architect network for each city and get colleges to formalize the inclusion of local practicing architects as mentors for design studios based on real-world sustainable design briefs. This should potentially mainstream energy efficiency within designs submitted by students. The programme seeks to implement this in its third phase of operations starting April 2018 (expected).

Policy Change

To ensure successful integration of sustainability into architecture curricula, the Fairconditioning programme has devised a set of engagements with the Ministry of Environment, Forestry, and Climate Change (MoEFCC) and the Ministry of Human Resource Development (MHRD). Enhancing the quality of existing architectural education implies a systematic review/re-think of syllabi of technical courses nation-wide. It also implies the development of a time-bound strategy to mainstream it into technical education, involving the following stakeholder/sub-stakeholder agencies: All India Council for Technical Education (AICTE), Council of Architecture (CoA) and Centre for Environment and Education (CEE). It would be naive to expect local, regional, and/or national policy level change without building evidence cases. This evidence base from experiments in curricula integration is being synthesized by the program from 2017 to 2020. These multi-semester pilot experiments in nuanced, integrative, and often implicit, curricula change to embed sustainable cooling ideas into the undergraduate pedagogy will be conducted in 24 colleges in India centred in 6 cities. Subsequently, policy recommendations will be derived from collective deliberation upon learnings in conjunction with government and academic stakeholders.

Assessing Impact & Key Metrics

Conducting customised and targeted workshops for key stakeholders to build capacity is a means to the end and a highly integral catalyst at that for a broader yet systematic curricula change. The end goal is for sustainable building design specifically, in this case through energy efficiency interventions, to become an ingrained and organic standard practice through policy change across colleges/institutions/universities across major Indian cities to begin with. That said, while the number of: workshops conducted; participating academic institutions; professors & students trained; and MoUs signed are key programmatic metrics to assess its impact, unless these translate into cohesive curricula integrations, the effort would be futile. Therefore, the number of pilot integrations and assessing its success/failure is the project's key metric and helps assess its true impact.

CONCLUSION

The upcoming phase of the program is currently in the pilot integration phase wherein specific interventions are underway in 4 architecture colleges in major Indian cities. Out of the 4 target colleges, 3 colleges that have partnered with Fairconditioning for its 2nd phase are: *Sushant School of Art & Architecture (SSAA), Gurgaon; Smt. K. L Tiwari College of Architecture (SKLTCA), Mumbai; and Dr Bhanuben Nanavati College Of Architecture For Women (BNCA), Pune*. The ongoing field experiences are being assimilated and will continually irrigate the strategy of the program going forward to achieve evidence- based policy making objectives (i.e. comprehensive curricula transformation across all Architecture and Mechanical Engineering Colleges). The key experiences that have surfaced are distilled here and constitute the 'way forward' for the program.

Positive transformations

1. Narrative shift of 'green' buildings from being a value-adding, hobby, USP etc. to being a non-negotiable global security and safety issue defined by inalienable ethical implications. The

necessity for action in the compelling field of energy, climate and environment (local and global) has been almost universally well-received by professors of all colleges. They have recognised the indoor cooling sector, with its current outstanding energy demand, as having the largest potential for improvement, using beginning of pipe strategies.

Teachers engaged by the program are shedding their simplistic notions about 'tree-planting', increasing green-cover, and trivial amounts of 'rooftop solar PV' and comparable renewable energy systems as being end of pipe "supply side replies". Their discourse is gradually but palpably shifting towards the pivotal nature of beginning of pipe 'negawatt' generation from thoughtful design to mitigate head loads, and use of passive cooling strategies with right-sized sustainable cooling technologies. In consonance with this transformed thinking, as illustration, a simple horizontal shading device for a window is now being seen from the lens of its 'negawatt' potential and thereby elevating its importance above 'solar PV' panels. This said, generating increasing amounts of renewable energy sources is capital to progress to an India powered 100% by renewable energy (RE). However, RE development must lose its current aura of being the beginning and end of solutions, shading the vital role of managing energy demand. See "***Energy Efficiency Potential"*** section below.

2. Professors are experiencing a paradigm shift in the way they view *indoor thermal-comfort* as opposed to *indoor cooling* in architectural design of Indian buildings. Achieving indoor thermal comfort by using the least amount of climatization is becoming an imperative strategy in India and in other major GHG emitters in tropical climates to achieving the international communities' objective of limiting warming by 2 degrees above pre- industrial levels.
3. Fairconditionings' 'whole-building' design studio requires formally engaging with local Mechanical Engineering colleges that are also part of the Fairconditioning network. "Whole building" prima-facie has been welcomed in all instances and is likely to be implemented successfully during the upcoming implementation period.
4. The advantages of horizontal integration amongst humanities, technical and design-studio subjects has been identified by actors. We have witnessed a general consonance with the idea that the learning on sustainability in the 'taught' subjects of humanities and technical must become a key impact evaluation metric during the design studio. As a result, we witness a reduction of 'siloed', 'fragmented' and incomplete sustainability education that merely raises 'awareness' levels without liberating environmentally sensitive education.
5. Advocating the replication of the precedent 'design' studio' approach, which creatively interweaves multiple modes of learning and interdisciplinary themes, in other 'taught subjects, firmly implants the idea amongst teachers that the program approaches curricula change in a contextual fashion. It seeks to encourage replication of beneficial existing methods to aspects of humanities and technical 'taught' subject pedagogy which is detrimentally affected by the absence of these multi-dimensional pedagogical techniques. This approach diminishes resistance, combativeness, and alleviates concerns of teachers who might sometimes feel that the program is excessively critical of all facets of their current efforts to create an environmentally-responsible design culture.

Challenges

1. Learning-centric pedagogy, while not entirely alien to all academic institutions and architecture pedagogues specifically, is not a widely applied practice. Choosing the learner-centric approach requires unlearning and de-centralizing the role of the 'teacher' who until now essentially used 'teaching content' as an object of exchange with the student. The relative 'power structure' is being deconstructed and the material and student are being placed in proximity so as to stimulate learning. This perceived 'displacement' of the teacher's role is sometimes resisted by those who feel insecure about their relevance in the revised order that is being established.
2. The elemental question of explicitly calling out sustainability in the design studio briefs is being constructively debated by some of the colleges and the program is considering running control studies to determine relative efficacy of 'invisible' integration.

3. Unlike horizontal integration, which is greatly embraced by most academics, vertical integration that links successive taught and applied subject over the 5 years of undergraduate education is proving to be challenging and there is adequate scepticism amongst academics of its possibility within the rubrics of the current curricula framework. Currently, the framework strictly separates 'semesters' from each other and within them, into discrete thematic elements. Thus the vision of formalizing the establishment of common design-studios which cultivate and simulate the working environment of a real architecture practice (wherein experienced mentors guide and advise less experienced practitioners) is still unrealised and might require rethinking as a major thrust element of the program's experimental matrix.
4. Enhancement of training material must include specific teaching/learning methodologies for specific subjects/topics, examples of integration practiced in other Indian architecture colleges, and evaluation mechanisms for those specific elements (i.e. ways in which it might manifest itself in the design and hence be considered a successful instance of integrated learning).
5. While the general response to interventions and change by academics has been encouraging, there has been regional variations in attitude. The conventional ostensible causes, for instance autonomous/deemed university versus those following a university syllabus or private versus government-supported colleges, are insufficient explanations for the disparate levels of acceptance / resistance to change. In general colleges in the Delhi NCR region have been recalcitrant while colleges in Bangalore have displayed a greater proclivity to embrace change. Professors from Delhi/NCR region usually echo the view that they would not have enough time on their hands to integrate 'everything' with respect to sustainability. They express the view that they are extremely short on time with just the bare minimum curriculum and integration of any concept beyond the prescribed syllabi needs to be minimal, at least initially to get buy-in from professors.
6. Some professors were worried that when architecture students acquire an instinctive and tactile understanding of climatology in design through experiential learning (which they agree is positive), this is done without quantifying benefits in terms of energy saved, like engineering pedagogy would be engaged in. This might precipitate the situation where expected skill-development and climate-literacy benefits are understood but not achieved.
7. The strategy of altering Architectural Theory and Method vs. more well defined Humanities subjects (eg. History of Architecture) remains to be resolved and refined. Should the program select only 'easy' receptacles for integration or should it strive for nuanced and powerful integration, but proportionally arduous, in even these less defined and nebulous courses ? This is a profound subject to be explored with evidence-creation and localized, contextualized debate for the specific conditions prevailing in a college.
8. The program has healthy apprehensions about the unintended consequences of 'templatizing' and homogenizing the change to achieve geographical and thematic scale. Significant ambivalence about this issue prevails, as it must, since there are genuine concerns that this intervention could get reduced to another 'additive' response if implemented too rapidly and broadly.

Energy Efficiency Potential

The program is expected to transform curricula in 30 Architecture Colleges as part of its large-scale pilot leading to evidence-based policy change. The 'negawatt' potential of the project was assessed by computing the energy conservation potential of project designed by 'transformed' graduates versus conventional students designing business-as-usual buildings. The parameters used in the assessment and outcomes are indicated in Table 1 and assumptions are highlighted below.

It is estimated that the project can lead to approximately 208 MW savings per college by the year 2050 and the cost per MW for achieving this scale of negawatt generation is approximately 4,614/MW.

The above calculation assumes that each batch across all Indian architecture colleges consists of 40 architecture students in their graduation year, with a 30% graduation ratio. Hence, 12 students would be moving on from education to practice per year.

Furthermore, each student starts practice after 4 years from graduation. Therefore, with 3,617 practicing years till 2050, 3,445 building projects would have been undertaken (0.95 projects per year).

These 3,445 projects/buildings would occupy an average area of 17,000 sq ft. per project/building[3]. Under the Business-as-usual (BAU) scenario, where a cooling capacity of 1 TR per 165 sq. ft. is seen to be prevalent in residential buildings, 103 TR cooling is required per project. Considering a 50% reduction of TRs required through energy efficiency enabled by enhanced passive design and sustainable cooling system skills and their application by ‘default’, the remaining 52 TR is being cooled through sustainable cooling technologies. This yields a peak-load power reduction 60.4 kW (based on 1.17 kW per TR for a typical system with a Coefficient-of-Performance of 3.0), which results in 208 MW of peak power reduction by year 2050 per college. Each architecture college intervention under the Fairconditioning programme costs 9.6 lacs, hence, a net negawatt (amount of energy saved at the source) cost equates to 4,614 per MW.

This is significantly lower than the cost of installing thermal or renewable power capacity in India in 2017 (approximately INR 5.3 crore per MW of installed capacity). Energy efficiency is still to become identified as the “first fuel” to supply India’s energy demand. It is also waiting to be identified as a vector for India to achieve its real- life independence.

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5. Internal cBalance Study, 2016.

[3] Approximate area of a 6 to 10 storey residential building , based on interviews with Architects from small-medium sized firms enlisted in the Fairconditioningnetwork.

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Table 1 Generating Negawatts

Sr. No.	Parameter	Value	Units
1	Gradudating Batch/College/Year	40	students/year
2	% Graduates moving to Practice	30%	
3	Years between graduating and leading design	4	years
4	Projects per practicinng graduate/year	1	building projects
5	Projects/college till 2050	3,445	projects
6	BAU sq. ft. TR	165	sq. ft./TR
7	BAU TR/project	103	TR
8	Energy Efficiency %	50%	
9	Sustainable Cooling TR/project	52	TR
10	TR savings/project	52	TR
11	Power savings/project	60	kW
12	Power savings/college till 2050	208	MW
13	Project Cost (30 colleges)	4,50,000	USD
14	Cost per intervention	9,60,000	INR
15	Cost per negawattt	4,614	INR/MW
16	Cost per megawatt (thermal power)	5.3	Crore INR/MW
17	Negawatt-to-Megawatt Cost Ratio	0.009%	

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HOW IOT IN BUILDINGS IS UNIFYING OPERATIONS, CATALYZING EFFICIENCY, AND BOOSTING UPTIME

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Keywords: Internet of Things, IoT, EcoStruxure, Schneider Electric

ABSTRACT

For building owners and operators, the Internet-of-Things (IoT) is enabling access to operational data from farther across, and deeper within, facility infrastructures. At the same time, increased systems integration and emerging analytic tools are extracting greater value from this data by converting it to actionable insights. These innovations are enabling greater levels of efficiency, reliability, and security. This paper will review the basic architecture of an IoT-enabled building and the value derived from each aspect, with supporting case studies.

INTRODUCTION

The world's urban population is growing quickly. By 2050, 66% of the world's people will be living in cities, compared to 54% in 2014. Cities will get bigger, and there will be more of them.

In these cities, buildings are currently consuming 33% of the world's energy. Comparatively, that's more than industry or transportation consume. In terms of what kind of energy, buildings consume 53% of the world's electricity, estimated to increase to 80% by 2040 (IEA, 2016).

Facility management teams from around the globe are facing corporate mandates and government regulations aimed at making their office buildings, campuses, or other facilities more efficient and sustainable. However, they are also facing higher capital and operational expenditures, as well as increasingly complex building systems. Complexity leads to inefficiency, so there is great untapped potential.

In terms of energy, buildings and data centers offer the greatest potential to improve performance, efficiency, and environmental footprint. With active controls, a 50% increase in efficiency can be expected. In terms of operational efficiency, maintenance represents 35% of a building's lifetime costs (IFMA, 2009). By implementing a program of proactive, predictive maintenance and analytics, a building can save up to 20% per year on maintenance and energy costs (US Department of Energy, 2010). And as people costs can represent 10 to 40 times the maintenance and operational costs over a building's lifetime (CABA, 2014), even small increases in staff efficiency can have a great impact.

Fortunately, new disruptive technologies are catalysts for huge efficiency gains. This includes the adoption of the Internet-of-Things within buildings. The information and control enabled by IoT-related technologies are helping create intelligent buildings that:

- minimize the energy and associated CO_2 needed to run assets and operations
- optimize the performance, efficiency, and lifespan of physical assets
- ensure the safety, security, and efficiency of people and processes

Navigant Research envisions that "2017 is poised to tip the scales for investment in intelligent building technologies" as well as proposing that "one IoT intelligent building solution can address big business pain points—e.g., energy efficiency for the head of sustainability and predictive maintenance for the head of engineering—while also generating enterprise- wide key performance indicators for the C-suite." (Navigant Research, 2017, Figure 1)

The following sections of this paper describe seven IoT-related innovations that are the key to achieving these greater levels of efficiency, reliability, and security.

IOT ARCHITECTURES

Smart devices

The first step toward an intelligent power distribution system is digitization. At the core of smart power distribution systems are smart devices.

On the energy supply side, smart electricity meter installations by energy providers continue to grow rapidly. The global market for smart meters is forecasted to cross USD 11 billion by 2024, with commercial meter shipments reaching as high as 30 million units. This growth is being driven by consumer demand for more accurate billing as well as to support energy conservation efforts. (Global Market Insights, 2017)

Beyond the service entrance, commercial and industrial energy consumers are also increasingly installing more sensors, meters, and other connected devices in new and existing facilities. In fact, Gartner says that by 2020 "devices … targeted at smart buildings will reach 4.4 billion units." Memoori is even more optimistic, estimating that the total number of connected devices across all categories of smart buildings will reach over 10 billion by 2021 (Figure 2).

Advances in computational power, accuracy, integration, and communication have enabled the new era of IoT in power and building management. Devices have become more than actuators. They now measure, collect data, and provide control functions. They enable facility and maintenance personnel to deeply access the power distribution network. And they continue to become more intelligent.

Devices can include digital power meters or power quality monitors. Beyond electricity, metering of other utilities such as water, compressed air, gas, or steam can be included. In many places throughout the power network this intelligence may be embedded inside other kinds of equipment, such as the smart trip units of circuit breakers. These smart breakers can provide power and energy data, as well as information on their performance, including breaker status, contact wear, alerts, and alarms. In addition to core protection functions, many devices are also capable of autonomous and coordinated control, without any need for user intervention.

It's now possible to meter energy use at every key point throughout a facility's power network, from the main utility incomer to individual loads, such as heating ventilation and air conditioning (HVAC), boilers, refrigeration, and lighting circuits, down to plug loads. This level of detail is important for profiling energy consumption to reveal energy waste, whether due to equipment malfunctions, occupant behavior, or the need to optimize HVAC setpoints, for example.

Real-time and logged data, power quality analysis, equipment status, and alarm notifications help operations and maintenance teams stay on top of conditions and address risks before they can cause downtime or damage. And devices with integrated control capabilities can help them take action remotely. These intelligent devices can also operate autonomously and deliver data to all building systems for faster control and higher reliability.

Connectivity

Device connectivity gives operations and maintenance teams the wide reach they need to the very 'edge' of the power distribution network, across an entire facility or beyond.

Real-time access to data and control from a smartphone or tablet can allow control actions to be performed from a safe distance from a circuit breaker, while also acting as a direct portal to expert services when needed.

The newest smart meters and smart trip units offer a number of communication options, including wireless and Ethernet. For simple measurements from dispersed end-load points, wireless meters may be a good choice for quick and non-disruptive installation. At critical power distribution points where intensive analysis and control are performed, or at smart panels and gateways where large amounts of data is being aggregated, a direct connection to a building's Ethernet backbone will ensure the fastest data throughput.

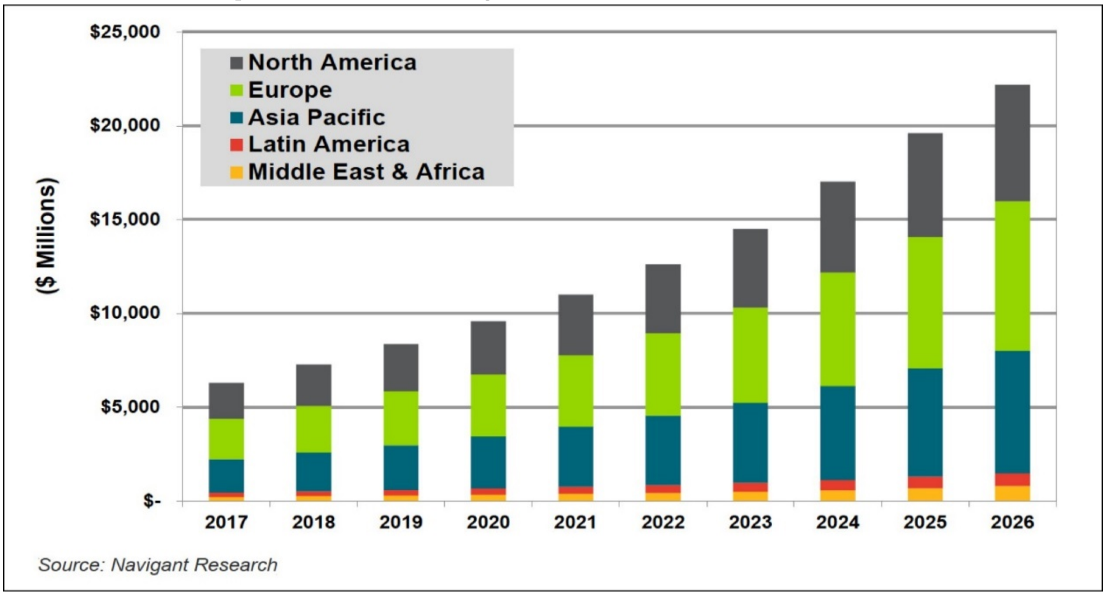

Figure 1: IoT for Intelligent Buildings Market Revenue by Region, World Markets: 2017-2026

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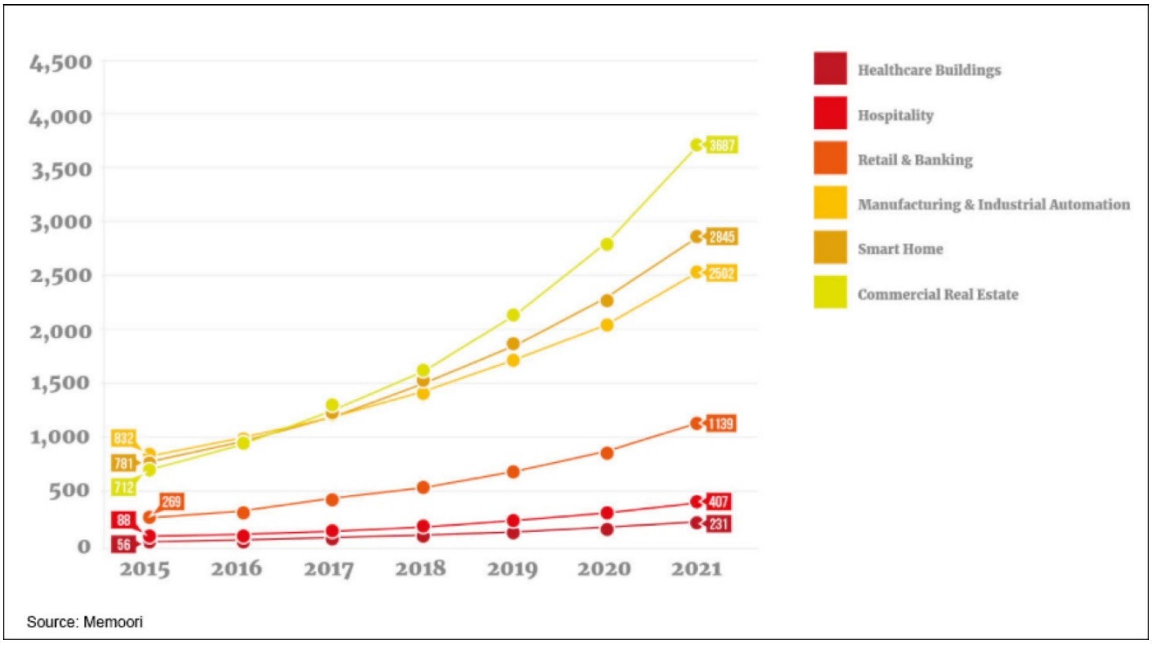

Figure 2: Growth of Smart Building Connected Devices over time (in millions)

Some devices also support multiple, simultaneous connections to upstream information and automation systems for added resilience in critical applications. Communication gateways can provide further data collection, recording, routing, and user access options. Many metering devices and gateways offer on-board web servers with data accessible through any web browser.

Device data can be automatically uploaded and stored in a cloud-based repository that's accessible throughout the lifetime of the installation, supporting a simpler and more thorough approach to asset management. The flexibility and extensibility of such networks allow all important energy assets to be included. This includes emerging distributed energy resources (DER), such as onsite solar generation, energy storage, electric vehicle charging stations, and combined heat and power systems.

Apps, analytics, and services

Data from smart devices located throughout power distribution and building automation systems is aggregated to cloud-hosted analytic platforms, sharing actionable information with everyone that needs it, anywhere they are (Figure 3). Applications can include power and energy management, building management, and asset management.

Facilities without the required in-house expertise can take advantage of associated remote monitoring, maintenance, and engineering consultation services.

Simpler device connectivity, broader interoperability, and options for cloud-hosted applications and services make IoT-enabled solutions easier and less expensive to install and use than traditional solutions. This makes them a more affordable option for small and medium sized buildings that may not already have an intelligent building solution.

INTEGRATED BUILDING SYSTEMS

At the next level of integration is the interoperability between different facility management systems. Rodolphe d'Arjuzon of Verdantix notes that "the majority of solution and service providers are now integrating some aspects of power, building, asset, and maintenance management". Integrating these systems

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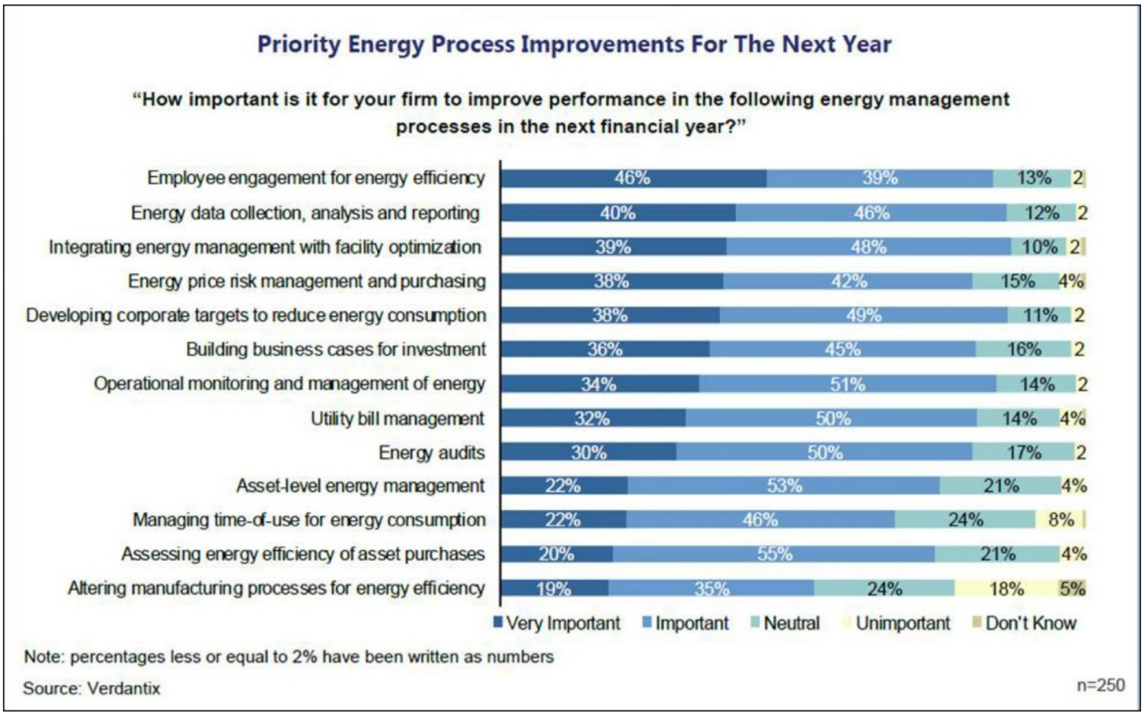

Figure 4: Priority energy process improvements for the next year (2016)

broadens the available data from which to draw energy

and operational insight. It can also help to catalyze collaboration across facility teams.

Navigant Research sees demand growing for this kind of data integration within intelligent buildings, with associated revenue reaching a compound annual growth rate (CAGR) of 30.3% from 2016 to 2025. (Navigant Research, 2016). A recent study by Verdantix further reinforces this trend, with 87% of facility professionals surveyed stating that improving integration of energy management and facility optimization will be an important or very important focus over the next year (Figure 4).

Newer IoT-enabled networks are allowing management of energy, HVAC, fire, security, etc., to be more tightly integrated, giving facility teams a unified source of data and, in turn, a unified view of operational conditions.

Data can be shared between systems or power management capabilities can be embedded directly into the building management system (BMS), for example. This helps put occupant comfort and energy efficiency in proper, balanced context while enabling facility staff to gain a wider operational perspective from a single interface.

An IoT-based solution is also more open and scalable than traditional networks. Navigant Research notes that "an IoT platform allows the end user to leverage one infrastructure to operate all BMS solutions. Internet-connected devices can provide automated response and enhanced strategic insights." (Navigant Research, 2017)

MOBILE PLATFORMS

Gartner predicts that, by 2022, 70 percent of all software interactions in the enterprise will occur on mobile devices, and that 50 percent of apps will trigger events for users to make them more efficient. (Gartner, 2017)

IoT and cloud-based platforms are already enabling operations and maintenance teams to use their smart phones or tablets to quickly access equipment data, share maintenance schedules, and be alerted to alarm conditions to improve response times. Verdantix notes that mobile devices "are not just for entering data on-the-go. Reductions in the cost of wireless sensors and improvements in wireless networks … have enabled vendors to develop software solutions that provide situational awareness, to identify a user's location and push pertinent data such as prioritized maintenance requests." (Verdantix, 2017)

When it comes to maintaining building systems, small and mid-sized buildings typically depend on outsourced contract-based services. Maintenance teams in large buildings have typically used what are termed computerized maintenance management systems (CMMS) to keep a record of all of their client's physical assets, and to keep track of maintenance scheduling and work performed.

A new breed of system is emerging that is more applicable to small and mid-sized buildings. Mobile maintenance software (MMS) is a cloud-based solution that is designed to be more accessible and interactive, enabling a more collaborative approach

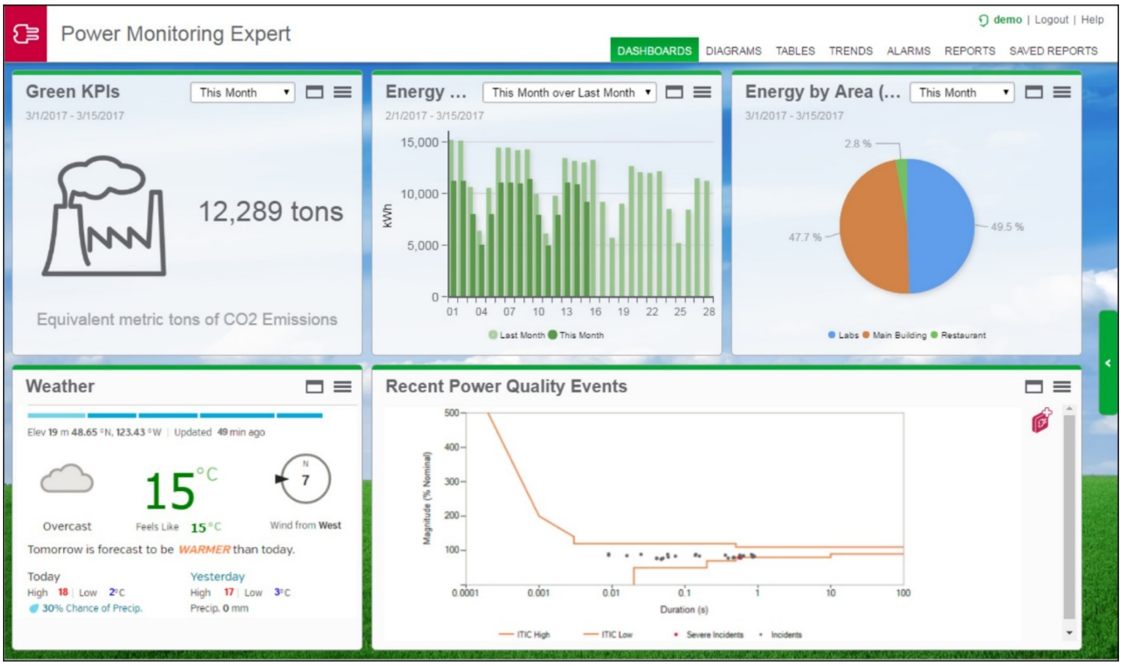

Figure 5: Example of power management dashboard displaying energy and power quality KPIs

between facility managers and contracted technical services.

Similar to traditional CMMS, new MMS systems will log maintenance activities and can provide a complete inventory of HVAC, fire, and lighting systems, as well as industrial machines. However, unlike CMMS, an MMS stays connected to those assets. An MMS goes beyond tracking maintenance activity by also monitoring equipment performance, using alarms to alert the facility manager and the contractor of any immediate maintenance needs. For example, a technician might receive a message by smart phone that a rooftop unit needs its filters cleaned.

With wireless access by tablet, smart phone, or laptop, MMS systems greatly increase efficiency for service personnel. In addition, some speed up equipment data entry using simplified templates that can be supplemented as required over time.

In addition, the cloud-hosted database allows sharing across the community of electrical and mechanical contractors, as well as the facility manager. This provides visibility to everyone on the progress of work performed by everyone involved in the management of a facility.

Ultimately, MMS can help prioritize work, manage all contractors, and enable predictive maintenance to boost operational performance.

POWER AND BUILDING EQUIPMENT ANALYTICS

A Verdantix survey of 250 global facility decision-makers found that 86% thought it was either important or very important for their organization to improve its performance in energy data collection, analysis and reporting. 85% of those same professionals also deemed it important or very important to improve operational monitoring and management of energy. (Verdantix, 2016, Figure 4)

IoT-enabled technologies are helping facility teams identify energy savings opportunities, predict equipment service needs and, in turn, enable improved asset management and reduced downtime through proactive maintenance. However, the result of so many IoT devices in place throughout a facility's power distribution and building management system is 'big data'. That data needs to be interpreted to extract it's value.

Fortunately, advanced analytic software is available today that helps make sense of everything by converting granular data into key performance indicators (KPIs) including clear, graphical views (Figure 5). Each corporate, energy, facility, and maintenance leader gets appropriate, actionable power and energy information tailored to his or her needs to simplify understanding and speed decision-making.

It's also easier to share information across the enterprise in formats everyone can understand. Raising energy awareness can encourage energy-efficient behaviors, while allocating costs to cost centers or tenants can lead to actions that reduce energy consumption.

For the first time, a complete picture of energy consumption throughout one or more facilities is available. Dashboards and reports help compare floor-to-floor or building-to-building performance. Teams can then set performance baselines, accurately track

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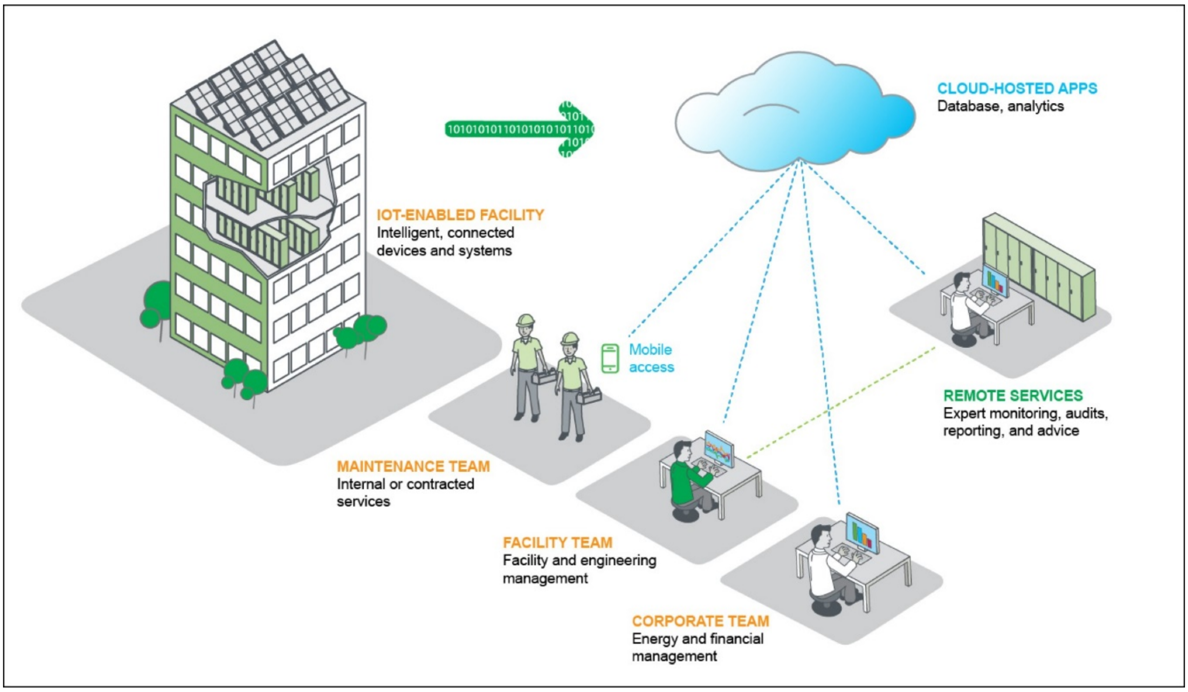

Figure 6: Cloud-hosted applications share actionable information with facility and remote services teams

the progress of efficiency initiatives, and validate savings.

Greenhouse gas (GHG) emissions and total carbon footprint can be automatically calculated to support corporate sustainability reporting. To optimize energy costs and avoid penalties, new energy analytic applications can be used to model and predict energy needs. These take into account energy pricing and weather forecasts, then provide the necessary decision inputs to automated peak shaving or load shifting. The high accuracy of onsite metering can be used to validate utility bills to uncover potential errors. Analytics can also enable participation in programs such as demand response. Signals received from the smart grid are evaluated based on the opportunity. If accepted, deployment of onsite DER is then coordinated in response to load curtailment requests.

Analytic capabilities can also help determine the most cost-effective periods to either self-consume renewable energy resources or recharge onsite energy storage.

Power analytic tools help diagnose problems and improve response times. Data analysis helps isolate problem sources in the network, including when and where conditions might be getting too close to safe tolerances. Rich data visualization tools can help improve system efficiency by balancing loads or uncovering losses or hidden spare capacity. The use of a facility's power infrastructure can be maximized without compromising its reliability. This is critical for minimizing capital expenditures (CAPEX), as overbuilding and unnecessary equipment upgrades are avoided.

Integrating data from BMS and other systems can help evaluate their true power and energy consumption and, in turn, optimize their settings to boost efficiency. Analytic capabilities can also help maintenance teams go beyond the confines of scheduled maintenance by using new techniques to predict breaker aging. These take into account not only contact wear and operational cycles, but also environmental conditions including corrosive gases, dust, and temperature. Predicting equipment conditions in this way makes for better capital planning, as teams can perform repair or replacement only when required. It can also improve service continuity by catching high-risk situations before failures can occur. With analytic tools providing a 'microscope' on every hidden risk and opportunity, managed services can deliver even greater rewards. Verdantix recommends that for "firms seeking to move beyond conventional reactive or basic scheduled maintenance, it will be more cost-effective to integrate equipment performance management by domain experts into existing facility management contracts. These experts will be able to identify improvement opportunities more efficiently while helping to optimize equipment uptime." (Verdantix, 2017)

CLOUD-BASED SAAS

Cloud-based computing delivers resources over the Internet, often termed software-as-a-service, or SaaS.

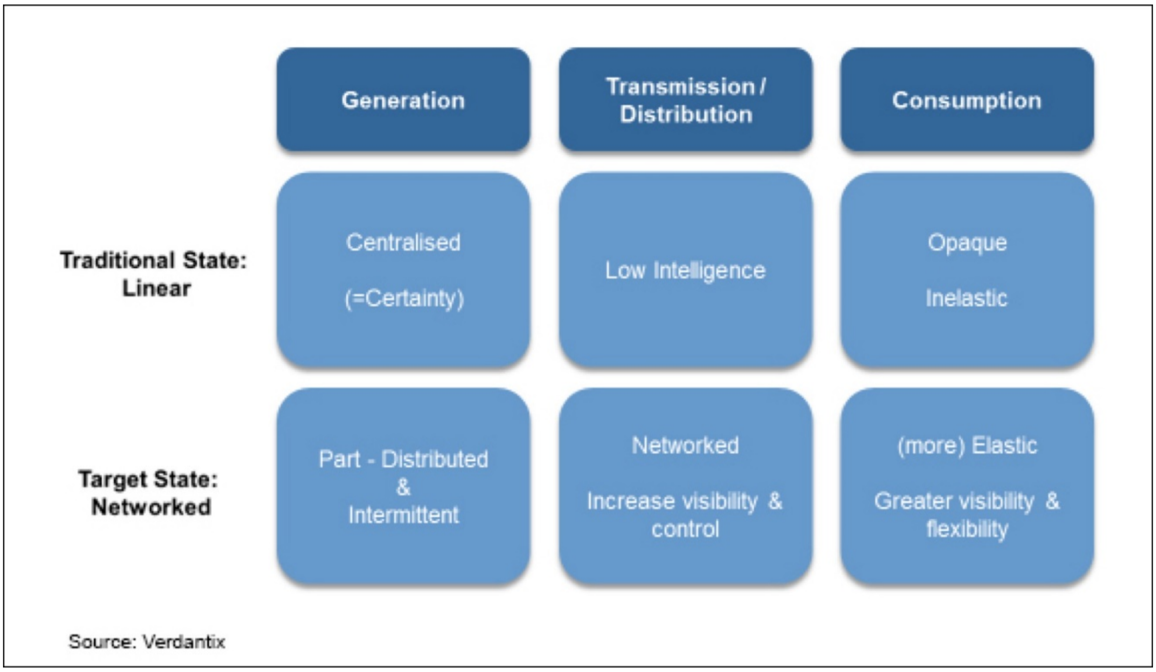

Figure 7: Moving the energy system to its new target state

IoT-based solutions depend on the affordability and scalability of cloud-based remote servers.

"While traditional, dedicated data servers offer limited bandwidth, cloud hosting can scale to accommodate dynamic demands," explains Navigant. "IoT solutions will increasingly, if not already, rely on cloud computing to ensure scalability at low cost." (Navigant, 2017)

New cloud-hosted applications continuously upload and aggregate power infrastructure data, while smartphone-ready digital logbooks track equipment and maintenance activity (Figure 6).

The cloud can also act as a remote services enabler, allowing facility management teams to take advantage of external expertise. According to a global survey by Verdantix, "26% of firms plan to continue outsourcing energy management to an external firm, or start outsourcing in the next two years or sooner. In France this number goes up to 45%. Interest in asset-level energy management is also increasing, especially in sectors such as retail and manufacturing where 27% and 26% of firms, respectively, plan to outsource."

Power network data is transformed into actionable insights, with information and alarms shared with facility personnel as well as a contracted service partner. This enables the partner to provide regular consultation and recommendations to the facility team, based on energy, operations and advanced analytic reports provided from the system. The service partner can also identify and correct equipment faults before they become critical.

Verdantix notes "Remote equipment monitoring and operations management can provide clients with multiple benefits, such as faster identification and resolution of maintenance events, fewer maintenance events and improved building operational efficiency." (Verdantix, 2017). Cloud-hosted solutions are accessed through PCs and mobile devices by facility personnel and contractors. This new 'energy cloud' taps into even greater value by enabling information sharing and collaboration between all parties. It keeps everyone engaged with the smart power distribution and building controls network, making sure they immediately receive and quickly respond to equipment alarms, helping avoid failures and downtime.

DATA FROM INSIDE AND OUTSIDE

The newest energy analytic applications will use normalization to adjust baseline energy use to control for factors that impact energy consumption such as hours of operations, units of production, and weather changes. Using this kind of predictive modeling technique ensures more accurate metrics when comparing the performance of different facilities, or tracking progress against efficiency goals. It also helps facility teams understand how efficiency and costs are influenced by a building's interaction with the environment.

Applications catering to the new energy 'prosumer' take into account real-time operational data from business processes and DER assets, as well as external data feeds, including weather prediction and energy pricing. From these inputs, decisions can be made regarding the optimal way to manage onsite energy production and consumption.

As Rodolphe d'Arjuzon of Verdantix observes, "The most effective energy management systems use connectivity to the outside world to optimize performance. Responding to external signals is fundamental to maximizing the flexibility of onsite renewable energy assets. As government policy and the penetration of renewables continue to drive the development of smart grid programs, managing the whole electricity system will require greater information flow to balance the intermittency of output using the flexibility of consumption." (Verdantix, 2017, Figure 7)

CYBER-SECURITY

Verdantix warns "As more pieces of equipment are brought online, through the proliferation of IoT-based sensors and devices in buildings, the threat of cyberattacks will increase." (Verdantix, 2017) This is corroborated by a Juniper Research report that estimates the cost of data breaches will rise to $2.1 trillion globally by 2019, with the average cost of a data breach exceeding $150 million by 2020, as more business infrastructure gets connected. (Juniper Research, 2015)

Events illustrating just how disruptive and costly these situations can be include the attack against retail giant Target in 2014 (nearly 1800 department stores across the US), the distributed denial of service (DDoS) attack on US-based Dyn in 2016, and the ransomware attack on the UK National Health Service and FedEx in 2017 (more than 300,000 computers in 150 countries).

With all of these new connections between smart devices, panels, systems, and the cloud, the threat of cyberattacks have become a growing concern both inside and outside of the buildings industry.

New standards and protocols are ensuring cyber-security is maintained and managed for all IoT-connected building systems. Many manufacturers now follow a disciplined process that includes providing security training to developers, adhering to security regulations, conducting threat modeling and architectural reviews, ensuring secure code practices, and executing extensive security testing. Some also provide partners and customers with full documentation and secure deployment instructions.

In addition, to counter the threat of equipment becoming unable to function from a breach, leading technology providers often provide dedicated cyber-security teams charged with supporting clients through installations, security lifecycle services, and responsive assistance and support when incidents and vulnerabilities are reported.

Creating a security policy and network infrastructure for IoT-based building systems requires the support of senior management. As attacks become more common and more sophisticated, processes and procedures need to be developed that secure building networks.

Training of people who manage these networks is a critical success factor. Vigilance and due diligence should include disciplined system maintenance with the latest updates, and evolving the strategies that account for the broad and deep defense of secure architectures. Training of employees and other end users should occur on a regular basis in order to guard against social engineering malfeasance.

Such investments will benefit the organization by reducing incidences that result in loss of revenue, and by safeguarding the organization's reputation with customers and partners.

CASE STUDIES

Schneider Electric, 'Le Hive'

Goal:

Achieve ISO 50001 certification for the company's seven-storey, 35,000 m^2, 1,850-employee corporate headquarters ('Le Hive'), as well as reduce and control energy consumption by a factor of four, and create a flexible footprint to meet changing business needs.

Solution:

A comprehensive IoT-based energy management solution, with retrofit carried out largely by the company's own in-house experts. Closely managed energy consumption with a dedicated manager for energy and the environment, and centralised control and monitoring using innovative tools. Also includes regular greenhouse gas emissions studies. The building management team is focussed on energy efficiency and occupier comfort. The occupant comfort level is monitored, and regular awareness events and surveys involve employees in the continuous improvement of the building's management.

Results:

- Helped reduce energy consumption by 47%. Energy use for HVAC and lighting have been halved from 150 kW/m2/year to 78 kW/m2/year in three years through active energy efficiency (without changing the structure of the building and without energy production).

- Enabled the building to become the first worldwide to obtain ISO 50001 certification.
- First in France to receive triple certification: ISO 14001, NF EN160001, HQE-certified.
- BREEAM In-Use rating: Asset performance ‘Excellent’, 75%; Building management performance ‘Outstanding’, 88%; Occupier management performance ‘Outstanding,’ 92%.
- Have already reached the French 2020 greenhouse reduction target for buildings.
- Improved employee comfort and productivity.

OVG Real Estate, The Edge

Goal:

The Edge is a 40,000 m^2 office building in the Zuidas business district in Amsterdam. OVG Real Estate and it’s main tenant, Deloitte, wanted to create an agile, high-performance workplace where innovation can thrive, and create a smart building to act as a catalyst for Deloitte’s transition into the digital age.

Solution:

IoT-based intelligent solution that integrates numerous smart technologies to create adaptable and intelligent work spaces. Energy management system provides access to critical building data via easy-to- use dashboards, enabling facility managers a single view to the building's HVAC and room control systems, as well as its state-of-the-art aquifer thermal energy storage and solar-generated energy. Occupancy, movement, lighting levels, humidity and temperature are continuously measured, and using smart technology – including Ethernet-powered LED connected lighting – the building systems respond to maximize efficiency. Heating, cooling, fresh air and lighting are fully IoT integrated and BMS controlled per 200 sq. ft. based on occupancy – with zero occupancy there is next to zero energy use.

Results:

- Energy consumption has been minimized to less than 0.3 kWh/m^2, using 70% less electricity than comparable office buildings.
- Enabled the building to become the world's most sustainable office building, with on-site and remote management of building operations and energy use for optimal occupant comfort.
- BREEAM Award for Offices New Construction in 2016, and also won the public vote for the prestigious Your BREEAM Award.

Hilton Hotels

Figure 10: Hilton Garden Inn, Dubai

Goal:

With energy as its second largest operational cost, and with eco-conscious travellers who judge a hotel by its environmental footprint as much as its amenities, the company sought a solution capable of supporting resource efficiency on multiple fronts. The goal was to achieve greater energy and operational efficiency without sacrificing guest comfort, and provide a framework that project teams can apply to create healthy, highly efficient, and cost-saving green buildings.

Solution:

A scalable, cloud-based software platform that makes real-time utility pricing and consumption data visible, comparable, and actionable across Hilton’s global portfolio of properties. By integrating the building, guest room, and property management systems, the solution leverages automation to increase both operational efficiency and energy efficiency, while achieving guest satisfaction far above benchmark.

For example, when the guest leaves the room, the system adjusts again to save energy. When the guest checks out, the room temperature goes into deep setback to further enhance energy savings. The end result is an entire, integrated energy management system preparing for and accommodating guests with the proper temperatures in their room at all times, while lowering energy costs for the hotel. And the seemingly minor temperature changes of one or two degrees can add up to thousands of dollars in energy savings for the hotel throughout the year.

Results:

- The Hilton Garden Inn in Dubai (the largest outside the U.S.) achieved LEED certified to the Gold level, and is now one of Hilton's most efficient and sustainable hotels.
- Integrated systems increase energy efficiency, operational efficiency, and guest control. Occupancy-based energy management ensures an exceptional guest experience by delivering comfort, convenience, and control while saving energy.
- Managers can configure personal dashboards and generate customized reports for water, waste, gas, steam, and electricity use to analyze performance and benchmark facilities. At Hilton sites around the globe, management can deploy solutions to optimize resource efficiency across each building's combined assets and systems.
- The staff has the ability to monitor conditions in every area of the property, allowing them to be in full control of what is happening throughout the facility. Engineering department can see and manage the entire system from the desktop. Alerts notify the staff when there's an issue with a system or connected device, and any potential concerns can be managed remotely before guests even notice. BMS can be configured for remote monitoring from laptop computers, smartphones, or tablets.
- Expert service consultants provide data-driven support to Hilton, advising on procurement decisions and sustainability programs.

CONCLUSION

The Internet of Things is converging with a range of other innovations to give the facility and services teams of buildings many more opportunities to achieve higher levels of efficiency, reliability, and safety. Greater levels of device intelligence and connectivity are giving access to richer data from farther across, and deeper within, the facility infrastucture. This is enabling actionable insights previously not possible.

Building management, power management, energy management, and other information and automation systems are becoming more integrated, giving facility teams a more unified view of conditions and interactions. Cloud-based and mobile platforms are delivering analytics and reporting capabilities that rationalize and simplify the understanding of the vast and growing amount of granular information available on energy consumption, power conditions, and equipment health. This is helping facility professionals and corporate management make more informed and effective decisions about energy use. It is also helping maintenance teams to more work more efficiently while they improve the reliability and lifespan of power distribution and building automation equipment. Ultimately, this is helping improve safety, business productivity, and occupant comfort while significantly reducing energy costs.

More connections are being made between equipment, within facility teams, with outside services, and with relevant data sources and programs outside the facility. This is enabling a broader range of expertise, a more collaborative approach to problem solving, faster response to risk conditions, and more opportunities to control costs and reliability. With the right policies, infrastructure, and training in place, these connections will remain fast, reliable, and secure from cyberattacks. Looking forward, smart, IoT-enabled buildings will be the global model for optimized efficiency and productivity.

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ENERGY EFFICIENT FANS – INFLUENCE OF PEOPLE'S BEHAVIOUR ON INCREASING ADOPTION

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Keywords: Energy Efficiency, Behaviour, Policies

ABSTRACT

This paper discusses the results of a study conducted in Kerala, India, based on a survey among 340 households, focusing on the behaviour of consumers while selecting Energy Efficient equipment/ appliances. The end-use energy efficiency is analysed based on the concepts of behaviour of customers.

A noticeable discrepancy was found in the selection and elimination process which depends more on biases and heuristics and the observable behaviour is less influenced by the availability of better or more efficient technology.

The study shows that consumers give more weight to non-technical factors such as brand in most of the cases. This shows that the focus of policy makers should be to bring in changes in the behaviour aspects, rather than technical optimisation, to enhance adoption of energy efficient equipment/appliances. The knowledge-action-intention gap is one of the most important behaviour aspects to be addressed to, while devising policies and intervention strategies.

Changing the behaviour and practices is probably more important than finding new sources of energy, as end-use energy efficiency through demand side management is a better option than supply side solutions. It is estimated that 3000 Million units of electricity per annum can be saved by improving the energy efficiency of fans alone, in India.

Key Words: Energy efficiency, behavioural economics, residential energy use, imperfect optimisation, bounded rationality.

INTRODUCTION

Many studies have been conducted the world over on the potential of energy saving by adopting latest technologies, on various barriers and drivers that affect energy efficiency enhancement, end use energy Efficiency, on energy management systems and on Demand Side Management (DSM) policies. (Parikh J K , et al.1996, Thollander P, 2007,2013, Boegle A et al, 2010, Sorrell, S et al. 2000, Reddy B S, 2013, Sathaye, J A, et al. 2006). The focus of these studies was on the technological aspects, the cost of conserved energy and return on investments by adopting more efficient technologies and quantum of energy saved; relying more on the concept that people are rational decision makers. Rational choice theory of neoclassical economics, which is based on the notion that consumers weigh the expected costs and benefits of different actions and choose those actions which are most beneficial or least costly to them, was one of the most widely, used behavioural theories. It is based on this principle that it is presumed that in order to weigh the costs and benefits of various options, the consumer needs information on the possible actions or goods they can choose from, in order to make rational choices. This theory was used in much of the 1970s energy conservation research, and researchers using measures such as information campaigns and workshops as tools of highlighting the benefits of energy saving measures in the home (Martiskainen, M 2007).

However, a growing body of recent scientific research demonstrates that people are rarely the rational decision makers envisaged by traditional economic models of human behaviour. Consumer s choices and actions often deviate systematically from neoclassical economic assumptions of rationality (Frederiks, et al, 2015) and one of the most plausible reasons for the failure of policy implementation is identified as behaviour (Stern P.C, 1987). The changes in energy consumption are not influenced by technical aspects only, but also by users psychological aspects, (Poznaka L et al, 2014) and the potential source of market inefficiency is consumers cognitive limitations and psychological

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biases (Madrian B.C, 2014). It is also opined that, to change the trajectory of energy systems we need to go outside the physical sciences for input, mainly economics (Stern P.C, 2014).

One such study applying behavioural economics to understand consumer decision-making and behaviour by Elisha R. Frederiks, Karen Stenner and Elizabeth V. Hobman, titled "Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour" observed that “even with adequate knowledge on how to save energy and a professed desire to do so, many consumers still fail to take noticeable steps towards energy efficiency and conservation. There is a sizeable discrepancy between people s self-reported knowledge, values, attitudes and intentions, and their observable behaviour”.

Prayas Energy Group, one of the leading energy research groups in India finds out that “little research has been carried out in behavioural science to inform public policy in India, let alone behavioural research in energy efficiency”. They feel that it is crucial that greater research should be carried out to understand the behaviour of people in India towards energy efficiency and conservation (Rathi S S, et al. 2015).

It is argued by many researchers that explanations are to be sought through cross-disciplinary studies and integrative approach that explicitly examine the interactive effect of economic, demographic, structural, and psychological variables (Stern P.C, 2014). Formulating strategies and policies to enhance adoption of energy efficient appliances through effective behaviour change programs, using innovation and design decision frameworks, is a less tried out method in India. Hence, a pilot study was planned to identify factors that influence end-use energy efficiency improvement in the residential sector, through various customer interaction strategies such as surveys, interviews, home energy audits, awareness campaigns and field demonstrations.

More recent research on behavioural economics identifies three broad categories of psychological biases such as imperfect optimisation, bounded self-control, and nonstandard preferences. (Madrian B.C ,2014). Imperfect optimisation arises because consumers have limited attention and cannot possibly focus on all of the information relevant for all of the decisions they are called upon to make. They have limited computational capacity, which leads them to apply simplifying heuristics to complicated choice problems. Bounded self-control is the discrepancy between the intentions consumers have and their actual behaviour. This theory identifies that consumers often plan to behave in a certain way but end up doing otherwise. Frederiks et al. (2015) say that " it is clear that what people say and what they do are sometimes very different things. In many domains of human behaviour, we see a knowledge-action gap, value-action gap, an attitude-action gap and/or an intention-action gap. For example, people may know about, intrinsically value, hold positive attitudes towards, and/or genuinely intend to act in some socially desirable way. Yet often these things do not translate into actual behaviour”

This paper focuses on a single, most significant, omnipresent electrical appliance viz. ceiling fan, identifying the factors that influence buying and replacing decisions and comparing with cases of other commonly used equipment such as lighting fixtures and refrigerators It is an attempt to analyse the knowledge-intent-action gap in choosing an energy efficient equipment, that can throw light for a detailed future study on consumer behaviour that incorporates the socio-demographic and psychological factors. This paper also intends to analyse the adoption of energy efficient equipment based on the concepts of neoclassical and behavioural economics, such as imperfect optimisation, bounded rationality, bounded self- control, and nonstandard preferences.

METHODOLOGY

The field surveys were conducted among 340 households, using a structured questionnaire, consisting of two parts. The first part consists of technical and demographic data and the second part consists of the attitude and behaviour of the respondent (decision maker) on the choices of end use equipment. The field study was primarily based on the interview of the decision maker in the house. The sample group was selected through multistage sampling from the population of consumers in the Ernakulam and Trichur Districts and explicit stratification was made through classifying the population based on the location of living like Corporation, Municipality and Panchayat. . After the preliminary data collection, detailed home energy audits were done in a few selected houses to verify the accuracy of the survey data. (A detailed statistical analysis using regression, principal component analysis etc. is beyond the scope of this paper)

RATIONALE

One simple question that can be asked about the end use energy equipment in the residential sector is that; "if people are willing to adopt energy efficient lighting system, why not energy efficient fans?”

The organized fan market is dominated by national brands like Crompton Greaves, Orient, Havells, Usha, Bajaj, Khaitan, etc. This Organized electric fan industry categorized fans on the basis of price viz. economy fans, regular fans and premium fans. Economy fans are those which are priced below Rs. 1200, regular fans come in the range of Rs. 1200 to Rs. 2500 whereas premium fans are priced above Rs. 2500 for a single fan. Regular fans category is the largest category in India both in value and volume terms. In India, ceiling fans alone account for approximately 6 % of residential energy use and this figure is expected to grow to 9 % in 2020 (la Rue du Can et al. 2009), This increase is equivalent to the energy output of 15 mid-sized (500-MW capacity and runs at 70 % efficiency) power plants. (Shah N, et al. 2015). Prayas Energy Group, Pune in their study on "Ceiling Fan, The Overlooked Appliance in Energy Efficiency Discussions" observes that "even though ceiling fans are probably the most common electrical appliance after electric lights in Indian households and offices, they are rarely mentioned in discussions of energy efficiency (EE). This omission results in the loss of an opportunity to realise significant savings in energy." (Singh D et al.2010)

The researcher has also observed that retrofitting of incandescent lamps with Fluorescent Lamps and Compact Fluorescent Lamps(CFL)[i] and now with Light Emitting Diode(LED)[ii] lights have gained good acceptance, whereas adoption of energy efficient fans are very poor.

Lighting had both the push and pull effects as the utilities, Bureau of Energy Efficiency (BEE, Govt. of India) and Energy Efficiency Services Ltd (EESL, A Joint Venture Company of PSUs of Ministry of Power, Govt. of India) gave the lamps at subsidised cost giving the push and then the market competition and technological development pulled down the initial cost. Retrofitting an ordinary incandescent lamp with these energy efficient lamps do not produce many hassles to the consumers unless otherwise, they are to be mounted on special fixtures (such as fancy or Flame Proof fixtures) or in areas where colour rendering is of primary importance.

Even though these energy efficient retrofits have reduced energy consumption they have led to many compromises on light quality, created many power quality issues (high harmonics and low power factor) and caused environmental hazards such as mercury pollution. Lighting system efficiency in terms of Lumen/Watt increased by a staggering factor of 6-10 when the consumers moved from Incandescent lamps to CFLs and LEDs. This has also led to a big rebound effect and the Jevons paradox[iii] as the number of lights used has increased to many folds in all sectors. Government initiatives such as the energy labelling had very little influence on this increased diffusion of energy efficient equipment in lighting and it was more based on the technological development and market mechanisms.

Fans consume almost two times the energy when compared to lights in almost all non-air conditioned buildings. Latest market data shows that 35 million ceiling fans are sold in India every year. The power consumption of these fans varies from 80 W for a non-branded low-cost one (Rs. 600/-) to 60 W for a branded Economy model (Rs 1200/-). There is a very tiny segment of energy efficient fans in the market, whose power consumption is much lower and varies from 50 W for a 5-star fan (premium) that costs Rs 2200/- to 28 W for a Super fan (Brush Less DC or BLDC)[iv] costing Rs 3300/-. The power consumption of a BLDC fan can be as low as 10 W at low speed.

Considering an average reduction of power to the tune of 40-50 W per fan, running for an average of 8 hours per day for 300 days, replacing a conventional fan with super-efficient fans, can save not less than 3000 Million units of electricity per annum in India. A Lawrence Berkeley research work also shows that "given consumers' lack of awareness of energy efficiency, particularly regarding fans, and the slow progress in DSM in most states, new avenues to bring about a rapid shift to super-efficient fans need to be found quickly (Shah N, et al. 2015).

The Prays group study finds that "while there is little interest in the efficiency of fans, customers are showing considerable interest in cosmetic features such as colour and shape of the fan. Most major manufacturers are responding to this demand and have a line of decorative fans with a wide choice of colours, blade-design and number of blades."(Singh D et al.2010).

This study also confirms these findings on the choice of fans, dominated by non technical factors, efficiency, life cycle cost etc. "Brand" becomes the most preferred choice because of imperfect optimisation. Replacing conventional Fans with energy efficient fans have many benefits to the consumer as the cost of conserved energy is often lower than the Utility Electricity tariff. However, lack of proper information on the technology, lack of trust in the sources of information, false claims of non-standard manufacturers, inertia among consumers- especially for retrofits - due to endowment effect and lack of awareness are some of the barriers to adoption of energy efficient fans. Another important factor in the case of fans is that the Brush Less DC (BLDC) Technology is not mature enough to compete with the traditional Induction Motor technology and BLDC fans are reported to be more prone to failures. Many consumers are not aware of the huge efficiency drop while rewinding and repairing a fan and there are very few good quality repair and rewinding centres. Hence, they have not realised that it is always prudent to go for a new fan whenever the fan fails. Since, Energy Efficient fans are not readily available in the market, especially those made by the reputed brands, the customer opts rewinding and repairs that do not promote energy efficiency. (Inputs received during interview and discussions with consumers)

Table 1: Energy Consumption/year: Lighting and Fan

	Incandescent lamp	CFL	Fluor. Tube	LED	Lighting kWh /year	Ceiling Fan	Exhaust fan	Pedestal/ Wall Fan	High Efficiency / BLDC fan	Fan kWh / year
Number	319	1757	825	587	361	1331	168	134	5	635
Average kWh/ year	67	113	168	13		561	38	33	3	

Source: All tables are based on the data compiled through the surveys conducted in Ernakulam and Trichur districts, Kerala, India among 340 households

STUDY FINDINGS AND DISCUSSIONS

The survey data shows that the fans consume approximately two times the energy consumed by lighting fixtures, in the selected residential sector. Penetration of Energy Efficient Fans and Superfans are just 0.37% of the total number of fans. But, in contrast to that, LEDs, CFLs, and Fluorescent lamps have a share of 91% and these more efficient gadgets have almost replaced the less efficient incandescent lamps. **Choice Preference**

Technical optimisation by reducing the energy needed to provide a certain service is an often tried out methodology by Energy Efficiency policy makers. But, it is evident from the data given in Table 2 that, in the case of choosing fan and light fixtures, consumers had given more weight to non- technical factor such as brand.

However, there is a clear shift in choice towards energy efficient equipment in the lighting sector whereas such an approach is less visible in the fan sector, even when they consume two times the amount of energy. One reason could be that, in the case of lighting, the efficiency or efficacy in terms of light (Lumen) per Power (Watt) is much more easily perceivable than that of the fan, where the efficacy is measured in airflow (cfm) per Power (Watt). Understanding quantity and quality of air delivery are burdensome in comparison with the understanding of luminous efficiency. Another reason could be that most of the consumers are not aware that energy consumed by fans represent (approx 40 %) of their electricity bills. This is a clear case of "Imperfect optimisation that arises because consumers have limited attention and cannot possibly focus on all of the information relevant for

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all of the decisions they are called upon to make. They have limited computational capacity, which leads them to apply simplifying heuristics to complicated choice problems and opt for brand instead of Efficiency and life cycle cost. A shift in consumer choice towards energy efficient equipment for future actions has a clear upward trend (Table 2, row 2). The consumers while procuring a new equipment can no longer depend on the choice of the electrician, or the suggestions from external agents, whom they might have depended more during the earlier stages of construction, are now willing to apply their own preference and knowledge. (Table 2, row 3 &5). This shows that the consumer is showing a increased inclination to go for energy efficiency and hence an awareness program modifying their standard behaviour -that is not promoting energy efficient fans- assumes greater significance. Bounded self-control between the intentions consumers have and their actual behaviour is another important factor to be addressed to. We observed that the consumers often plan to behave in a certain way but end up choosing a different option . This intent- action gap has to be addressed, to increase adoption of energy efficient fans.

Knowledge- Intent--Action gap

The consumers who have expressed that they are aware of the energy labelling system prevailing in the country are perceived as „knowledgeable . They are expected to show an intention to go in for high energy efficient equipment when they plan for a replacement either due to failure or due to its ageing will opt efficiency as first choice while replacing light , fan, refrigerator. For example, those who have opted efficiency as their first choice for replacement of fan is expected to buy a new fan to save energy and will not wait for the fan to fail for replacement. Also, they will not opt to rewind or repair.

Action is measured by checking whether those who are aware of energy labelling have one energy labelled equipment at home, have most efficient LED lights and have energy efficient fans such as Super fan or BLDC.

Table 2: Percentage Weights of selection criteria for Light fixtures and Fans

Row	Parameters	Existing		New	
		Fan	Light	Fan	Light
1	Brand	49.6	36.1	48.0	34.2
2	Efficiency	18.0	30.8	28.0 ↑	48.4 ↑
3	Electricians Choice	14.3	15.0	7.2 ↓	4.0 ↓
4	Initial Cost	9.8	12.0	10.4	9.0
5	Suggested by friends/relative/contractor /experts	6.0	1.5	2.4 ↓	2.4
6	Colour of Fan/Light	2.3	4.5	4.0	2.0

Table 3:Basic Assumption on Knowledge-Intent-Actions

Knowledge	Intent	Action
Those who are aware of energy labelling	will opt efficiency as first choice while replacing light , fan, refrigerator	
	Those who have opted efficiency as their first choice for replacement of fan	a)will buy a new fan to save energy – or will not wait for the fan to fail c) will buy a new one when fan fails –will not opt to rewind or repair
Those who are aware of energy labelling		will have one energy labelled equipment at home
Those who have preferred and opt for efficiency in lighting	will opt for energy efficiency while replacing fans	and would have installed Energy Efficient or BLDC fans

Fig 1: Knowledge-Intent –Gap (Response in Numbers)

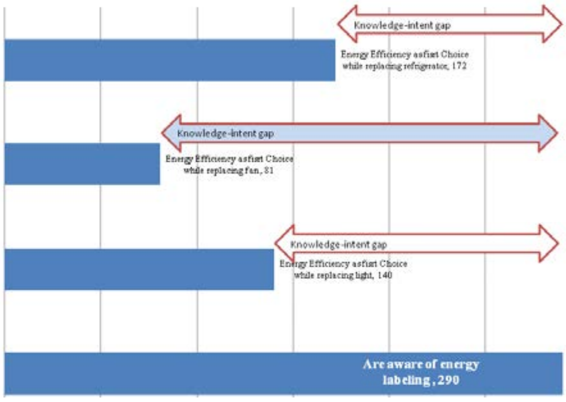

Fig 2: Intent –Action Gap (Response in Numbers)

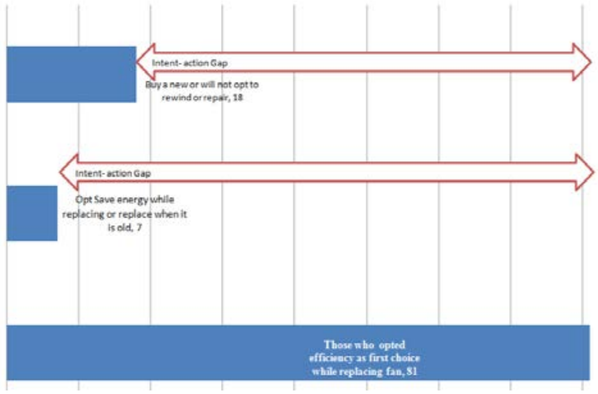

Table 3a: Knowledge-Intent- Action gap: (Response in Percentage Weight)

From the group who are aware of energy labeling (Professed Knowledge)- Figures in Percentage Weight				
	while replacing Fan	**while replacing light**	**while replacing a refrigerator**	**Buy new one while replacing a defective fan**
Intent - Prefer Efficiency/ Power as the first choice	28	49	57	23
Action – towards installing energy efficient equipment in house	**have labeled equipment**	**have more than one LED lamp**	**have one Super-fan/ BLDC**	
	75	28	0	

Table 3b: Intent -Action Gap (Values in Percentage Weight

When will you replace your fan?	**when it fails**	**for a new model**	**to save energy**	**when it is old**	**No response**
	90	0	2.5	6	1.5
Preference when replacing (intent)	**Colour**	**Brand**	**Electrician's choice**	**Suggested by friends, relatives or contractor**	**Efficiency**
	3	49	6	11	23
Action (when the fan is not working)	**buy a new one**	**rewind**	**repair**	**not sure**	
	23	8	62	5	

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Among those consumers who have indicated that they are aware of the energy labelling scheme of the government (perceived „knowledgeable group), though 75% have said that they have one labelled equipment in their house, it is found that just, 28% have more than one LED light in their house and none of them has an energy efficient fan or BLDC fans. Hardly 28% have given first priority to efficiency or power while replacing their fan . This knowledge –intent gap is narrow in the case of lighting (intent is 49%) and refrigerator (57%). It is interesting and relevant to note that among this „knowledgeable group, just 23 percentage of the respondents said that they will buy a new fan while replacing a defective fan; rest intent to repair or rewind the defective ones. The very low adoption rate of Super-fans/BLDC fans, among this group justifies the previous research and the very large gapbetween Knowledge, intent and action is to be properly addressed to enhance adoption of energy efficient fans.

Table 3b specifically looks into the intent- action gap while replacing a ceiling fan when it fails or when a new one is purchased.

It can be seen that even when 23 percentage of the people prefer efficiency when they are looking for a replacement (intent), hardly 2.5 percentage is willing to replace a fan to save energy (action) and 90% wait for the fan to fail to look for a replacement. This could be due to the endowment effect described in psychology and behavioral economics, where the people ascribe more value to things merely because they own them and tend to retain their old fan by repairing or rewinding them and are reluctant to trade it for another good of similar or higher value in terms of efficiency. Consumer preferences are often context dependent. This study shows that we could observe Individuals exhibiting significantly different behaviour and approach for different appliances and equipment. Choice or preference for efficiency is not consistent when they buy or replace a light fixture, refrigerator , fan or other household equipment like mobile phones, two wheeler or car. The decisions are also found to be more influenced by the opinion of friends, relatives, and the contractor than the initial cost (which was just 8%), as against the rational choice theory of economics where people often tend to maximise their benefits by opting low cost ones. It is also noted that the educational qualification has very little impact on the desire to choose energy efficiency as the first priority contrary to the popular belief that higher the education better will be the knowledge and inclination towards energy saving compared to the decision makers who are professionally qualified, have technical education and are post graduate.

Table 4: Energy Efficiency Preference and Educational Qualification of decision maker

Qualification	**Percentage(%)**
Up to Plus 2	54
Graduate	18
Post Graduate	7
Technical	10
Professional	4

The survey results show a contradictory picture with respect to the general belief that initial cost is often the most important factor in consumer choice. This is often put up as the main reason for the low adoption of Energy Efficient fans, which are expensive in comparison with the non branded and branded economy fans. However, it is found in this survey that initial cost is of very little significance for the decision maker in the case of Light Fixtures and Fans (Table 2). This was counter verified by looking into the choice preference of some other high valued equipment, in comparison with the fan, like mobile phones, refrigerator, two wheeler/car etc. Even in the case of high valued items, initial cost has very little significance and it is found to be less than 20 percentage. Brand plays a major role here also (Table 5)

Table 5: Preference of Choice (% share)

	Mobile Phone	**Two wheeler /car**	**Refrigerator**
Cost	16	20	13
Brand	39	46	42
Users choice/Size	19	26	3
Suggested by friend/relative/ expert	6	2	4

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CONCLUSION

Data analysis shows that Energy efficiency awareness has not gone beyond replacing incandescent lamps with CFL and Fluorescent lamps in many houses. Installation of Energy Efficient fans such as 5 Star Fans and BLDC fans are almost zero.

The knowledge-action-intention gap is one of the most important behaviour aspects to be addressed while devising policies and intervention strategies. This study was effective in providing various insights on the choices of people and was also useful in confirming the theoretical and research findings that behaviour plays a major part in decision making and shall be an integral part of the policy-making.

Enforcing efficiency standards for the branded equipment in the market through regulatory and supportive measures could be one of the important strategies that could be adopted by the Government while formulating policies to enhance adoption of energy efficient equipment.

Limitations and suggestions

It is observed that data on behaviour and attitude are to be obtained without giving choices to the surveyor and respondents as it can create many biases. Compiling data based on the past actions and future plans through interviews and questionnaire were also found to be affected by various biases and errors.

There is a need to get more accurate data on the behaviour of people on adoption of energy efficient technology/equipment and sustainability. A survey among the customers at the time of their action, through "sales door survey"(survey at the point of sales from the shops) enquiring about a minimum number of open-ended queries (without providing any choice and clue) on their "preferred action", would be a more a more suitable methodology. Later, necessary data can be compiled through other methods, including a personal interview and home energy audits, for analysing the influence of various psychological and socio-demographic factors.

ACKNOWLEDGEMENT

This study was done under the scheme constituted by Energy Management Centre, Govt of Kerala for the purpose of providing assistance in the form of grants to initiate research work in energy studies with particular relevance to the State of Kerala in the economic, social and industrial development.

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i Compact Fluorescent Lamps (CFL) give the same amount of visible light, using one-fifth of the electric power, and last approximately eight times longer. A CFL has a higher purchase price than an incandescent lamp. CFLs contain toxic mercury which complicates their disposal

ii LED (Light Emitting Diodes) lights are efficient than compact fluorescent lamps and lasts two to three times longer. They have fewer environmental concerns linked to their disposal

iii Jevons Paradox in economics occurs when technological progress increases the efficiency with which a resource is used, but the rate of consumption of that resource rises because of increasing demand. In the case of lighting the increase in number is due to the feeling that less energy is consumed per equipment.

iv A brushless Direct Current (BLDC) motor is a synchronous electric Motor powered by direct- current (DC) and having an electronic commutation system, rather than a mechanical commutator and brushes. BLDC motors offer several advantages over brushed DC motors, including higher efficiency and reliability, reduced noise, longer lifetime

A HOLISTIC OVERVIEW ON ADDRESSING INDIA'S COOLING ENERGY DEMAND THROUGH RESPONSIBLE SPACE COOLING STRATEGIES

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Keywords: Space Cooling, Codes and Standards, Solar Air-conditioning, Adaptive Thermal Comfort, Low energy cooling

ABSTRACT

India is poised to become the largest air conditioner (AC) market in the world in the next 15-20 years, given its tropical climate, large and growing population and rising lifestyle aspirations. This poses a significant increase in the nation's energy demand as well as its carbon footprint. Latest research shows that a combination of energy conserving and thermal comfort enhancing strategies and technologies, and a supporting policy framework, has the potential to reduce the energy demand for space cooling and associated carbon emissions in a significant way. Although multiple organisations are focused on decreasing the cooling demand, but there has not been an effort to promote an integrated approach that drives energy efficient, environmentally sustainable and cost-effective space cooling strategies. Toward this end, the *Sustainable and Smart Space Cooling Coalition*, comprising 12 not-for-profit organisations and academic institutions, was formed in 2016 to advance research, develop joint policy recommendations and facilitate market transformation. This paper highlights the importance of taking a holistic approach to managing India's burgeoning cooling demand through a combination of space cooling strategies, based on research and field-analysis, and the knowledge and insights of the Coalition members. The paper also presents a set of recommendations that are directed at the central and state governments as the primary influencers. These recommendations when implemented will involve and impact a diverse range of stakeholders – building industry, manufacturers, consumers, and researchers.

INTRODUCTION

Indoor thermal comfort affects the physiological and psychological well-being and productivity of occupants under normal conditions and their health in extremely hot conditions (Shaikh et al., 2014). For these reasons, thermal comfort for all should become an important goal for India, and positioned as a societal obligation available to all strata of society.

However, the challenge for India is twofold: (1) With extreme heat, large geographical regions with high relative humidity, and electricity per capita consumption of merely 1,000 kWh per year, a significant segment of the population has limited access to active space cooling. How does one bring thermal comfort to this segment in an affordable and sustainable fashion? (2) India is at the verge of an exponential growth in the AC market (Davis and Gertler, 2015). Presently, cooling energy is one of the largest drivers of power demand, as evidenced by the average daily load in Mumbai and New Delhi in summer versus winter (Figure 1). Under the business-as-usual scenario, room AC (RAC) penetration is expected to add approximately 150 GW to the peak demand by 2030, which is, nearly 30% of the total system load (LBNL, 2016). This poses severe environmental and societal threats: additional power generation requirements, peak load impacts, and an enormous carbon footprint both directly (through refrigerants) and indirectly (through electricity use).

In 2016, Alliance for an Energy Efficient Economy (AEEE), with support from Shakti Sustainable Energy Foundation (SSEF), took the initiative to bring together research and academic institutions, industry associations, and non-for-profit organisations, to build the Sustainable and Smart Space Cooling Coalition. The Coalition's mission is to lead India's transition to a responsibly cooled built environment by advancing research and policy recommendations, and enabling market transformation.

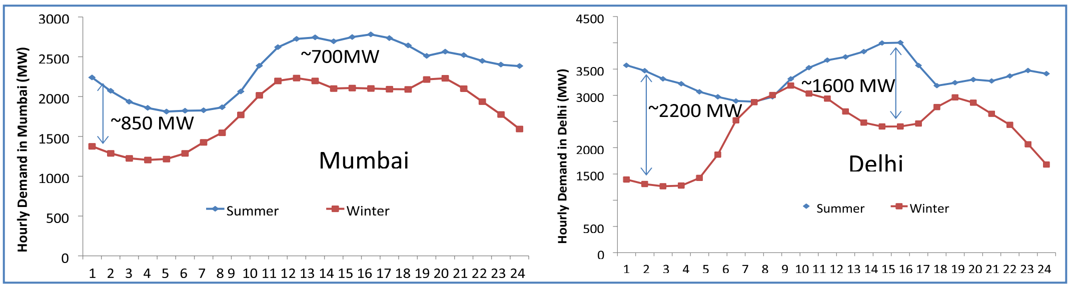

Figure 1: Average daily load curves in Mumbai and Delhi for summer v/s winter (LBNL, 2014)

The Coalition advocates the Lean-Mean-Green construct popularised by building scientist Bill Bordass (Bordass et al., 2001). A hierarchical approach, Lean-Mean-Green as it applies to responsible space cooling strategies advocates: (1) Lean: First, reduce the cooling load by incorporating efficient building design and construction. (2) Mean: Next, optimize energy use through energy efficient measures and efficient performance standards for appliances. (3) Green: Finally, reduce the carbon footprint to the extent possible through use of clean energy and low global warming potential (GWP) technologies (Figure 2).

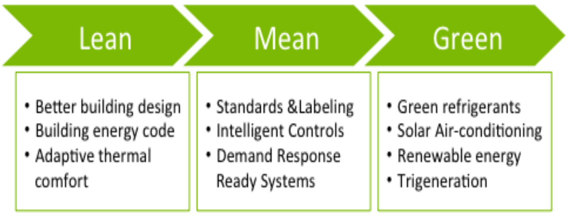

Figure 2: Lean-Mean-Green: a hierarchical construct for space cooling

Research shows that by utilizing a combination of the Lean-Mean-Green approach to space cooling, India can achieve a 33% reduction in peak demand and nearly 70% reduction in carbon emissions by 2030. India's electricity requirement for space cooling can be mitigated by up to ~100 GW by 2030 and ~250 GW by 2050 (LBNL, 2016).

STRATEGIES FOR SPACE COOLING

LEAN

One of the biggest impact on addressing India's cooling energy needs will be through incorporating the lean cooling methods to reduce the cooling load of buildings.

By utilising a combination of lean methods - energy efficient building design and construction, adaptive thermal comfort, and adoption of building energy code – the energy consumption of a new building could be effectively reduced as significantly as up to 50% (Bordass et al., 2001).

Efficient Design and Construction to Reduce Cooling Load in Buildings

A combination of building design strategies and energy efficient construction materials can make buildings inherently more thermally comfortable and reduce the reliance on active space cooling technologies. Some of the design strategies are:

Controlled ventilation. Even in hot-dry and warm-humid climate zones where air conditioning may be required during peak summer, buildings can be designed to operate in a mixed mode to enable night ventilation and natural ventilation during cooler seasons. Designing windows and vents to dissipate warm air and allow the ingress of cool air can reduce cooling energy consumption by 10-30% (Wbdg.org, 2017). Air velocities in the range 0.5 m/s to 1 m/s result in a perceived drop in temperature of about 3°C at 50% relative humidity (Yourhome.gov.au, 2017).

Window strategies – shading and glazing. Shading devices such as overhangs, louvers, vertical fins, light shelves and natural vegetation can reduce cooling energy consumption by 10-20% (NREL, 2000; Haghighi, Asadi and Babaizadeh, 2015). Shading used in combination with high-performance glazing can further reduce cooling energy consumption by cutting down on heat gain through conduction and radiation. The Energy Conservation Building Code (ECBC) of India prescribes a range of technical parameters for glazing for different climate zones at typical window to wall ratios (WWRs).

Insulation. Insulating walls and the roof cuts down heat flow through conduction, and can reduce cooling energy consumption by up to 8% (IGBC, 2008). The

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ECBC prescribes a 70-90% reduction in heat flow through the roof and walls with low U- values (BEEP, 2016).

Cool Roofs. Cool roofs reflect most of the sunlight (about 80% on a clear day), reduce solar heat gain and can decrease the use of air conditioning by up to 20% in the top floors (LBNL, 2011). A typical cool roof brings down the indoor air temperature by around 3-5°C (BEE and SSEF, 2011). Apart from helping enhance the thermal comfort, cool roof also offers significant reduction in urban heat island effect. Lawrence Berkeley National Laboratory (LBNL) and Indian Institute of Information Technology, Hyderabad (IIIT-H) research found that cool roofs could reduce peak energy demand by 10-19% in buildings in Hyderabad, leading to a potential of 2ºC reduction in citywide air temperature (Xu et al., 2012).

While proven building design and construction practices exist to reduce the cooling load in buildings, their rate of adoption continues to be a challenge. Primary reasons contributing to this are: lack of consumer awareness, market confusion about available options, and misaligned motivations among the building design and construction professionals. We see some immediate priorities to advance the integration of lean cooling strategies into mainstream:

- Utilize market transformation strategies to drive the adoption of energy efficient building materials
- Leverage ECBC to move the industry towards more efficient building design.

Building Energy Code for Building Envelope

The ECBC is a definitive pathway to energy efficient building design and construction practices. It specifies building design parameters and construction material properties to reduce the ingress of external heat through conduction, convection and radiation. Essentially, ECBC encapsulates the efficient building strategies alluded to in the previous subsection, to reduce the cooling load of buildings.

While the Code in itself is very effective, its implementation is not yet mainstream. Efforts are currently underway to drive its nationwide adoption. AEEE recently spearheaded 5 regional workshops to fast track the ECBC adoption, with support from National Institution for Transforming India (NITI Aayog), Bureau of Energy Efficiency (BEE) and (United Nations Development Programme – Global Environmental Financing (UNDP-GEF). Strong on-going governance will be essential to ensure compliance in order to effectively leverage the benefits of ECBC.

Adaptive thermal comfort – unexplored potential

People in warm, tropical countries need a different range of thermal comfort conditions compared to those in temperate or cold climates. Studies in India (Manu et al., 2016) and Japan (Indragati, Ooka and Rijal, 2014) indicated that close to 80% of occupants are comfortable with indoor operative temperature range of 24°C to 28°C in these countries. The India Model for Adaptive Comfort developed by CEPT University indicates that Indians' thermal comfort range is even wider for naturally ventilated and mixed mode buildings – at 19.6-28.5°C, and at 21.5- 28.7°C respectively. In spite of these findings, the set-point temperatures in homes and offices in India often hover around 18- 21°C. The possible explanation is that either the AC equipment is undersized for the space, or that the building envelope is inadequately designed. In theory, modifying the set-point temperatures to a higher operative range (in alignment with the IMAC findings) could potentially bring a substantial nationwide reduction in buildings' cooling load, and this is an area that should be explored further. Per a recent study (Manu et al., 2016), there can be 5-6% improvement in the Energy Performance Index (EPI) by increasing the thermostat temperature by 1°C. This can yield significant savings for buildings with large cooling and heating loads.

MEAN

Once the cooling load of a building has been downsized, or rather 'right-sized' using lean strategies, several methods exist to meet this cooling load in an energy efficient manner. These methods, grouped under 'mean' include:

Building Energy Code for HVAC

An inefficient heating, ventilation and air-conditioning (HVAC) system can have a big negative impact on the building's energy demand. ECBC plays an important role in ensuring efficient system design by listing mandatory and prescriptive requirements for some of the frequently used HVAC systems. The minimum system efficiencies are listed for unitary air conditioning equipment, chillers, heat pumps, furnaces and boilers. The prescriptive requirements cover minimum efficiencies for a range of air-conditioning equipment, and key HVAC controls strategy such as the use of economizers and variable flow hydronic systems. As previously mentioned, mandating and ensuring compliance is necessary in order to effectively leverage the benefits of ECBC.

Standards and Labelling (S&L)

Currently, RACs are the only space cooling appliance under the mandatory labelling scheme. Ceiling fans and variable speed ACs are under the voluntary labelling scheme. Super-efficient fans have been developed under the Super-Efficient Equipment Program (SEEP) to leapfrog to an efficiency level which will be about 50% more efficient than market average.

Room Air Conditioners (RACs). Significantly improving the Minimum Energy Performance Standard (MEPS) of RACs to an Indian Seasonal Energy Efficiency Ratio (ISEER) of 5.7 by 2026 and up to 7.1 by 2030 can shave nearly 40 GW off peak demand and reduce energy consumption by 64 TWh/year by 2030 (LBNL, 2017). The inflation-adjusted price of more energy efficient RACs has been coming down over the last decade.

India should follow in the footsteps of several countries that are raising RACs' energy efficiency standards aggressively with the objective of having only high efficiency equipment in the market. Japan is one such example where its Top Runner Programme has been able to double RACs' efficiency in 10 years while the inflation-adjusted prices have continued to drop (LBNL, 2017).

EESL recently requested manufacturers to supply 50,000 units with an ISEER of 5.2. It is to be noted that the latest RAC standard that BEE has launched puts the ISEER of 4.5- for 5-star RACs. The lowest price quoted by is on an average 25-30% lower than the average price of the 5-star RACs available to Indian consumers through the retail channel. A noteworthy concern is that there may be a 'rebound effect'. To counter balance this concern, our suggestion is that strategies such as EESL's bulk procurement are better suited for the commercial sector where the rebound effect may not be so magnified. For the residential sector, the emphasis should remain on stricter efficiency standards, coupled with reduced cooling loads through lean cooling strategies. Secondly, the consumers must be made aware that the purchase price of RACs is only about 20% of the total cost of owning a RAC! While a lower purchase price may reduce this 20%, the bulk of the cost of owning an RAC is in the form of year- over-year operating cost.

Air Coolers. Air coolers are widely prevalent in India. The number of air-coolers sold is in the range of 20-25 million units (about 4-5 times the number of RACs). Better engineered products, with a focus on improving both energy and water efficiency, would make a lot of sense in India. TORO WATT, Canada has developed a new space cooling technology, 'Ambiator', which works on indirect direct evaporative cooling (IDEC). It is 50% more energy efficient and 45% more water efficient compared to conventional air coolers and can replace them in hot and dry climate regions.

Ceiling Fans. Ceiling fans accounted for 6% of the energy consumed by residential buildings in 2000 and are estimated to consume 9% by 2020 due to the expected increase in the number of installed ceiling fans (Shah et al., 2015). With the sheer magnitude of number of fans in India, a market-wide labelling program should be explored and implemented to inform better purchasing decisions. At present, the Bureau of Indian Standards (BIS) standard specifies minimum efficacy for various fan sizes, whereas BEE assigns star ratings for only 1 size of fan with 1200 mm sweep, based on minimum efficacy requirements specified by BIS (BEE, 2017).

In April 2016, Energy Efficiency Services Limited (EESL) launched the National Energy Efficient Fan Programme to distribute 5-star rated ceiling fans at lower than market price. With a power consumption of 50 W, 5-star rated fans are 30% more efficient than typical models in the market (Pib.nic.in, 2016), but are not as efficient as brushless DC (BLDC) technology motor fans that consume 30-35 W. The BLDC fans are available in the market with a payback period of about 3 years.

Chillers. ECBC specifies minimum chiller performance efficiency based on AHRI specified test conditions that are more representative of climate found in the US and Europe. Realising the importance of the chiller standard, ISHRAE has taken up the task of developing test conditions, representative of typical climatic conditions found in India, for chillers with the help of RAMA which defines a new set of rating and performance testing conditions for air and water-cooled chillers. ISHRAE has also developed a standard for rating and performance testing of VRF systems. Attempts are also being made to develop standards for AHU, cooling towers and other HVAC components.

While standards and labelling have a strong potential to transform the market towards energy efficient equipment, a concerted and simultaneous effort is required to advance consumer awareness towards effectively utilizing the S&L for purchasing decisions. Consumer education is also important to remove the

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first-cost bias and understand the range of benefits of energy efficient products. Furthermore, enforcing strict compliance with standards and stringency of energy performance thresholds is also key in drawing benefits from S&L efforts.

Low Energy Cooling Technologies

These technologies can be used as either standalone cooling systems or in conjunction with the conventional air conditioning. Examples of low energy cooling technologies include: *Radiant Cooling System.* Maintaining lower indoor surface temperatures enhances radiant heat exchange between human body and indoor surfaces without requirement of circulating large amounts of air. This reduces energy consumption and is the central idea of radiant cooling.

Radiant based HVAC systems provide direct sensible cooling by absorbing heat from people and other surfaces that are at higher temperature in the space, which is taken away by the chilled water flowing in the pipes embedded in floors, walls or ceilings (structure integrated cooling systems), or through externally mounted wall and ceiling panels (panel cooling systems).

Radiant cooling is a relatively new concept in India and its application has been limited to few commercial buildings thus far. Infosys building in Hyderabad is the first radiant cooled commercial building in India and the biggest comparison of cooling systems in the world. The building is a live lab split into two symmetric halves, one half with conventional air conditioning designed per ASHRAE standards and the other with radiant cooling. Data over the last five years show that radiant cooling technology is 30% more efficient than conventional cooling. Energy performance index (EPI) of the radiant cooled building is measured to be about 70 kWh/Sqm/Year, among the lowest in the world for a hot and dry climate like Hyderabad. (Sastry, n.d.)

While the energy savings and efficacy of a radiant system are proven, there are constraints hindering wider adoption. A radiant cooling system needs to be appended with a dedicated outdoor air system to avoid condensation in highly humid conditions, which leads to increased costs. Also, radiant systems are difficult to install in existing buildings: the slab based systems could hinder flexibility with respect to changing space layout, and introduce acoustic concerns; the panel based systems require large ceiling surface area for cooling due to low cooling capacity. These panels also consist of multiple joints and have high pressure drops, making them difficult to install and maintain.

The market is moving towards more cost-effective radiant cooling solutions for the Indian climate. For example, Infosys spent a year developing a panel- based system in-house (Radiflux panels) that cost less than half of the available market products, needs 50% lesser time for installation, are much more efficient, flexible and easily replicable; MNIT, Jaipur is conducting research to increase the efficiency and adoption of radiant cooling systems.

Evaporative Cooling. The evaporative cooling technology is based on heat and mass transfer between air and cooling water. Conventional evaporative cooling is not very effective in humid climate. However, it can be used in humid conditions after the inlet air is dehumidified by suitable mechanisms such as a liquid desiccant system or a desiccant wheel.

Studies conducted by IIT Delhi (Kant and Mullick, 2003) for summer conditions in Delhi showed that an evaporative cooler could provide indoor thermal comfort in April and May in Delhi. However, in more humid months, discomfort can be partly mitigated by using a cooler of 20-40% by-pass factor and adequate flow rate up to 40 air changes per hour to maintain comfort level.

Desiccant Cooling System. A desiccant is a substance, either liquid or solid, which absorbs water molecules from the air and dehumidifies it. Integration with conventional HVAC systems to remove latent heat can reduce energy consumption by up to 30% for cooling and 5% for heating (Sahlot and Riffat, 2016).

Experiments performed in Saudi Arabia and the Persian Gulf Region have given remarkable results in energy saving and effectiveness in controlling temperature and humidity. However, desiccants can fail to reduce the air moisture content to the desired level in very humid climates and maintenance of desiccant cooling systems to deliver peak performance over long periods of time has proven to be challenging as well.

Several other low-energy cooling technologies have been explored in India such as the Earth Air Tunnel Heat Exchanger, Ground Source Heat Pump, and district cooling. While energy efficient, generally the low-energy cooling technologies have some inherent constraints to wider adoption, as the discussion above suggests. These technologies are at different stages of development and some of them have not been adequately explored for Indian climatic conditions. Lack of awareness, scepticism about efficacy in local

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climate, concerns about higher installation costs, or in some case practical reasons such as space limitations have contributed to slow market adoption. Demonstration projects (such as the Infosys success story in radiant cooling), R&D, technology papers, and appropriate policies can support wider adoption of low energy cooling technologies.

Smart HVAC Controls

HVAC control systems can be designed to save energy – this requires knowledge of the building, its operating schedule and the equipment. HVAC controls range from very basic applications to whole building integrated systems. At a very basic level is a system such as Optimum Start/Stop Control (OSSC) that schedules the timings for switching cooling systems on and off such that indoor temperature falls within the limits of acceptability during the period of occupancy without spending excess energy.

Complex HVAC systems can be interfaced with the Building Management System (BMS). Systems linked to a BMS typically comprise 40% of the building's energy usage (and up to 70% with lighting). Upon installation, smarter HVAC controls can increase energy efficiency by 20%. A programmable HVAC control called the Hartmann loop, which increase the efficiency of the system by 20%, is in use for the first time in the country, at the ITC Grand Chola, Chennai (ITC Hotels, 2017). To take full advantage of smarter HVAC controls, it is recommended that well trained facility staff should be deputed to run large central plants and BMS equipment and the inspection and calibration of different meters and sensors be done in a consistent and rigorous manner.

GREEN

Deploying technologies with a low environmental footprint, such as RACs with green refrigerants, solar air conditioning and trigeneration, wherever possible, will have a considerable impact on controlling India's emission levels and contribute towards mitigating climate change.

Green Refrigerants

It is widely understood that a good refrigerant should be non-flammable, non-toxic, and odourless, have very low global warming potential (GWP) and zero ozone depletion potential. Natural refrigerants offer the advantages of zero ODP, a negligible GWP, are part of the natural biogeochemical cycles and do not form persistent substances in the atmosphere, water or biosphere. Natural refrigerants are widely used in some RAC applications, for example isobutane in domestic refrigerators and ammonia in large cooling processes. A green refrigerant would have all the benefits of natural refrigerants and be energy efficient (Green-cooling-initiative.org, 2017). One of the foremost challenges with hydrocarbon based natural refrigerants is the safety concerns arising from the flammability. R-290 is a wonder refrigerant but its chemical composition (hydrocarbon) leads to flammability-related concerns. Lower-flammability-limit related safety standards defined by ISO 5149:2007 address these concerns adequately and all room AC products based on R-290 comply with maximum allowable charge limits set by the relevant ISO or equivalent regional standard.

Many next-generation refrigeration choices are non-flammable with ultra-low GWP that are ideal for chiller applications with larger refrigerant charge sizes or they are non-flammable refrigerant blends with moderate GWP of less than 750. Standards and codes are evolving to balance environmental impacts, safety (flammability and toxicity) and product costs. The HVAC&R industry will perhaps need to adjust product refrigeration charge sizes in many direct refrigeration expansion applications to accommodate these developing standards (Kujak, 2017). Research by WWF-India and CEEW (2014) points out that HC based room ACs are a bit expensive because of new design and safety features, but these are highly energy efficient, such that the lifecycle energy savings offset higher up front purchase costs.

Non-flammable, low-GWP refrigerants in high performance products is an easy path towards environmental goals, however there is lack of clarity on future refrigerants that will meet the goals set by the Paris Agreement and the Kigali Agreement. Industry experts, research organisations, and agencies such as the Ministry of Environment, Forest and Climate Change should take immediate steps to address the lack of clarity on the best set of refrigerants for the future. This may involve developing an evaluation framework or composite rating system to fully acknowledge the climate and environmental impacts of refrigerants, safety considerations, cost, energy efficiency and availability. Additionally, the work of industry experts and organizations such as the United Nations Framework Convention on Climate Change can be leveraged to drive the industry towards green refrigerants.

Solar Air-conditioning

Solar air-conditioning refers to any air-conditioning system that uses solar power. This can be done through passive solar, solar thermal energy conversion and photovoltaic conversion. Solar absorption chillers are very low in operating and maintenance costs and consumes little or no electrical energy. The current market potential for solar air- conditioning is about 0.7 million TR and is increasing at the rate of around 17% per annum (WWF-India and CEEW 2014). There are practical limitations to the widespread adoption of solar air conditioning. Most commonly, these are: site constraints such as inadequate solar radiation or lack of space for the solar panels; and upfront capital costs.

Trigeneration

Trigeneration systems at the end user sites can achieve excellent efficiency by using waste heat recovery system with no transmission losses. They could even supplement peak power demand and reduce damaging power cuts in India if they can sell to the grid. DLF Cyber City in Gurgaon has the CCHP installation with 11 million m^2 total area. DLF has 40 MW of power generation through gas turbines with 17,500 TR of absorption chillers running on waste heat. There are 59 generators with 30-35% efficiency, and 33 chillers are installed with the capability of recovering 85-95% waste heat. After utilizing the waste heat, the total efficiency of the system is shown to increase to 83%.

CASE STUDIES

Prabha Bhavan, MNIT Jaipur

Soon after the ECBC was adopted in Rajasthan, Malaviya National Institute of Technology Jaipur (MNIT, 2014) undertook a pilot project for ECBC compliance. The results have shown that the new building with all energy efficiency measures undertaken is likely to be 30% more efficient over the ECBC. Several measures were applied at MNIT's pilot building to reduce cooling energy demand such as double-glazed window with low U-value (glass - 1.9 W/m^2 °C & wall - 0.72 W/m^2 °C), low SHGC Glass with 0.28 value, heat recovery wheel of 1200 CFM enthalpy wheel, VRF based air conditioning systems with 3.75 COP. After applying all the measures and ECBC, MNIT reduced the EPI from 182 kWh/m^2/year to 128 kWh/m^2/year.

Infosys, Hyderabad

Infosys has achieved enhanced human comfort, and significantly reduced the cooling load and environmental footprint of their building portfolio.

The key outcomes (Infosys, 2017), using 2008 as the baseline year, are:

- 51% reduction in the average per capita energy consumption across their campuses; this is well over $100 Million savings in electricity bills.
- 53% reduction in air conditioning load, without compromising on thermal comfort.
- 62% improvement in campus-wide building energy performance index.

Infosys incorporated several smart cooling strategies such as: radiant cooling (discussed previously in the paper), highly efficient building envelope, and high-efficiency HVAC system with smart automation. After retrofitting and re-engineering 31 chiller plants, Infosys has reduced the number of chiller plants from 54 to 41. The steps taken have freed up almost a third of the space that was previously occupied in the plant room. Retrofits in air conditioning systems have helped Infosys achieve about 15 MW connected load reduction in the last four years.

Aranya Bhavan, Jaipur

Aranya Bhawan, the 14,000 m^2 new office building of the Rajasthan Forest Department in Jaipur, applied a combination of lean, mean and green strategies to enhance thermal comfort and reduce cooling demand. The WWR was maintained at 21%; the roof was insulated with 40 mm of PUF and sandwich brick walls with 50 mm of extruded polystyrene insulation; centralized water-cooled chiller system with COP of 5.8 was used in the building. After applying all the measures the EPI reduced from 77 kWh/m^2 to 43 kWh/m^2 with 44% energy saving.

RECOMMENDATIONS

While there is a wide menu of lean, mean and green cooling strategies available, the adoption of some is easier and more prevalent than the others. Overall, a concerted effort is needed through government support, market enablement, and consumer awareness to bring about a transformative change that will positively impact India's cooling energy demand. Table 1 encapsulates the Coalition's recommendations to promote responsible cooling strategies to effective manage India's cooling energy demand. For each of the recommendations, the paper identifies supporting actions that are grouped per suggested timeframes - short-term: 1 to 3 years, medium-term: 3 to 8 years, and long-term: past 8 year.

Table 1: Coalition's recommendation categorised in short, medium and long terms

	Short Term	**Medium Term**	**Long Term**
Leverage ongoing government initiatives and integrate smart cooling strategies to maximize potential benefits	• Government policies related to Housing for All and Smart Cities should advocate the inclusion of affordable thermal comfort concepts in the housing schemes. • Large and densely populated cities can take leadership and develop programs on actions like cool roofs and cool pavements that would bring about a positive change in heat island effects. • R&D should be encouraged in low energy cooling technologies as well as clean energy cooling technologies focussing on overcoming the engineering and practical challenges that have demonstrated technical potential. • Government Technology Alerts should be developed for low-energy cooling solutions to create awareness in public and end-users and encouraging innovation by providing the carrot in the form of govt endorsement for tried and proven technologies carrying significant potential. • Link subsidies for residential rooftop solar system or bulk-procurement of super-efficient ACs for large developments with significant reductions from baseline cooling load.	• Set up a cool roofs rating council in India which oversees a labelling program for roofing products and rates the reflectivity and emissivity for a particular paint or coating. • Policy framework to enable DISCOMS to implement a DR programme for room air conditioners. • Develop or evolve the existing standards and labelling program for cooling equipment to be based on life-cycle GHG emissions and equipment features.	
Institute comprehensive legislation as a cornerstone to achieve a viable market for smart cooling	• Develop mandatory standards and labelling programs for all ceiling fans. • Enforce stringency of energy performance thresholds • Make standards and labelling mandatory for VRFs and Chillers. • Implementation of ECBC should be made mandatory in all states within the next 12 months.	• Develop variants of ECBC or simplified energy efficiency codes/guidelines to cover small commercial and residential buildings. • Drive adaptive thermal comfort implementation in building design & operation through mandates for code compliance and annual energy performance reporting. • Encourage R&D for more efficient technologies and track the performance of such projects. • Encourage R&D for green technologies such as solar air conditiong and trigeneration.	• Promote a voluntary framework to enable cooling efficiency benchmarks. • MNRE should consider providing financial support and structuring performance based incentives for solar air conditioning and trigeneration.
Generate market momentum towards smart cooling through awareness campaigns, access to information and technical assistance	• Create consumer awareness campaigns to promote and cultivate energy conserving behaviour in space cooling. • Concerted effort to educate customers to make informed product selection based on operational savings versus first-cost. Facilitate market transformation for penetration of labelled products and create awareness about checking the efficiency of the RACs before purchasing. • Sensitize the building professionals - architects, engineers and technicians – towards the need for smart cooling through training and skill development.	• Support educational institutions to provide technical assistance including setting up a centre of excellence for smart cooling strategies.	

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Drive adoption of energy efficient building materials and equipment into mainstream through consistent testing and rating protocols, and market transformation strategies.		• Develop protocols for EE ratings for building materials – wall/floor/roof construction blocks, insulation, paints/coatings/finishes, glazing and whole window systems. • Commission testing labs and enforce performance testing and certification of energy efficient building materials. • Create an open access platform, which maps data of energy efficient and responsibly cooled buildings to act as decision support and enable evidence based policy making.	
Undertake bold actions to phase out HFCs and drive the industry towards green refrigerants	• Government of India should set up an evaluation framework for rating refrigerants, by establishing criteria that send a strong signal to manufacturers towards safeguarding the interest of citizens and the environment. The framework should look at the total global warming potential of the refrigerants. • Facilitate R&D on green refrigerants.	• Design upstream incentive schemes to phase out HFCs.	

CONCLUSION

The criticality of addressing India's space cooling challenge cannot be overstated, particularly against the backdrop of two recent international climate change agreements. First is the Paris Agreement (2015) wherein India, through its Nationally Determined Contribution (NDC), has committed to significantly reduce its emissions intensity. Second is the Kigali Amendment to the Montreal Protocol (2016) wherein India has committed to stop production and freeze use of HFCs by 2028. The Coalition strongly believes that timely and bold intervention to adopt responsible cooling strategies into mainstream will lead us towards significant societal, national and environmental benefits. While the path to get there may be challenging, it is one that must be embraced with conviction. The Coalition has laid down the first steps; now is the time for the policy-making entities at the Centre - such as Ministry of Power, Bureau of Energy Efficiency, Department of Science & Technology, Ministry of Environment, Forest & Climate Change, Ministry of Housing & Urban Poverty Alleviation, and Ministry of Urban Development - and relevant State level departments, - to marshal their resources and policies to lead us towards a responsibly and sustainably cooled built environment.

ACKNOWLEDGEMENTS

We thank the following Sustainable and Smart Space Cooling Coalition members for sharing their insights and expertise towards addressing India's growing cooling energy demand:

Shakti Sustainable Energy Foundation (SSEF): Chinmaya Acharya, Shubhashis Dey, Rana Pujari
Council on Energy, Environment and Water (CEEW): Vaibhav Chaturvedi
CEPT University: Rajan Rawal, Yash Shukla
Collaborative Labelling and Appliance Standard Program (CLASP): Archana Walia, P K Mukherjee
Fairconditioning: Vivek Gilani
ICLEI - Local Governments for Sustainability, South Asia: Ashish Verma
Indian Society of Heating, Refrigerating and Air-conditioning Engineers (ISHRAE): Sachin Maheshwari, Ashwini Mehra
Malaviya National Institute of Technology (MNIT): Jyotirmay Mathur
Natural Resources Defense Council (NRDC): Sameer Kwatra, David Goldstein, Karan Chouksey
Prayas (Energy Group): Aditya Chunekar
Smart Joules: Arjun P. Gupta

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IMPACT OF CLIMATE CHANGE ON BUILDING ENERGY CONSUMPTION

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Keywords: Climate change; Residential buildings; Building simulation; Energy consumption; Future weather files, Test Reference

ABSTRACT

We are witnessing climate change and this change is expected to impact the indoor thermal comfort and building energy consumption. Similar to this, a study conducted in Brazil has predicted an increase in the annual energy demand ranging from 19-65% in residential buildings. Also, a study conducted in Finland predicted 40-80% increase in energy demand for cooling in residential buildings. In addition, several other countries have also predicted that the change in weather conditions affected energy consumption and thermal comfort in buildings. Therefore, the present study assesses the impact of climate change on building energy consumption by considering an example of a residence in Hyderabad.

A multi-dwelling residential block (G+4, 4 housing units/floor) located in a composite climate of India is chosen for the study. The residential block model is developed in Design Builder and simulations are run for Present-Day weather file in Typical Meteorological Year-2 (TMY2) format. Building models are also simulated using weather files of 2020, 2050 and 2080 of TMY2 format considering an A2 scenario, proposed by Intergovernmental Panel for Climate Change (IPCC).

This study infers that the energy consumption due to climate change increases by 4.28% in 2020, 8.11% in 2050 and 13.83% in 2080 for the “as built” case under 250C thermal comfort set point and 2.76% in 2020, 4.93% in 2050 and 8.24% in 2080 for the “as built” case under adaptive thermal comfort set points. Further, the study recommends retrofit measures which have a potential to reduce energy consumption by 30.9%, 29.95%, 29.11% and 28.00% for the present day, 2020, 2050 and 2080 climate scenarios under 250C thermal comfort set point and 33.37%, 32.77%, 32.27% and 31.55% for the present day, 2020, 2050 and 2080 climate scenarios under adaptive thermal comfort set point.

INTRODUCTION

Intergovernmental Panel on Climate Change (IPCC) in its fifth assessment report (AR5) by Revi, A. et al., 2014 projected future global mean temperature increase of 4^0C. The report also states that with rising urban population in low, middle and high-income nations, climate change hazards are more likely to be faced in urban areas. The rising air temperatures in urban areas due to climate change and Urban Heat Island (UHI) effect are expected to cause the rise in building internal temperatures. In such cases, to maintain thermal comfort in indoor temperatures, occupants will increase the use of cooling appliances leading to increased energy consumption and demand.

According to International Energy Outlook 2016 (IEA, 2016), the world’s residential energy consumption would increase by 48% from 2012 to 2040. Frank, T., 2005 has predicted 33-44% decrease in annual heating energy and also increase in cooling energy for Switzerland residential buildings for period 2050-2100. Radhi, H., 2009 has deduced that global warming is likely to raise the energy required for cooling by 23.5% for UAE residences. Asimakopoulos, D.A. et al., 2012 for the period 2010-2100 have predicted a decrease in heating energy demand by 50% and an increase in cooling energy demand by 85% for Greece residences. Similarly, Chow, D.H.C., Kelly, M. & Darkwa, J., 2013 for China, Dodoo, A., Gustavsson, L. & Bonakdar, F., 2014 for Sweden, Jylh, K. et al., 2015 for Finland and many other studies representing various countries predicted an increase in cooling energy demand for residences.

All the studies referred above have studied the impact of climate change on residential energy demand using Building Simulation (BS), Degree Day (DD) and Thermal Electrical Analogy (TEA) methods. In most of these studies, BS method is widely deployed. Simulation tools like Design Builder, HELIOS, Visual DOE, TRNSYS, VIP+, IDA-ICE, and EnergyPlus were used. DD method

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followed by Christenson, M., Manz, H. & Gyalistras, D., 2006, Semmler, T. et al., 2010, Yi-ling, H.O.U. et al., 2014 and Olonscheck, M., Holsten, A. & Kropp, J.P., 2011 predicted the future air temperatures for predicting the energy demand. In BS method, Typical Meteorological Year weather file format for future is used. This weather file consists of parameters such as air temperature, Wind Speed, and Direction, pressure solar radiation including direct and horizontal, and humidity. In comparison to BS method, the DD method does not consider the heat losses or gains by fabric, equipment and appliance load in calculating cooling or heating load required. However, the methodology used by Olonscheck, M., Holsten, A. & Kropp, J.P., 2011 considered the losses and gains in DD method. The TEA method used by Andri, I. et al., 2016 used resistance – capacitance (RC) model based heat transfer algorithm instead of building energy simulation tools.

Many studies have been conducted in countries like USA, Germany, Sweden, Switzerland, Finland, Brazil, Taiwan, and China and so on. The present study analyses the impact of climate change on energy demand in Hyderabad mid-rise residential apartment.

Hyderabad is located in the composite climate and the building chosen for the study is a faculty residence quarter located in International Institute for Information Technology (I.I.I.T), Hyderabad. The study used Building Simulation approach to analyze the impact of climate change on the building energy consumption. In addition, the building is simulated is also simulated considering few retrofit measures in equipment and envelope to identify the change in energy consumption compared to the As-Built scenario.

METHOD

SIMULATION TOOL

In this study, DesignBuilder (DB) is used to model the residences to identify the Energy Use Intensity (EUI) of the residence. This graphical user interface (GUI) uses EnergyPlus (EP) as computing engine to perform building energy simulations. However, to reduce the effort, both as-built case and retrofit case models have been developed in DB and respective Input Data Files (IDF) have been exported to conduct group simulations with multiple weather files.

CLIMATE DATA

‘Present-day’ weather file

The present study uses EP weather (‘.epw’) file obtained from the EP database. This is generally available in Typical Meteorological Year-2 (TMY2) weather file format that consists of data sets with hourly values of solar radiation, air temperature, humidity, pressure, wind speed, and direction. The TMY method was developed by National Renewable Energy Laboratory (NREL). The future weather files will also be required in the same format for analyses. The future files are developed according to the Anon, 2000. IPCC Special Report Emissions Scenarios (SRES).

Emission Scenarios

Climate change is caused due to Green House Gas (GHG) emissions produced by anthropogenic activities. IPCC has developed 40 emission scenarios to address climate change mentioned in SRES. These scenarios are developed based on the technological and economic development. These emission scenarios are arranged into six families according to Third assessment report. The A1 scenario is characterized by rapid growth in the economy, population, and technology. It is classified into A1F1 (Fossil intensive), A1B (Balanced) and A1T (Non- Fossil Energy). A2 is considered for regionally oriented economic development with increasing population yet independently operating, self-reliant nations. All the assumptions consider the increased consumption rate of fossil fuels except for B1 considering lower level consumption in 2100 compared to 1990. However, the B2 scenario has also increasing population like A2 but at a slower rate with medium economic and less rapid technological change. Hyderabad located in India has rapidly increasing heterogeneous community with vast technological development. However, it has regionally oriented economic development signifying A2 scenario for future climate predictions.

Climate Models

Aerosol contents in the atmosphere impact natural cyclic activity between hydrosphere, biosphere, and atmosphere. The emissions scenarios predicted by SRES provide brief input to develop Atmosphere-ocean General Circulation Models (AOGCM’s). These models represent the interaction between Atmosphere, Biosphere, and Hydrosphere dividing the earth into imaginary grids. This grid with a spatial resolution of 200-500kms provides inputs to develop future weather files. Meteorological research centers around the world are developing models. Table-1 shows few models and research centers mentioned in IPCC Data Distribution Centre (DDC).

Table 1: General Circulation Models

MODELS	
CSIRO	Australia's Commonwealth Scientific and Industrial Research Organisation.
CCCma	Centre National de Recherches Meteorologiques, France
HadCM3	UK Met. Office
MPI-M	Max-Planck-Institute for Meteorology, Germany
BCC	Beijing Climate Centre, China
BCCR	Bjerknes Centre for Climate Research, Norway
MPIM	Max Planck Institute for Meteorology, Germany
LASG	Institute of Atmospheric Physics, China
GFDL	Geophysical Fluid Dynamics Laboratory USA
INM	Institute for Numerical Mathematices, Russia

'Future weather files

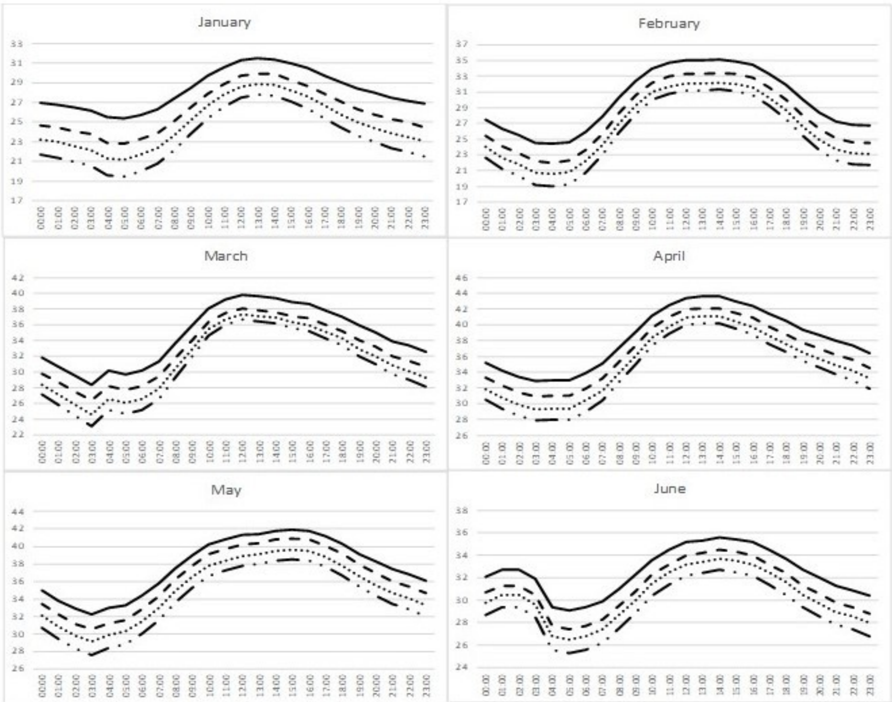
The future weather file data sets are generated using Climate Change World Weather File Generator V1.8 tool (CCWorldWeatherGen). The tool is developed by the University of Southampton which allows generating future weather files for the scenarios proposed by IPCC. The tool works on Microsoft Excel interface, uses the data of Hadley Centre Coupled Model, Version 3 (HadCM3). The HadCM3 A2 experiment ensemble data is available from IPCC DDC.

HadCM3 is Atmosphere-Ocean General Circulation Model (AOGCM) coupled. It is developed by Hadley

Centre in the United Kingdom, one of few major models used in IPCC Third Assessment Report (TAR). The tool uses the coarse General Circulation Model (GCM), 'present day' weather file and morphing technique to produce hourly weather files in the TMY2 format for A2 emission scenario.

This study generates the weather files based on the information from Jentsch, M.F., 2012. Technical reference manual for the CCWeatherGen and CCWorldWeatherGen tools Version 1.2 provided on the official website. Morphed EPW file of A2 emission scenario for 2020, 2050 and 2080 is produced using weather file of Hyderabad obtained from Energy Plus website.

The present day weather file has maximum Dry Bulb temperature of 41.2^{0}C. However, weather files projected for 2020, 2050 and 2080 show maximum DBT of 42.2^{0}C, 43.5^{0}C, and 44.3^{0}C respectively. Figure 1 below displays the variation in DBT projected in 2020, 2050 and 2080 with respect to present-day weather on the 15th day of every month.



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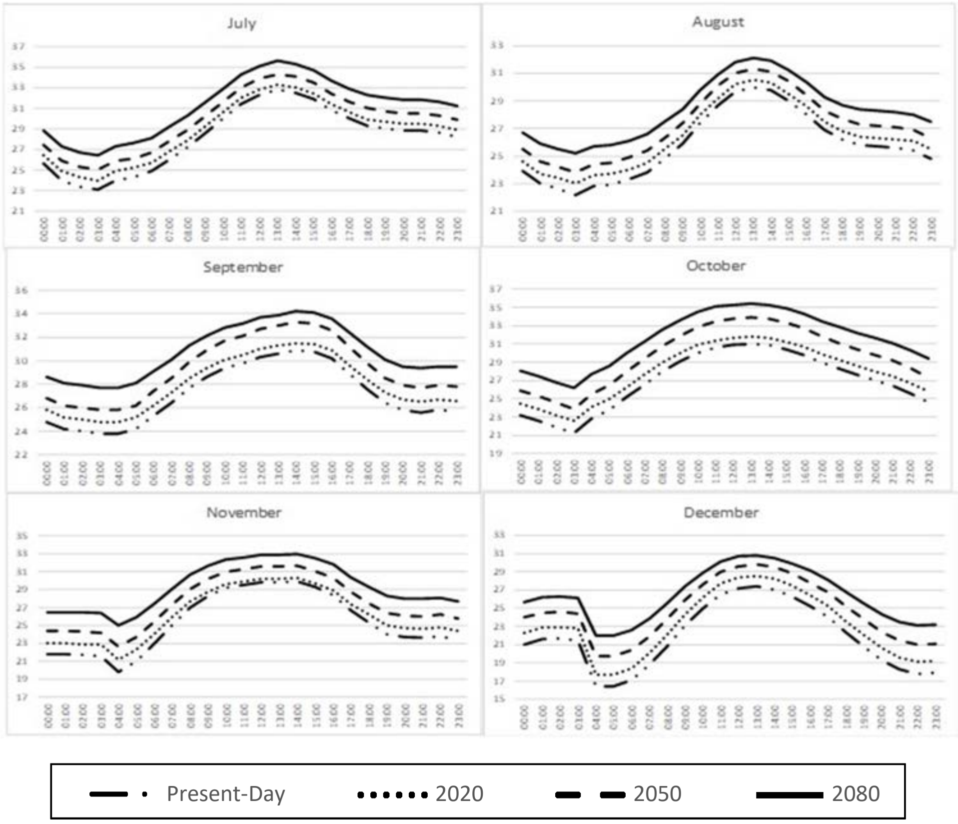

Figure 1: Ambient Temperature on 15th day of every month according to present-day, 2020, 2050 and 2080 weather files

BUILDING AND EQUIPMENT DATA

Anand Nivas, the faculty residential quarters has a total built-up area of 4,392.837 m^2 with total corridor area of 688.595 m^2. Architecturally, the apartment has two Bedroom, Hall and Kitchen residences (2- BHK) with 134.63 m^2 carpet area and three Bedroom, Hall and Kitchen residences (3 BHK) with Hyderabad apartments have adapted to temperatures between 27^0C and 32.5^0C. So, two scenarios one with the fixed thermal set point of 25^0C and other with adaptive thermal set point based on equation (1) given ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) standard 55 have been considered for the study155.39 m^2 carpet area. Figure 2 shows the floor plan of the residential apartment. Ten- two bedroom and

$$T_{comf} = 0.31 \text{ X } T_{mmo} + 17.8 \quad (1)$$

ten- three bedroom residences are arranged in a five-floor structure including ground (G+4).

The building is concrete framed structure enveloped with burnt clay bricks for external and internal walls. Material properties of the envelope and equipment loads in the as-built case is mentioned in Table 2. To assess the impact of envelope retrofit on building energy demand, a retrofit case model is also developed, the envelope properties and equipment loads that have been changed from the as-built case are shown in Table 3.

THERMAL COMFORT SETPOINT

In general, the air temperature between 24^0C and 26^0C with relative humidity between 40% and 50% is considered to be thermal comfort conditions. A study conducted by Madhavi Indraganti (Indraganti, M. & Rao, K.D., 2010.) has inferred that the people in Table 2: As-built case, envelope and equipment load properties

BUILDING COMPONENT	THERMAL PROPERTIES
External wall	U-value -2.514 W/m^2K + Solar reflectance -0.3
Roof	U-value - 3.937 W/m^2K+ Solar reflectance -0.3
Floor	U-value - 3.00 W/m^2K
Glazing	3mm clear
Shading	Overhang – 0.45
Lighting	32 W (T8 fluorescent)
Fan	56 W (3-star)
Audio	85 W
LCD	172 W
Water Heater	2000 W
Exhaust Fan	50 W
Micro Oven	3400 W
Refrigerator	600 W
Mixer	600 W
Kitchen Miscellaneous	500 W
Packaged Terminal Air Conditioner (PTAC)	COP – 3.00

Table 3: Retrofit case, changed envelope and equipment load properties

BUILDING COMPONENT	THERMAL PROPERTIES
External wall +cool paint	U-value -2.514 W/m^2K + Solar reflectance – 0.7
Roof + cool paint	U-value - 3.937 W/m^2K+ Solar reflectance – 0.7
Glazing	6mm clear
Shading	Overhang – 0.45
Lighting	28 W (T5 fluorescent)
Fan	55W (4-star)
Water Heater	Solar
Refrigerator	500 W

DISCUSSION AND RESULT ANALYSIS

CLIMATE PREDICTION ANALYSIS

In Figure 3, we can observe that the minimum and maximum degree Celsius of ambient air temperature is increasing from present day to 2080. In addition, we can also observe the increase in positive skewness and kurtosis (peak) in future climate scenario. From these observations, we can infer that the internal air temperature in the residences might increase in future and the need for cooling appliances with higher loads might increase.

BUILDING ENERGY CONSUMPTION

When thermal comfort set point is considered to be 25^0C

The EUI of the residence increases from 42.07 $kWh/m^2/year$ to 47.89 $kWh/m^2/year$ with a standard deviation of 2.47 from present day to 2080 in the case of as-built as shown in Figure 4.

Whereas in the case of a retrofit, the EUI of the residence increases from 29.07 $kWh/m^2/year$ to 34.48 $kWh/m^2/year$ with a standard deviation of 2.30 from present day to 2080 as shown in Figure 4.

However, the deviation in energy consumption between the as-built case and retrofit case from present day to

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2080 is increasing from 9.19 to 9.48.

When adaptive thermal set point is considered

The EUI of the residence increases from 38.36 kWh/m^2/year to 41.52 kWh/m^2/year with a standard deviation of 1.34 from present day to 2080 in the case of as-built as shown in Figure 4.

Whereas in the case of a retrofit, the EUI of the residence increases from 25.56 kWh/m^2/year to 28.42 kWh/m^2/year with a standard deviation of 1.21 from present day to 2080 as shown in Figure 4.

However, the deviation in energy consumption between the as-built case and retrofit case from present day to 2080 is increasing from 9.05 to 9.26.

Analysis on Total Energy Consumption

In both the thermal comfort scenarios, the consumption in the retrofit case and the as-built case is increasing. But the rate of increase in energy consumption for the as-built case is high compared to retrofit case especially when the thermal set point is considered to be 25^{0}C.

COOLING ENERGY END USE

When thermal comfort set point is considered to be 25^{0}C

The study predicted that the end energy consumption for cooling increased from 35357.73 kWh/year in present day scenario to 55495.04 kWh/year in 2080 scenario with standard deviation of 8554.37 in as-built case as shown in Figure 5. In the case of retrofit, the consumption raised from 29278.69 kWh/year in present day scenario to 48065.42 kWh/year in 2080 scenario with standard deviation of 7986.69 as shown in Figure 5.

When adaptive thermal set point is considered

The study predicted that the end energy consumption for cooling increased from 22967.71 kWh/year in present day scenario to 34032.21 kWh/year in 2080 scenario with standard deviation of 4680.58 in as-built case as shown in Figure 5. In the case of retrofit, the consumption raised from 17577.42 kWh/year in present day scenario to 27624.90 kWh/year in 2080 scenario with standard deviation of 4256.10 as shown in Figure 5.

Analysis on Cooling Energy Consumption

In the case of adaptive thermal set point and 25^{0}C thermal set point scenarios, the mean deviation between as-built case and retrofit case is 4176.92 kWh/year and 4763.74kWh/year respectively.

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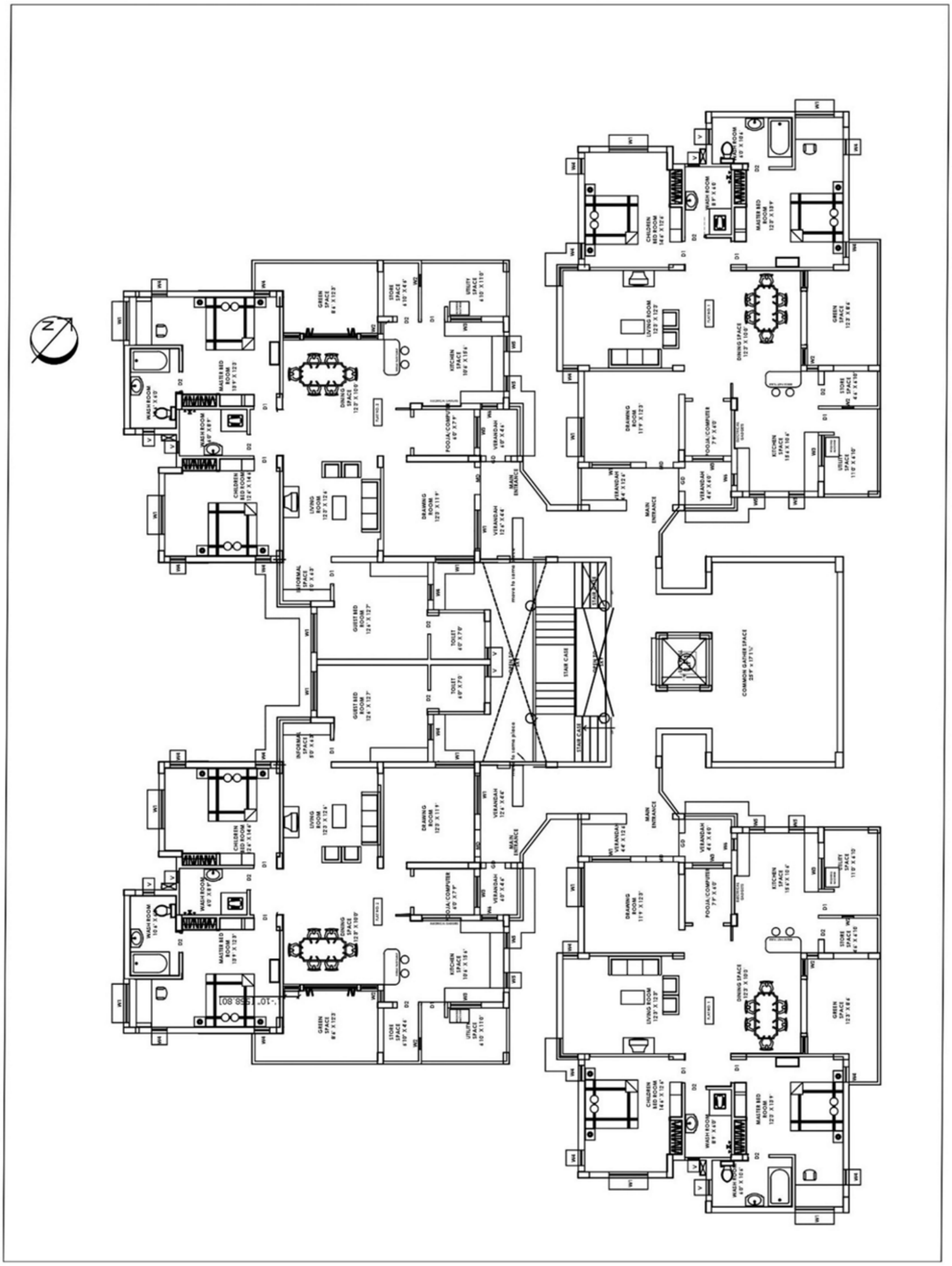

Figure 2: Floor plan of Anand Nivas

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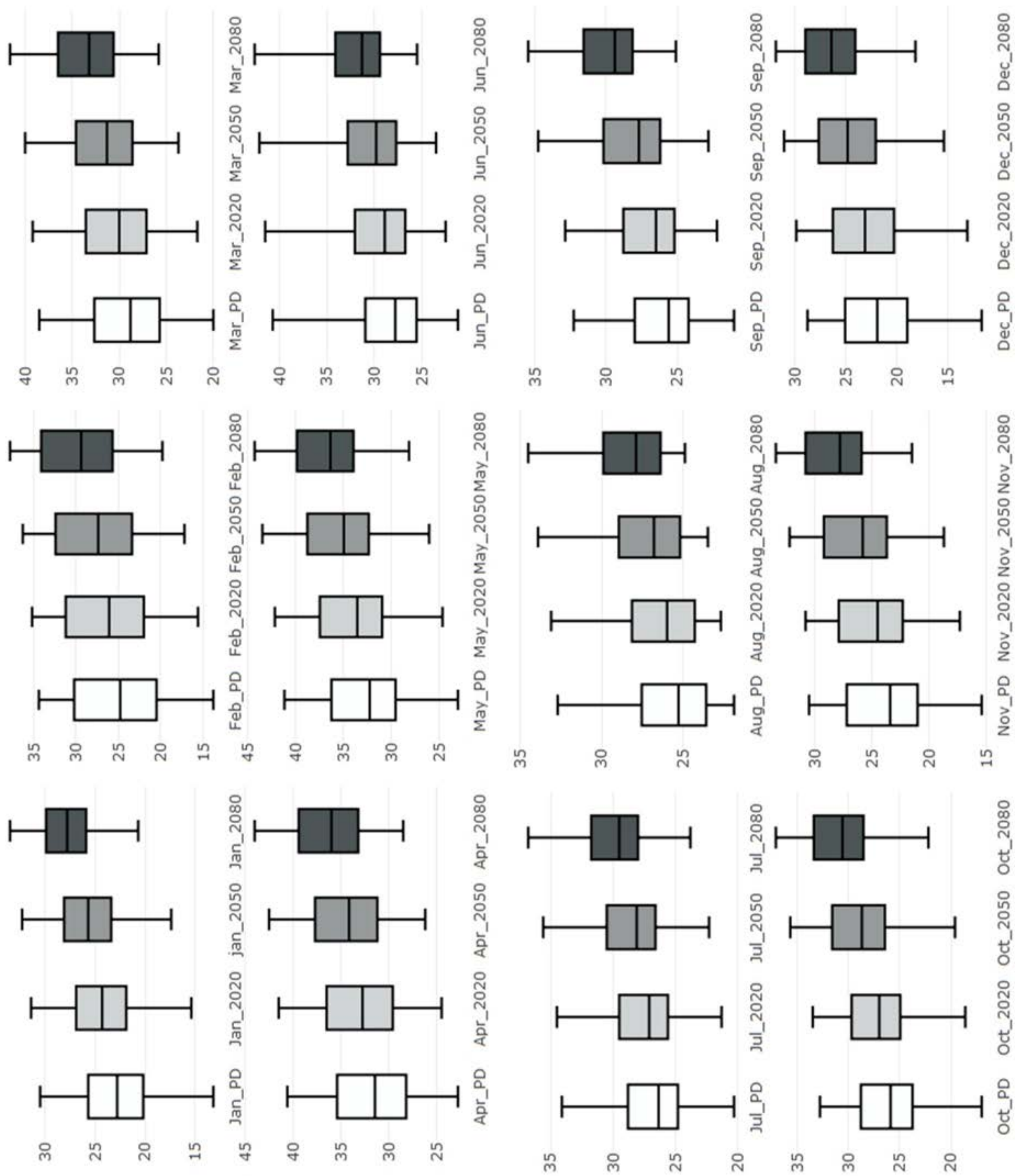

Figure 3: Box plotter showing the varying range, skewness and kurtosis of ambient air temperature predicted in comparison with ambient air temperature in present-day weather file.

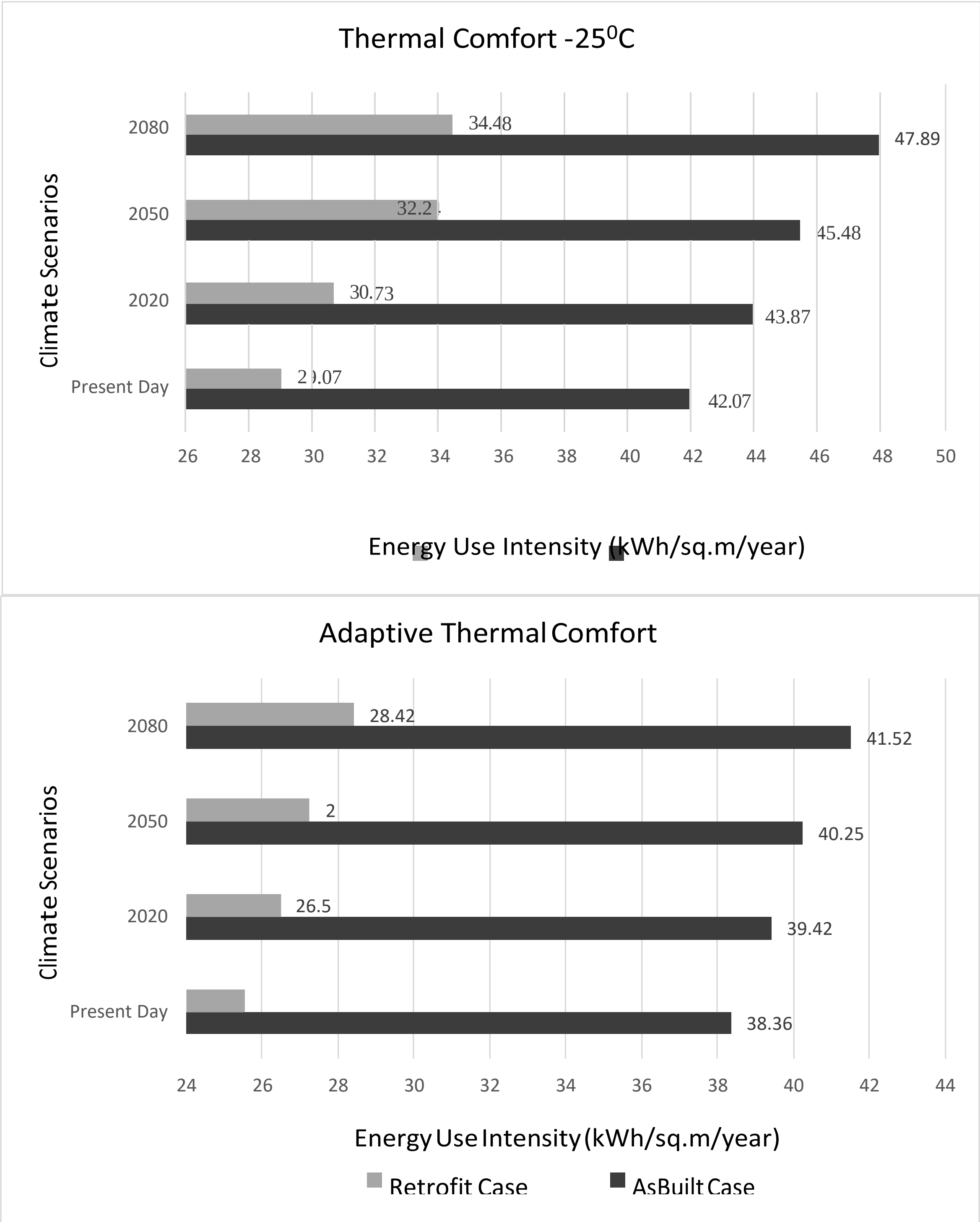

Figure 4: Energy Use Intensity of Anand Nivas

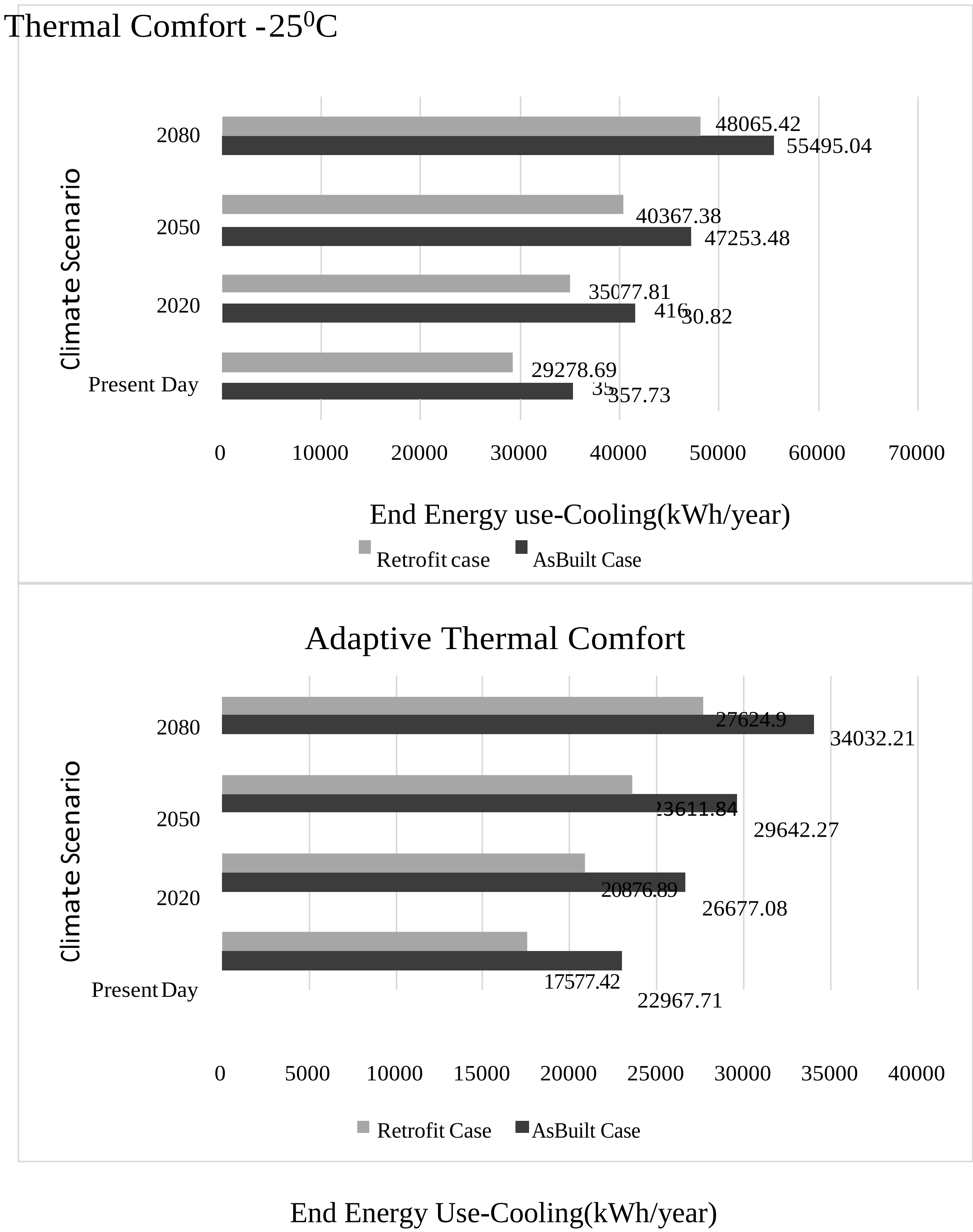

Figure 5: Energy End Use-Cooling of Anand Nivas

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TOOLS AND RULES-OF-THUMB FOR PASSIVE DESIGN STRATEGIES FOR INDIAN CLIMATIC CONDITIONS

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Keywords: Passive design strategies, climate zones, climate responsive building design, design guidelines, rules of thumb

ABSTRACT

Energy required by the building sector in India accounts for 33% of the national energy use. Climate- responsive design can drive the building sector in India towards a low energy future because including passive design approaches and materials can decrease cooling by 60%–90% for new buildings and 50%– 90% for retrofits. Different passive design strategies are applicable for the 5 climate zones in India.

This study uses literature to identify prescriptive approaches to passive design strategies along with published rules of thumb. Of the 45 strategies identified through the literature research, only 19 were found to have rules-of-thumb that help sizing of building elements during design. For the 45 strategies, a Strategy Index for India is compiled, which includes the rules-of-thumb where available, applicable climatic as well as building conditions. Where specific values for climate conditions relevant to the strategies are not found and only generic climatic conditions, such as Hot-Dry, Warm-Humid or cold are found, the specific climatic conditions are derived by cross-referencing the climate zone definitions and their threshold values from the literature. However, when this approach is applied to TMY weather data of Indian cities, it leads to recommendations that do not correspond with the strategies found in those cities. This analysis is presented in the paper. A monthly climate assessment method is proposed, which enables building designers to select passive design strategies that respond to seasonal variations within a climate. A Strategy Decision tool is formulated to help building designers select strategies that are applicable based on the local weather data and site conditions. Taken together, the Strategy Decision tool and the Strategy Index can be an important toolkit for building designers in India.

INTRODUCTION

In a building designed with passive design strategies, the architectural elements including windows, walls and floors are designed in such a manner that they accumulate, store, and distribute sun's energy in the form of heat in winter and reject that heat during the summer. The basic approach for designing a building with passive design principles is to take advantage of the local climate. Some of the design decisions that need to be considered for passive design are building layout, orientation, spacing between building blocks; size and position and protection of the openings; glazing type; assemblies of walls, floors, roofs, which include thermal insulation, thermal mass, and; shading and other external features. Over many centuries, people in all the five climate zones of India have developed examples of building designs and techniques that provide more or less comfortable living conditions without the use of sophisticated technical devices (Bansal, 1995). However, the application of these building design strategies is not common in contemporary architecture. Literature sources provide passive design guidelines and recommendations for each of India's climate zones. However, most of these sources provide simple recommendations based on broad generalization of climate zones. As a result, designers are either left with the choice of simple recommendations based on climate zone descriptions, or using sophisticated analysis and simulations. Most architects hesitate to use simulations because they require specific expertise and are time consuming. The study limits its focus on the prescriptive approaches found in the literature for residential buildings in India, as they are more accessible, easy to understand and less time consuming. Each literature source is reviewed for the prescriptive information available for each strategy, the climate conditions it relates to, and any site or building conditions that it is dependent on. The focus on literature allows structuring the identified strategies for passive heating and cooling along with rules of thumb in to a Strategy Index that is assisted by Strategy Decision tool. This Decision tool uses the average monthly climate data for Indian locations and its usability is tested. For an easy analysis of the climate data of locations a Climate-to-Strategy Mapping tool is also developed. The proposed Strategy Index and the

Decision-Making tool will be useful, especially in the early stages of residential building design when important design decisions can help reduce heating and cooling loads on mechanical systems.

NOMENCLATURE

RoT = Rule of thumb
DBT = Dry Bulb Temperature *WBT* = Wet Bulb Tempearture *DV* = Diurnal Variation
SC = Sky Condition
RH = Relative Humidity

LITERATURE REVIEW

Literature review is used to identify the principles behind passive design strategies, prescriptive recommendations available in the literature, and related climate conditions. It also identifies the gaps in the literature. This led to the identification of 45 passive design strategies and their related RoTs and recommendations. These strategies are classified under the following headings:

- Passive Cooling
  - Comfort Ventilation
  - Radiant Cooling: Direct and Indirect
  - Evaporative cooling: Direct and Indirect
  - Nocturnal Ventilation
  - Earth Cooling
- Passive Heating
  - Direct Heat Gain
  - Indirect Heat Gain
  - Isolated Sunspaces

This synthesized information on each of the 45 strategies in the index is composed under the following subheadings:

- Strategy name
- Diagram with Rule of Thumb or Recommendation
- Climate conditions (under which the strategy is applicable)
- Site conditions/constraint (relevant)
- Objective
- Building system (component)
- How it works
- Sources
- Notes (if any)

A sample strategy sheet is presented in Appendix B. Observations from the literature research are as follows.

Prescriptive Recommendation and RoTs for Passive Design Strategies

Varying information is available for RoTs of some strategies. The values for sizing the building elements in the RoTs vary between different sources.

- Some RoTs require heat gain calculations to calculate the size of the building component. The values available from the reviewed sources cannot be used for Indian locations and some work to develop these values is needed.
- Most sources give recommendations for passive design but only four sources have sizing information with RoTs. Of the 45 strategies identified for India under the different approaches adopted for passive heating and cooling:
- 19 strategies have values for sizing the building elements with RoTs.
- 12 strategies have recommendation with values as sizing information for the building elements without RoTs.
- 14 strategies have simple recommendations for strategies.

Climatic Conditions for Passive Design Strategies

Bansal & Minke, (1995) classify the Indian climate based on the then available monthly mean values of over 36 years, recorded for 233 stations located across India. They classify India into six climate categories labelled as Hot and Dry, Warm and Humid, Moderate, Cold and Cloudy, Cold and Sunny and Composite (appendix A). Categories other than Composite need the defined conditions (refer table in appendix A) to prevail for more than 6 months. However, Nayak & Prajapati (2006) observed that any location does not experience the same climate for the whole year. Therefore, it is difficult to identify strategies for a location in India using climate zone definitions alone (see appendix A) because a location can experience different seasons at different times in a year that would prevail for different lengths of time. This may lead to different or additional passive strategies to be considered for a climate zone. Thus, there is a need to identify the climatic applicability of passive design strategies at the granularity of a season or a month.

- Of all the sources referred, 8 sources have strategy recommendations based on climate zone classification (generic conditions) and only 4 sources link the strategies to more specific climate conditions. However, because of higher temperatures experienced in India, not all the strategies can be applied. A total of 45 strategies were identified when their related climate conditions exist in India. Givoni (1994), gives specific climate conditions, Lechner (2015) gives specific as well as generic conditions, whereas

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other sources provide only generic conditions. Of the 45 strategies identified for India,

- 23 are recommended based on generic climate conditions.
- 8 out of 45 strategies have specific climate conditions.

When absolute values for climatic conditions applicable for a strategy are not found in the literature and climate zone based recommendations (such as Hot and Dry, Warm and Humid, or Cold) are found, the specific conditions are derived by cross referencing the threshold values for climate zones for India from Bansal & Minke (1995), and other conditions from Givoni (1994). The climate parameters that determine the applicability of a strategy for a location are its dry bulb temperature, relative humidity, sky cover, diurnal variation and wet bulb temperature. Using the threshold values from the literature, the following conditions are compiled for applicability of passive design strategies to India:

- Passive Cooling is applicable when the average monthly DBT > 30°C.
- Passive Heating is applicable when the average monthly DBT < 25°C.
- Night-flush ventilation (nocturnal) is applicable when the average monthly DBT > 30°C and RH < 55% and DV > 10°C.
- Evaporative cooling is applicable when the average monthly DBT > 30°C and RH < 55% and WBT < 24°C.
- Comfort Ventilation is applicable when the average monthly DBT > 30°C and RH > 55% and DV < 10°C.
- Radiant Cooling is applicable when the average monthly DBT > 30°C and RH< 55% and DV > 10 and SC < 33%.
- Earth cooling can be applied when the mean annual temperature of a location is less than 15°C and DBT > 30°C.
- Heat gain (Direct, Indirect and Isolated Sunspaces) can be applied when average monthly DBT < 25°C.

These climatic conditions are presented for each strategy in the Strategy Index developed for all the 45 strategies.

TOOLS DEVELOPED

STRATEGY DECISION TOOL

The study proposes a tool that helps architects select relevant strategies. Strategies found in the literature and the conditions for their applicability were analysed to construct a logic for the selection of a strategy. The strategies were grouped and organized in to a Strategy Decision tool. The Strategy Decision tool is a horizontal and a vertical classification of passive design strategies that uses clades, leaves, nodes and flowchart symbols. Each branch in the Decision tool is a consequence of the test conducted at the previous node. The tool leads the user down a decision tree using average monthly weather data and site conditions. It helps the user arrive at the applicable strategy. The Strategy Decision tool measures 10’x4’. It is compressed into seven A4 sheets. Two sheets are provided in Appendix E as a sample.

The Strategy Decision tool and the Strategy Index were tested by five architects to evaluate usability. The architects provided verbal feedback based on their use of the tools. This feedback was used to refine the tools.

CLIMATE-TO-STRATEGY MAPPING TOOL

The logic connecting the strategies with the climatic conditions compiled in this research was encoded in a Microsoft Excel tool. The input for this tool are relevant statistics of hourly weather data exported from Climate Consultant (see Appendix C for an example). The output from the tool is a table that shows the number of months a strategy is considered applicable based on the climatic conditions (Appendix C). Once the user identifies the number of months from this Climate-to-Strategy Mapping tool, the user can write the month counts in to the Strategy Decision tool. While the Climate-to-Strategy Mapping tool does not give a direct recommendation on the applicability of a strategy, the month counts help the user determine the weightage to be given to any strategy for its applicability. This approach leaves the final decision to the user, and provides flexibility in decision-making that allows the user to select more than one strategy that may be applicable during different seasons.

Testing the Tool

TMY weather data[1] for 12 locations[2] are used to test the Climate-to-Strategy Mapping tool and the resultant strategy recommendations that result from the use of the thresholds for the climatic conditions. These 12 locations span all 5-climate zones. Table 1 shows the analysis of the average monthly values of the TMY Data based on identified climate thresholds. Table 2 shows the applicable passive strategies for these 12 locations based on the thresholds discussed in the previous section and Table 2 summarizes the outputs for the Climate-to-Strategy Mapping Tool. The values in the table are the number of months in a year in which these strategies are applicable.

Observations

The results in Table 2 show that Sundernagar, Shillong, Pune and Bangalore require passive heating for 9, 12, 8 and 9 months in a year respectively, implying the applicability of direct, indirect and isolated sunspaces. Allahabad and Delhi require passive heating for 5 months each and passive cooling for 3 months each in a year. Night flush ventilation, evaporative cooling and radiant cooling are also applicable for 2, 1 and 1 month respectively. However, comfort ventilation is not applicable in Allahabad while it is applicable in Delhi for 1 month. And earth cooling is not applicable in both the cities. Passive heating is applicable in Chennai for 2 months and passive cooling for 4 months only. And night flush ventilation, evaporative cooling, radiant and earth cooling are not applicable in Chennai. However, comfort ventilation is applicable in Chennai for 4 months. Passive heating is applicable in Trivandrum and Mumbai for 3 months each and passive cooling for 2 and 1 month respectively in a year. Night flush ventilation, evaporative and radiant cooling are applicable only for 1 month in Trivandrum in a year while comfort ventilation and earth cooling is not applicable at all. Similarly, the results for Mumbai show that night flush ventilation, evaporative cooling, radiant cooling and earth cooling are not applicable in Mumbai and comfort ventilation is applicable only for 1 month. Results for Jaisalmer show that passive heating and cooling are applicable for 5 and 6 months respectively in a year. However, night flush and radiant cooling are applicable only for 3 months, while evaporative cooling and comfort ventilation are applicable for 2 months each in a year. The table shows that passive heating and cooling are applicable in Ahmedabad for 3 months each. Night flush ventilation, evaporative and radiant cooling are applicable only for 1 month each and comfort ventilation and earth cooling are not applicable for any month of the year. Analysis for Aurangabad shows that passive heating and cooling is applicable for 5 and 2 months each respectively in a year. While night flush ventilation, evaporative and radiant cooling is applicable for 2 months each, comfort ventilation and earth cooling are not applicable. The earth-cooling column shows zero for all the locations because either the location does not require cooling or the annual mean temperature for these locations is not less than 15°C. This is because passive cooling is not required in Shillong, Sundernagar, Bangalore and Pune and therefore earth cooling is also not required; while in case of other cities, the mean annual temperature is not less than 15°C and hence earth cooling is not applicable.

Overall, the passive heating numbers seem higher than the author's understanding of Indian climates, and the passive cooling numbers seem low.

Consultation with a panel of experts on results from the Climate-to-Strategy Mapping Tool.

The results in Table 2, led to recommendations that do not correspond with the author's understanding of the strategies relevant to those locations. To validate this, interviews with a panel of experts were conducted.

The summary of results of all 12 locations was presented to a panel of 9 architects experienced in the area of passive design. These architects were asked to review the number of months a strategy was applicable. If their opinion was different from the results of the Climate-to-Strategy Mapping tool they were asked to write in the number of months they thought the strategies were applicable for that location.

Observations from the interviews:

- The results from the Climate-to-Strategy Mapping tool show a higher need for passive heating than passive cooling for these 12 cities. However, responses from the architects show a higher need for passive cooling than passive heating.

[1] TMY weather data is commonly used by architects in the design stage analysis of the climate of a location.

[2] Cold: Sundernagar, Shillong. Temperate: Pune, Bangalore. Composite: Allahabad, Delhi. Warm-Humid: Chennai, Trivandrum, Mumbai. Hot-Dry Jaisalmer, Ahmedabad, Aurangabad.

- There are differences between the results of the tool and the opinions of the architects for all the cities.
- There are differences between the opinions of the architects for the number of months of applicability of strategies for a city.
- Two architects did not agree with the results from the tool, but declined to provide their own numbers.

Table 1: Analysis of the average monthly values from TMY Data based on identified climate thresholds. The values are the number of months a condition is satisfied.

City / Location	Average Monthly DBT>30°C	Average Monthly DBT<25°C	25°C< Average Monthly DBT<30°C	Average Monthly RH >55%	Average Monthly DV >10°C	Average Monthly WB<24°C	Average Monthly SC <33%
Sundernagar	0	9	3	10	8	12	4
Shillong	0	12	0	12	7	12	2
Pune	0	8	4	9	7	12	6
Bangalore	0	9	3	9	5	12	4
Allahabad	3	5	4	9	9	7	6
Delhi	3	5	4	9	9	8	8
Chennai	4	2	6	12	0	5	0
Trivandrum	2	3	7	7	10	9	10
Mumbai	1	3	8	12	5	5	6
Jaisalmer	6	5	1	3	10	9	10

Ahmedabad	3	3	6	7	10	7	9
Aurangabad	2	5	5	7	10	12	7

Table 2: Output of the Climate-to-Strategy Mapping Tool. The values are the number of months a strategy is applicable.

City / Location	**Passive Heating**	**Passive Cooling**	**Night Flush Ventilation**	**Evaporative Cooling**	**Comfort Ventilation**	**Radiant Cooling**	**Earth Cooling**	**Heat gain**
Sundernagar	9	0	0	0	0	0	0	9
Shillong	12	0	0	0	0	0	0	12
Pune	8	0	0	0	0	0	0	8
Bangalore	9	0	0	0	0	0	0	9
Allahabad	5	3	2	1	0	1	0	5
Delhi	5	3	2	1	1	1	0	5
Chennai	2	4	0	0	4	0	0	2
Trivandrum	3	2	1	1	0	1	0	3
Mumbai	3	1	0	0	1	0	0	3
Jaisalmer	5	6	3	2	2	3	0	5
Ahmedabad	3	3	1	1	0	1	0	3
Aurangabad	5	2	2	2	0	2	0	5

- The largest variation amongst architects is observed in their opinions for passive cooling, earth cooling and comfort ventilation.

There is a disagreement between the expert opinion and the recommendations derived from the use of the TMY data and the thresholds in the literature. It is possible that the architects' opinions are based on direct experience of the climate of these cities, and that the TMY data represents an older climate. The TMY data shows higher needs for passive heating and lower needs for passive cooling. This warming trend could be result of global warming or the heat island effect in these cities. Since, the architects' responses differ from each other; it is likely that their understanding of the climates is also different from each other. To correct for these variations, additional research and development work is needed. Some ideas for future work are suggested below:

1. Use more recent climate data in the analysis.
2. Revise the thresholds so that they are more in tune with the experience of the practicing architects.

CONCLUSION

- The study identified 45 strategies with prescriptive recommendations from the literature. Of these:
  - 19 strategies have values for sizing the building elements with RoTs.
  - 12 strategies have recommendation with absolute values for sizing building elements.
  - 14 strategies have simple recommendations for strategies with no sizing information.
  - Some RoTs require heat gain calculations for sizing the building components. The values presently available for this calculation cannot be used for Indian locations. Future work to develop these values is needed.
- Of all the sources referred, 8 have strategy recommendations based on climate zone classification and only 4 sources link the strategies to specific climate conditions. For strategies that are based on climate zone classification, the specific climatic conditions are derived using threshold values for Indian climate zones. Of the 45 strategies identified for India, only 8 can be recommended based on specific climatic conditions. Analysis showed that climatic conditions for several Indian locations have enough variations that they cannot be clearly classified in to the climate zones.
- It is not enough to identify strategies for a location using climate zone definition for India because a location can experience different seasons at different times in a year that would prevail for different length of time. Therefore, this study proposes the use of monthly average weather data to arrive at strategy recommendations.
- A Strategy Decision tool is developed in this study for architects to help identify a strategy to be used. The study identified relationships between climatic conditions, site conditions and passive strategies for India. This information is synthesized for the identified 45 passive strategies into a Strategy Index.
- A Climate-to-Strategy Mapping tool is developed to use monthly average weather data and combine it for use with the Strategy Decision Tool. When the results of this tool, that uses TMY weather data were presented to a panel of experts, their responses showed that the tool under predicts the need to passive cooling and over predicts the need to passive heating. This warming trend could be result of global warming or the heat island effect in these cities, which is not represented in the TMY data used in the analysis. Further work can be carried out for validating this tool by using more recent data, or by revising the climate zone classification thresholds for India. The discrepancy in the numbers provided by the 9 architects during their interviews, also suggests is necessary to have an objective methodology to identify applicable passive design strategies for India.

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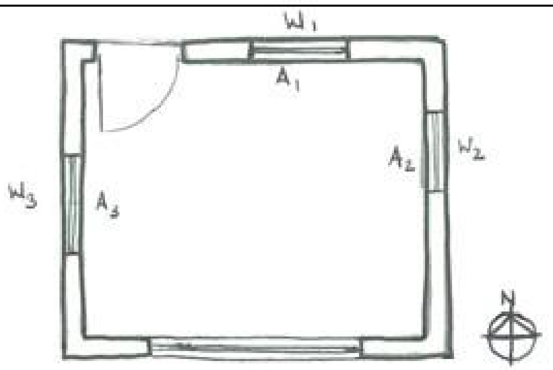
APPENDIX A: CRITERIA FOR THE CLASSIFICATION OF CLIMATES

Climate zones	**Mean monthly temperature (° C)**	**Relative Humidity (%)**	**Precipitation (mm)**	**No. of clear days**
Hot and Dry	> 30	< 40	< 5	> 20
Warm and Humid	>30	> 40	> 5	< 20
Moderate	25-30	> 70	< 5	< 20
Cold and cloudy	< 25	> 55	> 5	< 20
Cold and sunny	< 25	< 55	< 5	> 20
Composite	This applies, when six months or more do not fall within any of the above categories.			

APPENDIX B: SAMPLE STRATEGY SHEET

S1.1 Strategy: Limiting the area of non-south windows.



$$A = A_1 + A_2 + A_3$$

$$W = W_1 + W_2 + W_3$$

$$W = 5 - 10\%\ of\ A$$

$$\frac{W}{A} = 5 - 10\%$$

Rule of Thumb: the non-south double-glazed windows should be limited to 5-10% of the non-south facing wall area

Climatic Condition: Average monthly DBT< 25°C

Site Condition/Constraint: Windows on the directions other than south are necessary for function or aesthetic reasons.

Objective: To reduce heat loss through non-south windows and retain the heat gained through sun facing south windows

Building System: walls, floor, roof, double glazed window

How it works: In India, winter sun is on the south, so south facing glass is maximized, to maximize solar gain. The sun enters the space from the south facing windows. The interior materials absorbs this heat and then emit long wave radiation. The window glass is opaque to this radiation much of the energy is trapped and hence the inside temperature rises. This is the desired greenhouse effect. However, glass also loses heat through conduction. Hence, glass on other orientations, where there is little solar gain, is minimized.

Source/s: Brown, 1985, p. 134

APPENDIX C

	DB	DB	DB	WB	WB	WB	RH	RH	RH	GH Rad	GH Rad	GH Rad	GH Rad	Diffuse Rad	Diffuse Rad	Diffuse Rad	Wind Speed	Wind Speed	Wind Speed	SC	SC	SC
	Avg Daily	Avg Daily Low	Avg Daily High	Avg Daily	Avg Daily Low	Avg Daily High	Avg Daily	Avg Daily Low	Avg Daily High	Avg Daily Total	Avg Daily	Avg Daily Low	Avg Daily High	Avg Daily	Avg Daily Low	Avg Daily High	Avg Daily	Avg Daily Low	Avg Daily High	Avg Daily	Avg Daily Low	Avg. Daily High
	C	C	C	C	C	C	%	%	%	wh/m2	w/m2	w/m2	w/m2	w/m2	w/m2	w/m2	m/s	m/s	m/s	%	%	%
Jan	14.1	8.05	21.19	11.2	7.32	14.5	74.6	47.1	95.5	3245	312.2	49	609	106	29.8	217	1.19	0.119	2.78	25.215	1.2903	55.2
Feb	16.5	11.4	21.76	13.3	10.3	15.5	72.5	50.6	92.4	3678	336.1	90.1	634	147	51.3	286	1.43	0	3.81	46.771	7.8571	85
Mar	21.9	15.3	28.72	15.9	12.9	18.1	56.8	32.5	83.4	5386	454.7	158	867	142	47.4	315	1.54	0.039	3.75	28.777	2.9032	57.7
Apr	28.3	20.7	35.04	17.9	15.2	19.6	38.4	20.9	61.2	6958	547.5	158	987	136	38.6	332	1.48	0.013	3.55	21.694	1.3333	53
May	31.8	25.8	37.73	23.1	20.7	24.9	50.5	32.5	73.6	6605	490.9	172	952	191	71.4	439	1.54	0.09	3.97	26.048	1.6129	66.8
Jun	33.2	27.4	38.07	24.8	22.7	26.5	54.1	39.4	73.4	3785	492.3	203	920	200	82.1	420	2.4	0.517	5.14	34.472	9.6667	73.3
Jul	31.3	27	35.56	25.5	24.1	26.8	65.1	48	84.9	5924	435.1	150	847	229	86.6	468	2.39	0.29	4.9	56.935	23.871	88.1
Aug	30	26.6	33.57	25.8	24.5	26.9	73.5	57.8	89.5	5097	392	98.5	744	237	68.5	456	1.49	0	3.46	59.126	30	86.5
Sep	29.3	25.1	33.93	24.4	22.5	25.6	68.7	49.8	87.6	4838	398.4	124	763	208	65.6	418	1.11	0	3	23.819	6	50.7
Oct	25.3	19.7	31.6	20.3	17.8	22.1	65.8	41.4	88.4	4279	380.2	185	716	159	80.4	316	1	0.074	2.23	8.0511	0	26.5
Nov	19.5	13	27.84	14.3	11.2	17	62.3	31.2	87.1	3921	370.5	110	714	95.9	32.8	224	0.97	0	3.05	9.5833	0.6667	27.3
Dec	14.8	8.72	22.22	11.1	7.4	14.3	67.8	40.6	90	3258	319.1	74.1	621	94.6	33.8	209	1.13	0.068	3.07	11.747	0	41.3

Figure 1: Climate data for Delhi exported from Climate Consultant, input for the Climate-to-Strategy Mapping Tool

	Passive Heating	Passive Cooling	Night Flush	Evaporative Cooling	Comfort ventilation	Radiant Cooling	Earth Cooling	Heat gain
Jan	1	0	0	0	0	0	0	1
Feb	1	0	0	0	0	0	0	1
Mar	1	0	0	0	0	0	0	1
Apr	0	0	0	0	0	0	0	0
May	0	1	1	1	0	1	0	0
Jun	0	1	1	0	0	0	0	0
Jul	0	1	0	0	1	0	0	0
Aug	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0
Oct	0	0	0	0	0	0	0	0
Nov	1	0	0	0	0	0	0	1
Dec	1	0	0	0	0	0	0	1
Total	**5**	**3**	**2**	**1**	**1**	**1**	**0**	**5**

Figure 2: Passive design strategies for Delhi based on analysis, output from the Climate-to-Strategy Mapping Tool

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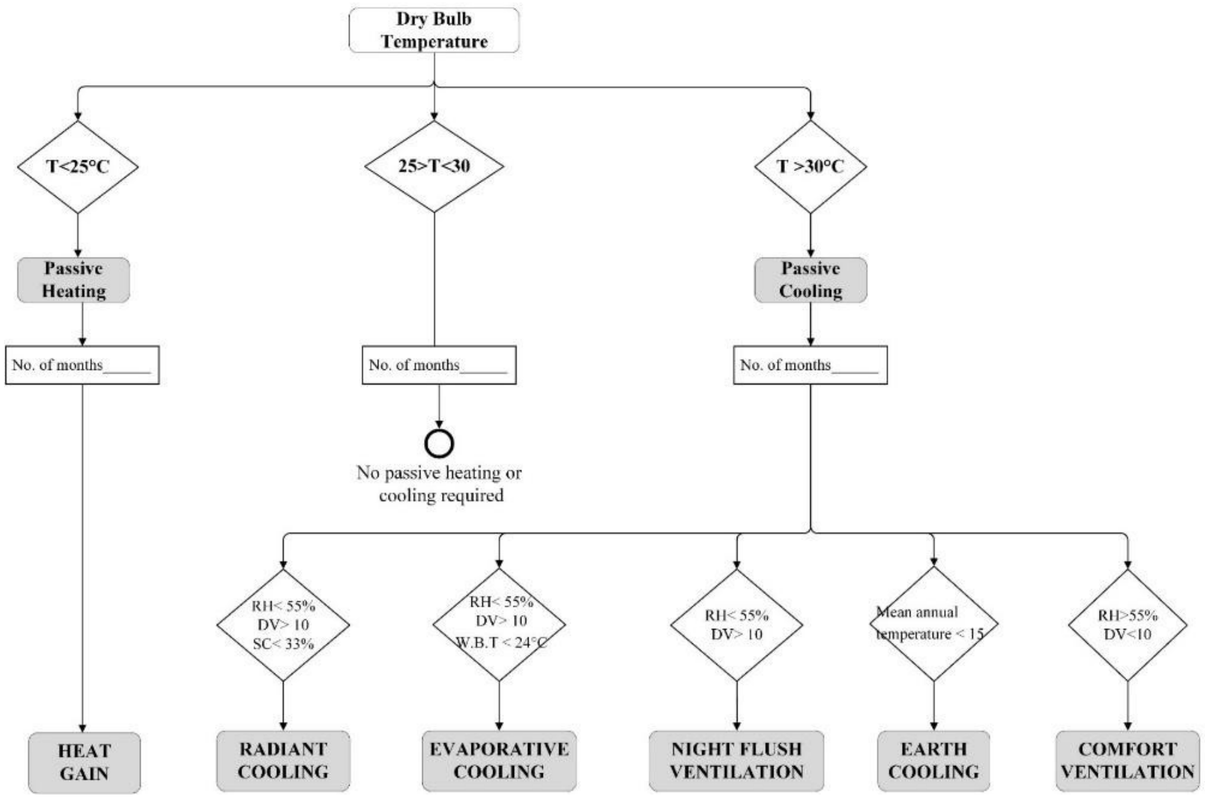
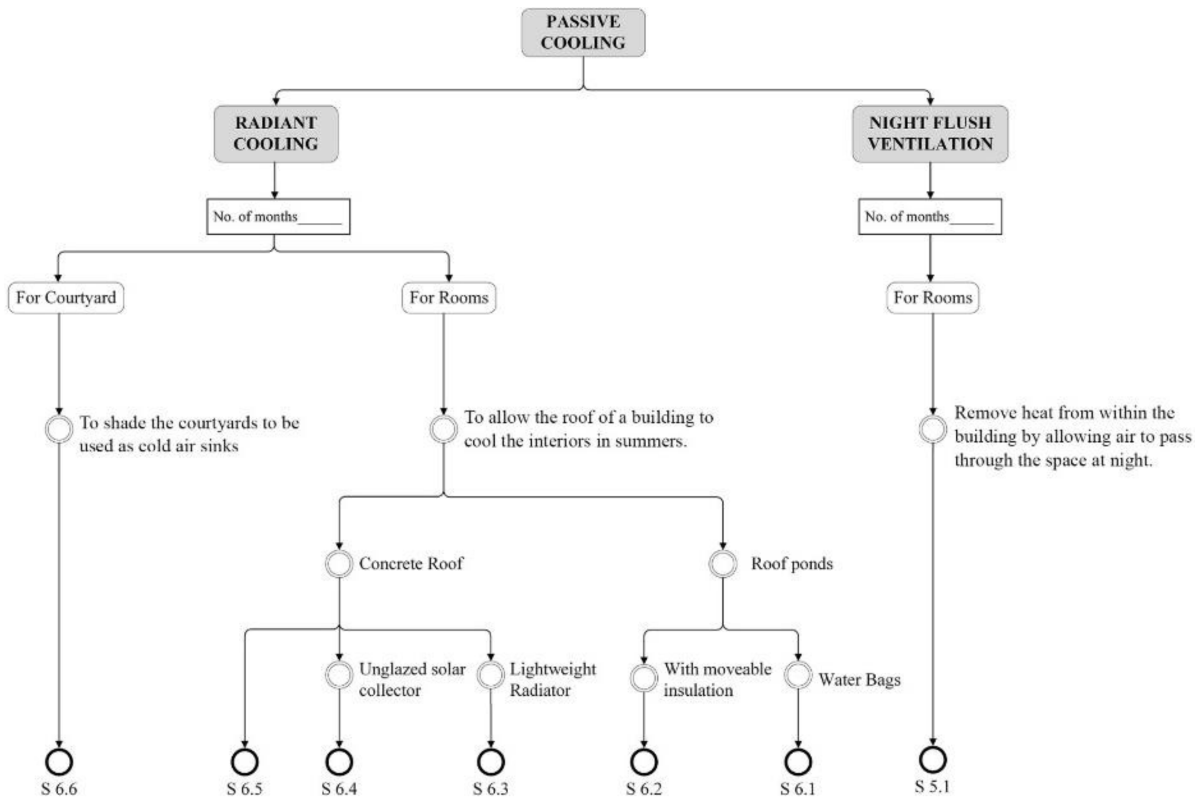
APPENDIX D: Strategy Decision Tool: 2 A4 Sheets





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COOL ROOF IMPLICATIONS ON THERMAL ADAPTATION IN BUILT ENVIRONMENT

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Keywords: Cool roof, Thermal adaptation, Naturally conditioned, Air-conditioned, Building simulation

ABSTRACT

High-albedo roof reduces heat gain into the built space, mainly due to high solar reflectance and thermal emittance. Few studies have been conducted in tropical climates to evaluate the effect of high-albedo roof on thermal adaptation in naturally conditioned (NV) and air-conditioned (AC) buildings. Therefore, present study intends to analyse the effect of cool roof on reduction in discomfort hours in NV and improvement in energy efficiency in conditioned environment.

Building simulation was adopted to examine above study gaps considering ASHRAE Adaptive Thermal Comfort (ATC) and India ATC approach of thermal comfort. Thermal comfort conditions were assessed based on air temperature (AT), operative (OT) and mean radiant temperature (MRT) in NV building space. And, energy saving was determined using fixed thermostat and hourly variable adaptive thermostat settings in AC space. A five zone energy simulation model was developed for both daytime & 24 hours building operation.

Discomfort hours were reduced by 16.23% following ASHRAE ATC and 22.62% by applying India ATC approach for daytime occupancy. Also, study found improvement in comfort conditions by 24.23% by following India ATC over ASHRAE approach. Furthermore, while varying roof reflectivity from 0.3 to 0.8 in AC building, energy savings of 26.51% was found by operating AC on fixed thermostat in daytime operation, whereas application of adaptive thermostat resulted in 27.64% savings. The benefits of cool roof were found high in buildings of tropical climate, both in terms of thermal comfort and energy savings, although previous studies underestimated advantages of high-albedo roof.

KEYWORDS

Cool roof; Thermal adaptation; Naturally conditioned; Air-conditioned; Building simulation

INTRODUCTION

Cool roof reflects a large fraction of incoming sunlight and keeps the roof surface at a lower temperature than that of grey roof (roof that absorbs most of the incoming solar radiation), mainly due to high solar reflectance and thermal emittance. A lower roof surface temperature leads to lower heat conduction into the building and hence reduces the cooling load of the building (Akbari, Levinson, and Rainer 2005). Also, studies show the benefits of cool roof in mitigating the effect of Urban Heat Island (UHI). UHI is a common phenomenon wherein, urban temperature is higher than that of the surrounding suburban areas, mainly during summers (Xu et al. 2012).

Several experimental and simulation based studies have been conducted to demonstrate the benefits of cool roof in terms of energy savings and improvement in thermal environmental conditions. A study conducted by (Xu et al. 2012) estimated annual savings of 13-14 kWh/m^2, corresponding to cooling energy savings of 10-19% on application of white coating over uncoated concrete roofs. A study performed in Florida found 10% reduction in chiller power consumption for built up area of 10000 sq foot. The study also observed reduction in peak electrical cooling demand by 5.6 kW (Parker and Barkaszi Jr 1997). Similar study conducted on three commercial buildings in California, estimated the savings in cooling energy, (Akbari, Levinson, and Rainer 2005). The study found 52%, 17-18% and 3-4% energy saving in retail store, school building and fruit packing facility, respectively.

Table 1. Description of studies conducted in various climatic conditions

AUTHOR	CONCLUSIONS
(Akbari, Matthews, and Seto 2012)	• Hot and temperate regions, increasing albedo of 1 m^2 of a surface by 0.01 decreases the global temperature by 3 fK • Long-term offset in CO_2-equivalent to 6.5-7.5 kg. • Study performed at global locations
(Synnefa, Santamouris, and Akbari 2007)	• Increasing the roof solar reflectance by 0.65, cooling loads reduce by 8-48 kWh/m^2, discomfort hours by 9-100% and maximum temperature by 1.2-3.7 ºC • Location : Abu Dhabi, Delhi, Casablanca, Damascus, Tokyo
(Zingre et al. 2015)	• Reduction in heat gain was found to be 0.21 kWh/m^2, on a flat double-skin roof for Singapore
(Gao et al. 2014)	• Lowered roof surface temperature by 20 °C, and reduced energy use by 9%. • Reduced daily roof heat flux by 66%, for Chongqing, China
(Uni.Melbourne 2011)	• Benefit of cool roof found between 0.88 & 1.53 MJ/m^2 /year • Location : Melbourne, Australia
(Pisello 2015)	• Save 50% of primary energy for attic cooling in the hottest month (from 782 kWh to 398 kWh). • Energy need for cooling becomes less than 100 kWh (Adaptation and cool roof) for Perugia, Italy.
(Garg et al. 2016)	• Electricity savings for high-albedo roof (0.8) is 23 kWh/sqm-year • Temperature reduction in May is 3.9 ºC for Delhi, India
(Mohamed, Chang, & Alshayeb 2015)	• SR 0.8 & TE 0.9, energy conservation equal to 73% • Location : Mosu, Baghdad and Basrah, Iraq
(Bhatia et al. 2010)	• High reflectivity results in up to 49% reduction in heat flow • Energy saving of 19.4 kWh/m^2/yr, corresponding to a 8.8% reduction in energy use, for Hyderabad, India
(Dabaieh et al. 2015)	• High albedo coating shows a fall of 53% in discomfort hours and saves 826 kWh during the summer season • Location : Cairo, Egypt

A study conducted by (Akbari, Menon, and Rosenfeld 2009) demonstrated that retrofitting roofs and pavements in the tropical and temperate regions with solar reflective materials, would have an effect on global radiative forcing (RF), equivalent to a one-time offset of 44 Gt of CO_2. Similar study was conducted by (Levinson and Akbari 2010) in US for 236 cities found reduction in CO_2 to be 1.07 kg/m^2 for Alaska and 4.97 kg/m^2 for Hawaii (national average 3.02 kg/m^2). Another study carried out in Hyderabad found reduction in CO_2 as well as in cooling energy as estimated to be 11-12 kg CO_2/m^2 of flat roof area (Xu et al. 2012). Furthermore, an experimental study performed by (Dhaka, Mathur, and Garg 2012) on

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conditioned environment in composite climatic region of India, presented 9.18% energy savings by applying cool roof considering adaptive thermostat settings. On a similar simulation model, study of (Dhaka, Mathur, and Garg 2013) found improvement in comfort hours (598 hours) with application of cool roof following adaptive comfort approach.

Several research have been conducted globally to study the effect of cool roof on energy, UHI, comfort and GHG emission. However, very few studies have been performed in evaluating implications of cool roof on thermal adaptation in AC and NV buildings of tropical and subtropical climatic regions. In the study of cool roof, aging is also an important aspect, though, limited studies demonstrate the impact of aging on comfort and energy. Therefore, present study intends to evaluate the following:

- Variation in roof reflectivity by 0.3, 0.45 (aging) and 0.8 for both NV and AC building model, daytime and 24 hours occupancy
- Comfort improvements in NV considering thermal adaptation, both ASHRAE and India ATC based on Air Temperature (AT), Operative Temperature (OT) and Mean Radiant Temperature (MRT)
- Reduction in peak cooling load (kW) and energy consumption (kWh) while operating air-conditioner on fixed thermostat (24ºC) and hourly variable adaptive thermostat settings

METHODOLOGY

Building energy simulation is performed wherein; a five zone simulation model is developed. Further, simulation is performed to evaluate the effect of cool roof on thermal adaptation for various climatic conditions of India. Methodology of the study is shown in Figure 1.

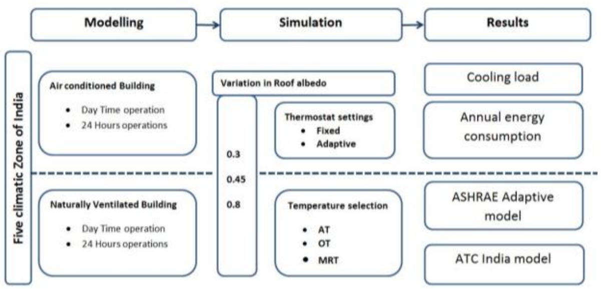

Figure 1. Study flowchart

Cool Roof and Climatic Conditions

Several studies have been conducted to characterize the features of various climatic conditions. The study carried out by Chen and Chen classifies various climatic regions namely, climate A (Tropical), climate B (Dry), climate C (Mild Temperate), climate D (Snow) and climate E (Polar), (Chen and Chen 2013). Implementation of cool roof could be significant in climate A and climate B. Additionally, India has been divided into five climatic zones such as hot & dry (for example, Jaisalmer), warm & humid (Mumbai), composite (Hyderabad), temperate (Bangalore) and cold (Sri Nagar), (ECBC User Guide, 2009). Hence, to analyze the effect of cool roof on adaptation, above mentioned cities are considered in the present study.

Building Model Description

An office building with two occupancy schedules, one is daytime and the other is 24 hour occupancy schedule, is being analyzed for both AC and NV operation. The simulation model was developed using EnergyPlus V8.3. The five zone simulation model of a single storey building with 1 core and 4 perimeter zones (20m x 20m, each zone of area 80 m^2, floor to ceiling height 3.12m), was developed. The simulation model represents the conventional construction practices of India as tabulated in Figure 2. A Packaged Terminal Air Conditioning System with a COP of 2.8 is operated for air-conditioning. For NV model, windows are kept open to ventilate the air.

Parametric Simulation

Parametric simulations were performed for both NV and AC building models varying roof reflectivity for 0.3, 0.45(aging) and 0.8. In case of NV building model, reduction in discomfort hours were determined on the basis of AT, OT and MRT for both daytime and 24 hours operation, following ASHRAE ATC and India ATC approach. Adaptive comfort range of ASHRAE Standard-55 (Ashrae 2010) was between 20.96 ºC and 31.53 ºC, whereas comfort range of India ATC (Shivraj Dhaka et al. 2015) was between 21.27 ºC and 33.8 ºC. For each model of AC building, that is both daytime and 24 hour occupancy schedule, fixed thermostat of 24 ºC and an hourly variable adaptive thermostat schedule were opted. Annual energy consumption and cooling load were determined for each model.

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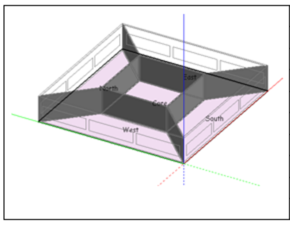

Core zone + 4 perimeter zones	
Wall U-value	2.014 W/m²-K
Roof U-value	3.911 W/ m²-K
Glass SHGC	0.78 W/ m²-K
Glass U-value	5.778 W/ m²-K
LPD	10 W/ m²
EPD	10 W/ m²
WWR	40%
Occupancy	100 sq ft / person
Shading	No

Figure 2. Simulation model of study building

RESULT AND DISCUSSIONS

Implication Of Cool Roof In Indian Climatic Conditions

Implication of cool roof improves thermal comfort conditions in NV and increases energy savings in AC buildings, especially in tropical and dry climatic conditions. Present study evaluates the variation in temperatures (AT, OT and MRT) for minimum (0.3) and maximum roof reflectivity (0.8) for east zone being a representative zone in the present study, as described in the section Case Study – Model Description. The maximum temperature reduction in AT, MRT, and OT observed were 1.59 ºC, 5.65 ºC and 3.6 ºC respectively. Figure 3 shows that maximum reduction in temperature was found for MRT. Present study found significant reduction in MRT as compared to AT and OT.

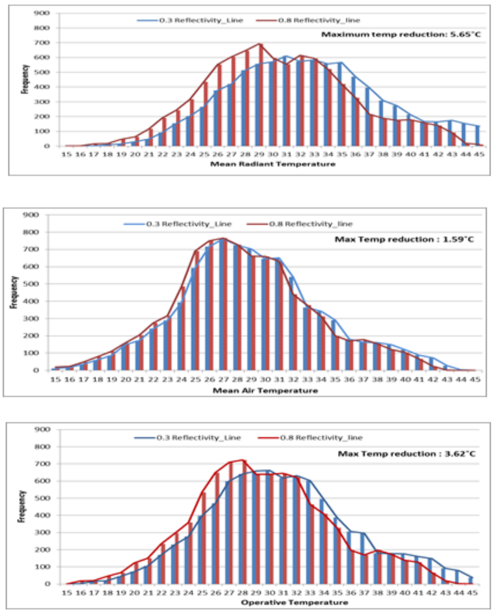

Figure 3. Shift in MRT, AT and OT for composite climate, Hyderabad, India

Therefore, MRT was chosen to study the implications of cool roofs in all four climatic locations of India, namely Bangalore, Jaisalmer, Mumbai and Srinagar. Figure 4 and Figure 5 show the variation in MRT for the roof reflectivity of 0.3 and 0.8. Maximum shift in temperature at roof reflectivity between 0.3 and 0.8 was found for Bangalore and Mumbai, being temperate and warm & humid climate respectively. Interestingly, the study observed maximum temperature difference of 6.23 ºC in the month of June in Jaisalmer during summer. However, during winter in Jaisalmer, application of cool roof reduces MRT to a large extent resulting in thermal discomfort. Similarly, in Srinagar, maximum temperature difference was 6.18 ºC, when the MRT was found to be 39 ºC. Due to internal loads, indoor temperature was found higher. Summer being lengthy in Jaisalmer and winter in Srinagar, present study observed lesser shift in temperature reductions between 0.3 and 0.8 reflectivity. Therefore, further study shall be carried out to evaluate the effect of cool roof on thermal adaptation in these climates.

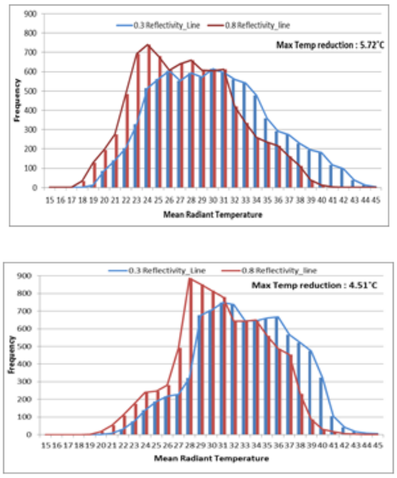

Figure 4. Analysis of shift in MRT for Bangalore (top), temperate and Mumbai (bottom), warm & humid

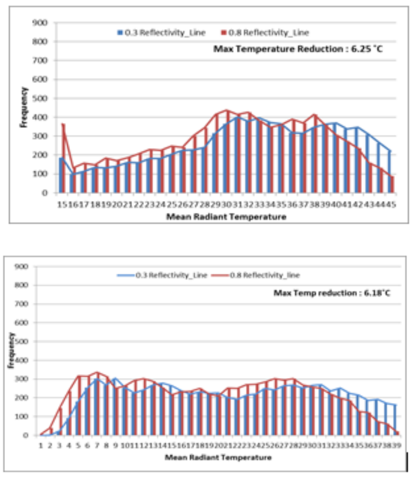

Figure 5. Shift in MRT for Jaisalmer (top), hot and dry and Srinagar (bottom), cold climate

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Three parameters, namely, solar radiation, inside surface temperature and outside surface temperature were chosen to select the representative zone for analyzing reduction in energy and discomfort. Both inside and outside wall surface temperatures were found higher for east and west zones as compared to south and north zones wall surface temperatures during summer (April to September) and moderate (March and October) months. Although, Figure 6 indicates that only during winter (November to February), south zone had higher inside and outside wall surface temperatures due to higher solar radiation.

It was also observed that east zone showed higher wall surface temperatures as compared to west zone. Figure 7 depicts variation in solar radiation for all the facades. Total solar radiation falling on east and west wall surfaces are 1450.2 and 1423.8 kWh/m^2 respectively. Therefore, east zone is selected as the representative zone for performing analysis of AC and NV building model.

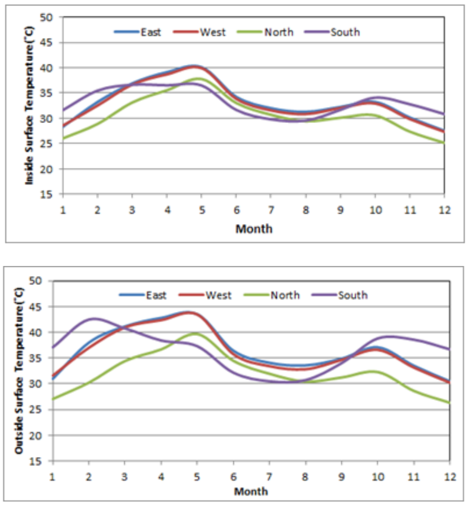


Figure 6. Variation of inside and outside surface temperature, Hyderabad, composite climate

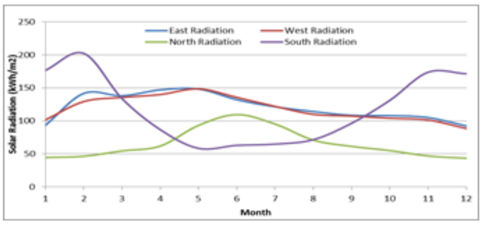


Figure 7. Variation in Solar radiation, Hyderabad, composite climate

Effect Of Cool Roof On Thermal Adaptation In NV Building

Daytime operation

Simulation was performed for roof reflectivity 0.3, aging and 0.8 and reduction in discomfort hours were calculated for both ASHRAE ATC and India ATC approach. Figures 8, 9 and Figure 10 show the variation in discomfort hours for Hyderabad. The study observed minimal reduction in discomfort hours when reflectivity was found varying between 0.3 and 0.45. However, significant reductions in discomfort hours were observed for 0.8 reflectivity on the basis of MRT as compared to OT and AT.

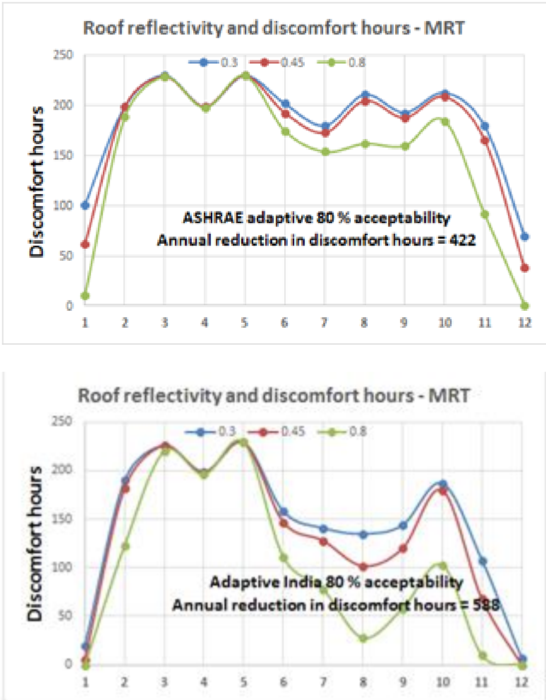
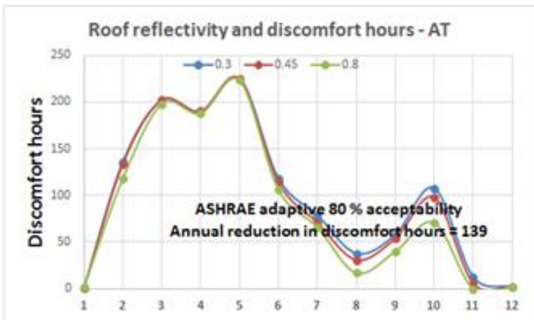


Figure 8. Variation in discomfort hours, out of 2600 occupancy hours based on MRT



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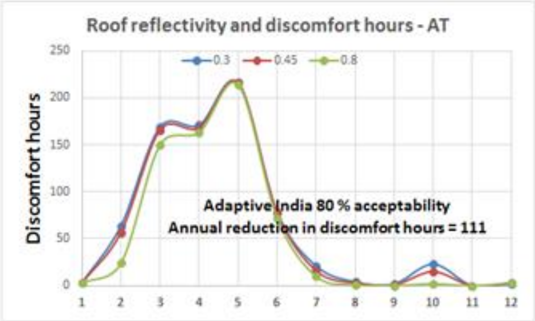

Figure 9. Variation in discomfort hours out of 2600 occupancy hours based on AT

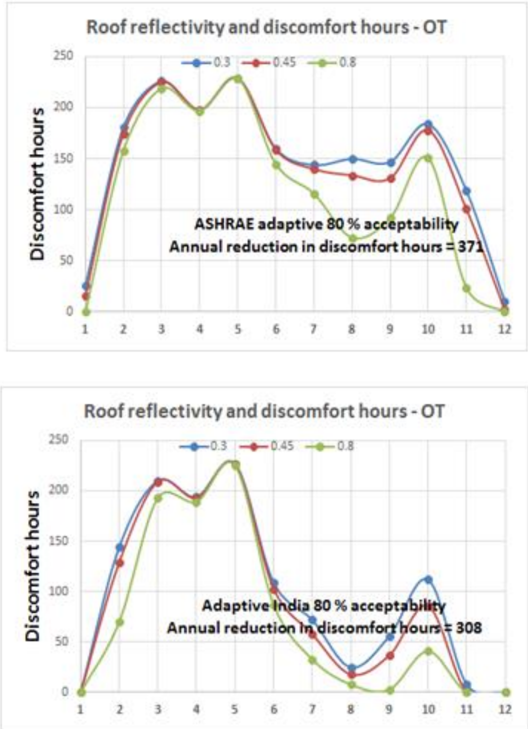

Figure 10. Variation in discomfort hours out of 2600 occupancy hours based on OT

On varying roof reflectivity from 0.3 to 0.8, total discomfort hours were found to be decreased from 2208 to 1786 hours (by 422 hours, 16.23%) based on ASHRAE ATC, whereas according to India ATC, discomfort hours were reduced by 588 hours or 22.62% (1744 to 1156 hours), based on MRT, as shown in Figure 8. On comparison between ASHRAE ATC and India ATC for 0.8 reflectivity, discomfort hours were reduced by 630 or 24.23% (1786 to 1156 hours) on the basis of MRT. Thus, India ATC approach demonstrates significant reduction in discomfort hours over ASHRAE ATC including MRT, OT and AT approaches, as shown in Figure 11 (b).

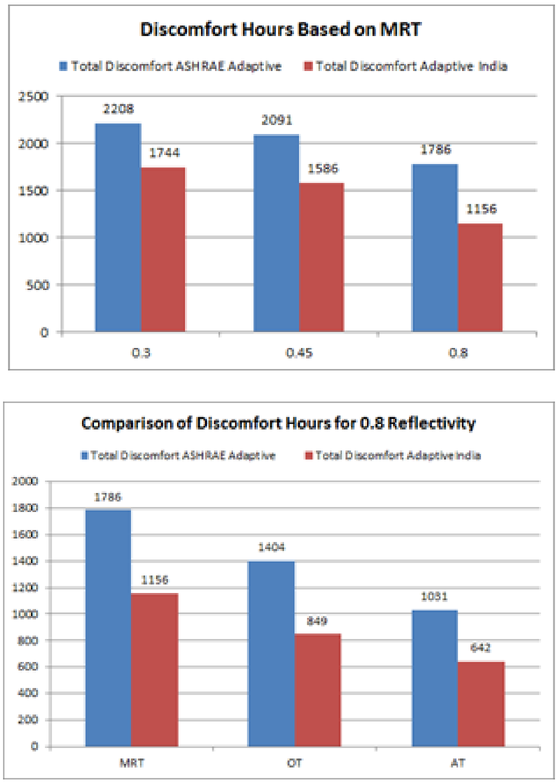

Figure 11. Variation in discomfort hours (top, a) and Comparison of Discomfort hours for 0.8 Reflectivity for ASHRAE ATC and India ATC Approach (bottom, b)

24 hours operation model

Similar to analysis performed for daytime operation, on the basis of MRT (while varying reflectivity from 0.3 to 0.8), total discomfort hours were reduced by 846 hours or 13.17% (from 3550 to 2704 discomfort hours) based on ASHRAE ATC approach. Whereas, by following India ATC approach, a reduction of 865 discomfort hours were found. On comparison between ASHRAE ATC and India ATC for 0.8 reflectivity, discomfort hours were reduced by 964 or 15.01% (2704 to 1740 hours). Thus, a significant reduction in discomfort hours is observed in India ATC approach over ASHRAE ATC including MRT, OT and AT, as shown in Figure 12 (b). Present study reveals that implications of cool roof improve thermal environmental conditions. Therefore, benefits derived from application of cool roofs shall not be underestimated, in terms of thermal comfort, in NV buildings.

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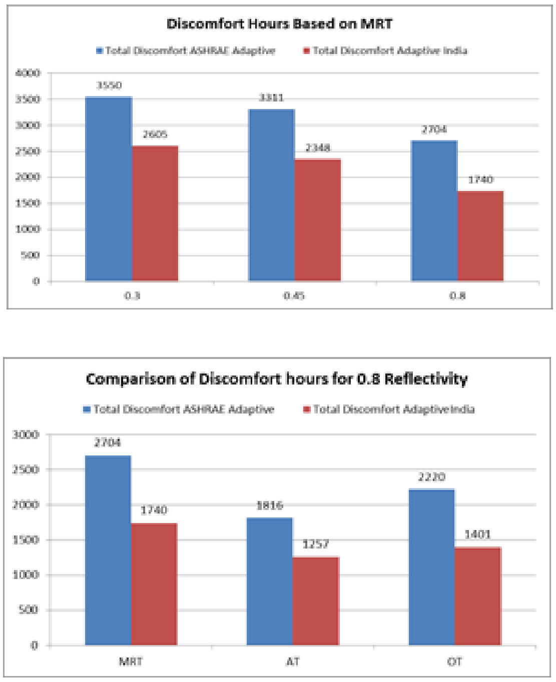

Figure 12. Variation in discomfort hours, out of 6420 occupancy hours (top, a) and Comparison of Discomfort hours for 0.8 Reflectivity for ASHRAE ATC and India ATC Approach (bottom, b)

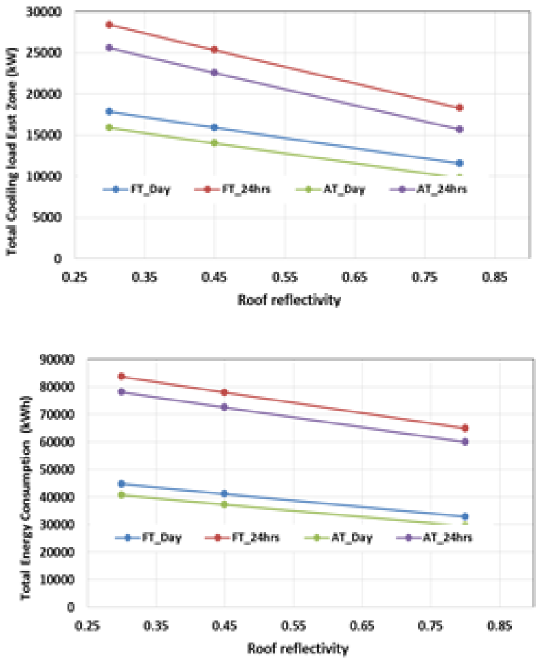

Figure 13. Annual cooling load (top, a) and energy consumption (bottom, b)

Effect Of Cool Roof On Thermal Adaptation In AC Building

For AC building, simulation was performed for both daytime operation and 24 hours operation model, varying roof reflectivity (0.3, aging 0.45 and 0.8), based on fixed thermostat (24 °C) and adaptive thermostat settings (25 ˚C - 26.5 ˚C). Reduction in annual cooling load and energy consumption for the representative zone were evaluated, as demonstrated in Figure 13. On increasing the roof reflectivity from 0.3 to 0.8 for fixed thermostat settings, reduction in annual cooling load was found to be 35.23% for daytime and 35.66% 24 hour building operation. Similarly for adaptive thermostat settings, reduction in cooling load was found to be 38.44 % in daytime and 38.67% in 24 hour building operation.

Furthermore, on same increase in roof reflectivity for fixed thermostat settings, reduction in annual energy consumption was found to be 26.51% in daytime and 22.41% in 24 hour building operation. Similarly for adaptive thermostat settings, reduction in annual energy consumption was found to be 27.64 % in daytime and 23.16% in 24 hour building operation. Thus, significant reduction in cooling load for representative zone and total energy consumption was observed, on increasing the roof albedo from 0.3 to 0.8.

CONCLUSIONS

Studies reveal that implication of cool roof in tropical and dry climates improves comfort and also offer opportunities for energy efficiency in conditioned environment. Present study analyses the effect of cool roof on thermal adaptation in both AC and NV building. The study concludes the following findings:

- Significant reduction in temperature (MRT) was observed on increasing roof reflectivity from 0.3 to 0.8 in all climatic locations of India.
- The study shows that MRT plays an important role while analysing comfort conditions in NV building model of composite climates.
- Thermal comfort conditions are found to be improved by application of cool roof in composite climate. Maximum discomfort hours in MRT were observed to be reduced by 16.23% using ASHRAE ATC approach and 22.62% using India ATC approach, while increasing roof reflectivity from 0.3 to 0.8, for daytime operation building. For 24 hour operation building, maximum discomfort hours were reduced by 13.17% using ASHRAE ATC and 13.47% using India ATC, for the same increase in roof reflectivity. This reveals that application of cool roof shall not be neglected in tropical (composite) climatic conditions. Further, India ATC approach results in significant

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(24.23% for 0.8 reflectivity) discomfort reduction as compared to ASHRAE ATC approach for daytime operation and 15.01% for 24 hour operation model.

- On increasing roof reflectivity from 0.3 to 0.8 for air-conditioned buildings, reduction in total energy consumption was 26.51% in fixed thermostat daytime operation, 22.41% in fixed thermostat 24 hour operation, 27.64 % in adaptive thermostat daytime operation and 23.16% in adaptive thermostat 24 hour operation. Also, a significant reduction in cooling load was observed. Thus, the study reveals that the application of cool roof reduces energy consumption and cooling load to a large extent, thus contributing in significant energy savings.

ACKNOWLEDGEMENT

The U.S. Department of Energy (DOE), and the Department of Science and Technology (DST), Government of India (GOI) provided joint funding for work under the U.S. – India Partnership to Advance Clean Energy Research (PACE-R) program's "U.S. – India Joint Center for Building Energy Research and Development" (CBERD) project. The Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, of the U.S. DOE under Contract No. DE-AC02-05CH11231 supports the U.S. CBERD activity. The DST, GOI, administered by Indo-U.S. Science and Technology Forum, supports the Indian CBERD activity.

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LIFE CYCLE ASSESSMENT OF HIGH-RISES RESIDENTIAL BUILDING IN INDIA AND COMPARATIVE ANALYSIS OF ENVIRONMENTAL IMPACTS WITH ALTERNATE WALL MATERIALS

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Keywords: Life Cycle Assessment, Embodied carbon, Operational energy, Construction Materials, Cradle to gate, sustainability, carbon footprint

ABSTRACT

The building sector accounts for more than 40% of the overall global consumption of natural resources and energy, and it emits almost 33% of the total emission of carbon dioxide. Therefore, a particular attention is required in the selection of the materials used in buildings. The objective of this study is to investigate the carbon consequences of constructing high-rise residential tower with various types of wall materials such as Brick wall, Reinforced cement concrete (RCC) wall and Autoclaved aerated concrete (AAC) block wall, flyash brick wall, insulated brick wall, insulated flyash brick wall, solid concrete block wall using "Cradle to grave" approach. The influence of selected materials on building embodied carbon is analysed using GaBi software.

Considering RCC wall as base case scenario, the use of AAC block in high-rise residential tower construction reduces 23.9% embodied carbon emissions. Similarly flyash brick wall and brick wall results in reduction of 17.6% and 13.6% respectively. Similarly, EPS insulated brick wall scenario and EPS insulated flyash brick wall scenario results in reduction of 7.35% and 10.1% embodied carbon emission respectively. In addition, AAC reduces associated primary energy demand by 24.9% when compared to RCC wall. Similarly, Flyash brick wall and brick wall results in reduction of 10.8% and 5% embodied energy compared to RCC masonry.

INTRODUCTION

Resource depletion and climate change have become topics of major concern, as it becomes more and more apparent to government & public that human development on the earth is not sustainable at its current rate. Amongst others, the construction industry is striving to achieve the difficult task of reducing the environmental impact resulting from its processes, while still providing a high quality product

In India, the construction industry is a major contributor to socio-economic development and a major user of energy and natural resources. Building construction industry consumes 40% of the materials entering the global economy and generates 40–50% of the global output of greenhouse gases (Asif et al.,2011). Hence they need to be analyse from life cycle point of view.

Apart from having a large environmental footprint in terms of raw material use, the production of building materials also requires an enormous amount of energy. Out of the emissions from construction sector, 80% are resulting mainly from the products/industrial processes of four energy intensive building materials (such as concrete and reinforced, compared to masonry materials). Moreover, with the rapidly growing population there will be an increasing requirement of these materials, particularly in housing, which accounts for nearly 60% of the materials consumed by the construction sector annually (Reddy and Jagadish, 2003). Masonry wall construction (bricks and concrete units) has undergone considerable change in the last few decades with the introduction of lightweight materials (Hendry, 2001). In such kind of lightweight construction material, AAC Block wall considered as a sustainable construction material, which can offer significant energy savings due to the thermal mass and integrated insulation, thermal bridging control and air- tightness of buildings. These factors are able to decrease the cooling energy by 12% (Radhi, 2011). In recent years, the typical Indian residential sector includes 2 BHK, 2.5 BHK and 3 BHK flats in a single tower and the trend is set to continue. The study focuses on understanding the impact of such types of residential developments with respect to embodied carbon during the time of construction.

CASESTUDY

The case study refers to a multi-storey residential building located in the city of Chennai. Among five climatic zones, Chennai falls into hot and humid category. The temperature during summer ranges from 35º to 45ºC. The residential building consists of a ground floor and eleven floors above the ground floor. The ground floor used as a common parking slot. Each Floor plate consists of four residential units as shown in fig-1. The external wall structure is made up of RCC. In simulation, the external wall is replaced with various materials to find suitable sustainable material.

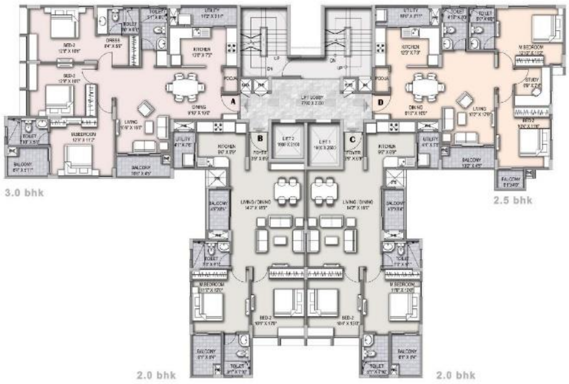

Figure 1: Typical Floor Plan of Residential Tower

The residential tower has a total built-up area of 67405 sq. feet. Out of the total built-up area, 85% is residential flats and 15% is basement and parking areas. In addition to the residential units, the study also accounts the common areas (corridors, lift lobbies & staircase), car parking areas provided in ground floor and basement.

For the purpose of study, the residential tower construction is categorized as substructure, super structure, exterior finishes and interior finishes. The construction of basement, ground floor including foundations, stich slab, columns & walls and finishes considered as substructure. Construction of residential flats from first floor to 11th floor considered as super structure. The exterior finishes include windows, ventilators, parapet walls, balcony drops, staircases, terrace flooring and exterior paints. The interior finishing woks comprises of plastering, flooring, interior paints, PVC and wooden doors. The construction specification of the residential tower is given in Table 1.

The super structure of residential tower has wall of varying thickness 150 mm to 175 mm and the majority of external wall is of 150 mm. The walls of the superstructure occupy a volume of 1600 cu.m of building material. The residential tower is studied for different wall materials to support the selection of more sustainable walls. The details of different wall materials considered for this study is detailed out in following section.

Table 1: Construction Specification of Tower

S. No	Construction Specifications	
1	Foundation Type	Raft Foundation, Isolated Footings & Stich Slab
2	Basement & Ground Floor Wall	Reinforced Concrete of M30 Grade (Normal)
3	All other Floors-Walls, Floor slab and Floor Beams	RCC of M30 Grade (self-compacting concrete)
4	Windows	Single Glazed window with UPVC Frame
5	Flooring (1 to 11 Floors)	Vitrified Tiles
6	Sunken Toilet Floor Slabs	CLSM Concrete
7	Basement Flooring	IPS Flooring with M15 Concrete
8	Terrace Roofing	PCC of M7.5 Grade

DIFFERENT WALL MATERIALS

Reinforced Concrete Wall

The reinforced wall is self-compacting concrete as it can be pumped to higher floor and makes the construction less complex. The components of the wall are reinforced concrete of M30 grade and steel.

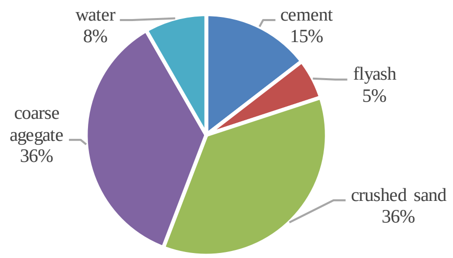

Figure 2: Mix Design of RCC-M30 SSC

The concrete mix design for one cu.m of M30 grade requires 36% coarse aggregate, 36% crushed sand,

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15% cement and 5% fly ash by weight respectively. The mix design proportions of RCC M30 are shown in fig 2. The thickness of the wall is 150 mm with no plastering is considered for the study.

AAC

The thickness of AAC walls are 150 mm with 10 mm plastering on both sides. The AAC block considered in the study is of size 600 mm x 200 mm x 150 mm. The mix design of AAC Block includes fly-ash, cement, lime, gypsum and waste from ACC block production and is presented in fig-3

Flyash is the main ingredient, which is 60% by weight of total AAC Block Mix design. The weight percentages of cement, lime and gypsum are 17%, 7% and 2% respectively.

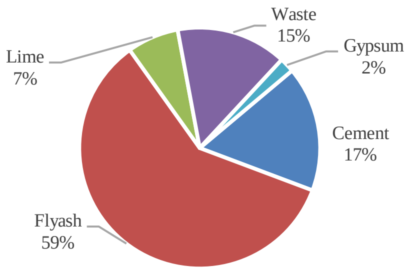

Figure 3: Mix Design of AAC Block

Brick Wall

The thickness of brick walls are 150 mm with 15 mm plastering on both sides. The bricks considered for the study is of 230 mm x 75 mm x 125 mm. The majority of brick production takes place in the unorganized using the Bull's Trench Kiln (BTK) and temporary firing structures called Clamps.

Solid Concrete Block Wall

The basic mix design of solid concrete blocks is cement, flyash, crushed sand and coarse aggregate. The sizes of concrete blocks are 400 mm x 200 mm x 200 mm. Densification of a lean concrete mix to make a regular shaped, uniform, high performance masonry unit produces solid concrete blocks and they are usually produced using a semi mechanized stationary type machine.

Burnt Flyash Brick Wall

The mix design of flyash brick requires 40% flyash and 60% Clay. Flyash consists of inorganic materials, mainly silica and alumina, with some amount of organic material in the form of unburnt carbon. In presence of moisture, fly ash reacts with lime at ordinary temperature to form a compound possessing cementitious properties. The size of Fly ash bricks are 230 mm x 75 mm x 125 mm same as of standard brick size.

Insulated walls

Insulation material of 50 mm thickness at 48 kg/cu.m of Expanded polystyrene (EPS) and Glass-wool insulation are added externally to burnt clay brick walls and flyash brick walls to form four combination of insulated walls namely as 1.EPS insulated burnt clay brick wall 2. EPS insulated flyash brick wall 3. Glass-wool insulated burnt clay brick wall 4. Glass-wool insulated flyash brick wall.

LCA FRAMEWORK

The rise in resource depletion for constructing buildings and the related emissions urged us to evaluate and understand the environmental impacts of the construction materials.

The LCA Frame work for the study is based on, ISO 14040 and ISO 14044. Within the meaning of ISO 14040, LCA method can be defined as, compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

The LCA Frame work is based on, the following phases

1. Goal, scope and definition
2. Inventory analysis (LCI)
3. Impact assessment (LCIA)
4. Interpretation

Scope & Goal of study

The study presented in this paper uses LCA software tool (GaBi software), from cradle to construction of a residential tower. The goal of the study is to investigate the carbon consequences of constructing new residential tower, comparing different approaches and identifying areas that could deliver reductions in embodied carbon.

Functional Unit

The functional unit is the quantified definition of the function of a product. In this study, the functional unit considered for the building construction material is as "one kilogram of material". (For example 1 kg of cement, or 1 kg of steel)

System Boundaries

The system boundary defines which processes will be included in, or excluded from, the system. The presented paper choses the system boundary as cradle to gate approach (cradle to end of construction).

Life Cycle Inventory

The inventory analysis includes data collection and the compilation of the data in a life cycle inventory (LCI) table. The data collection on design drawings, material type and bill of quantities, are collected from the construction site. Pre-construction plan estimates environmental impact of fuels used in construction process. The related embodied carbon emissions are presented as aggregated values for the major construction equipment's and further detailed analysis is beyond the scope of this paper. The datasets used in the study is based on CML (Methodology of the Centre for Environmental Studies of university of Leiden) or TRACI.

RESULTS

Scenario 1: Residential tower with RCC wall

As per the LCA Methodological framework, it is observed that, the residential tower with RCC wall construction results in total embodied carbon emissions of 2049.6 MT of CO_2 and 19,041 GJ of primary energy. From the analysis perspective as shown in fig.4, the super structure construction contributes the maximum with 58% of embodied carbon emissions whereas substructure, exterior finishes and interior finishes contribute to 23%, 6% and 13% of embodied carbon emissions respectively.

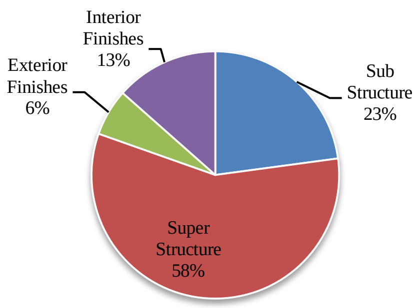

Figure 4: Embodied carbon emission proportions-category wise

In substructure construction, raft foundation contributes high embodied carbon emissions of 203 MT of CO_2 (10% of total), columns & walls and Roof beams & slab each contributes to 93 MT of CO_2 (4.6 % of total) and 104 MT of CO_2 (5.1% of total) embodied carbon. The stich slab in substructure contributes to 46 MT of CO_2 (2.3% of total) embodied carbon. Basement finishes contribute to 26 MT of CO_2 (1.1% of total) embodied carbon.

In superstructure construction, RCC walls contributes high embodied carbon emissions of 775 MT of CO_2 (38.2% of total), floor slabs & beams contributes to 405 MT of CO_2 (20 % of total).The interior finishes and exterior finishes contribute to 252 MT of CO_2 (12.4% of total) and 126 MT of CO_2 (6.2% of total) of embodied carbon respectively.

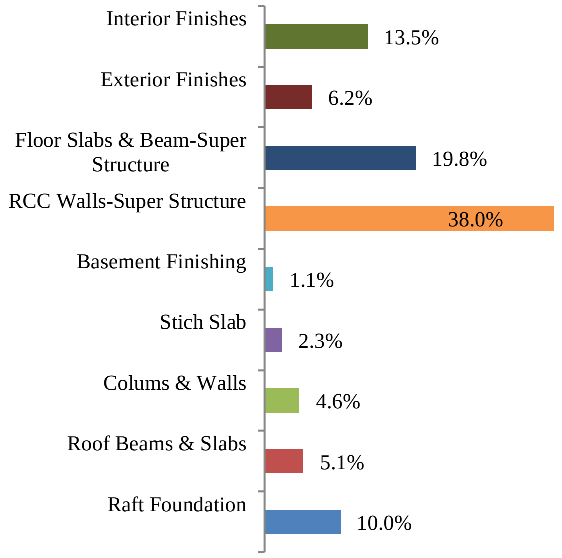

Figure 5: Proportion of embodied carbon attributed by each building component

The detailed information on embodied carbon emissions attributed by each component of the residential tower is depicted in fig-5

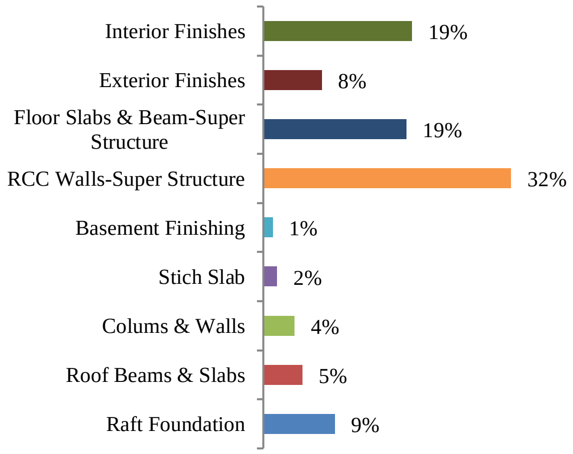

Figure 6: Proportion of primary energy demand attributed by each building component

Similarly, results from the LCA analysis shows that the RCC walls in superstructure requires 32% of the total residential tower construction primary energy whereas interior finishes and floor slabs & beam of super structure each has 19% primary energy demand. The raft foundation and exterior finishes has primary

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energy demand of 9% and 8% respectively. The detailed primary energy demand for the residential tower construction is shown in fig. 6

The total material mass contribution in the construction of residential tower is presented in fig. 7

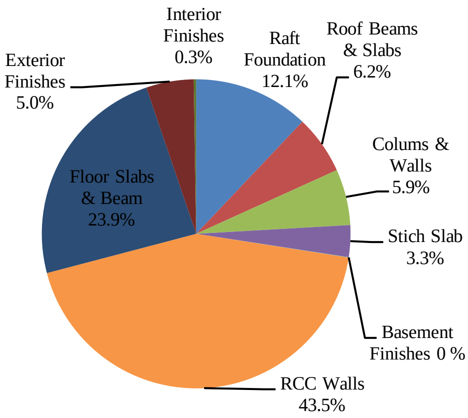

Figure 7: Proportion of material mass contribution residential tower construction

From the material perspective, the material used in residential construction are categorised as concrete material, steel material and finishing materials. The results of LCA are interpreted as categorized above. Concrete materials such as RCC, PCC, CLSM, Plaster, and mortar were the most significant material category, accounts for 72.4% of total embodied carbon of residential tower. The next significant category was steel accounts for 24.3% of embodied carbon emissions. The rest of the emissions accounts for 4% were contributed by flooring materials, paints & cladding, windows and doors.

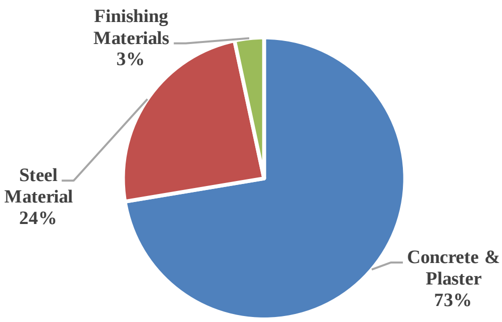

Figure 8: Proportions of embodied carbon emissions-material wise.

Further breakup on embodied carbon for concrete materials is shown in fig 9, The RCC concrete contributes high with 83% embodied carbon and concrete block work which is used in toilet partitions contribute to 14% embodied carbon in overall concrete category

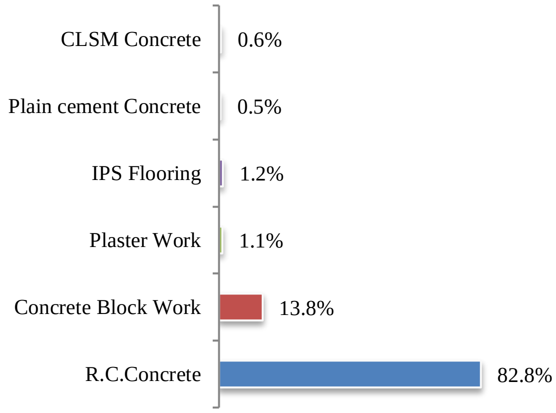

Figure 9: Embodied Carbon emissions-Concrete Materials

Likewise, the breakup of embodied carbon for finishing materials is shown in fig 10. Tile flooring, paints and windows are the major contributor of embodied carbon with 59.8%, 24% and 19.2% respectively in finishing materials. The wooden doors have negative embodied emissions that shows wood is carbon neutral and the wood doors are recycled at the end of life.

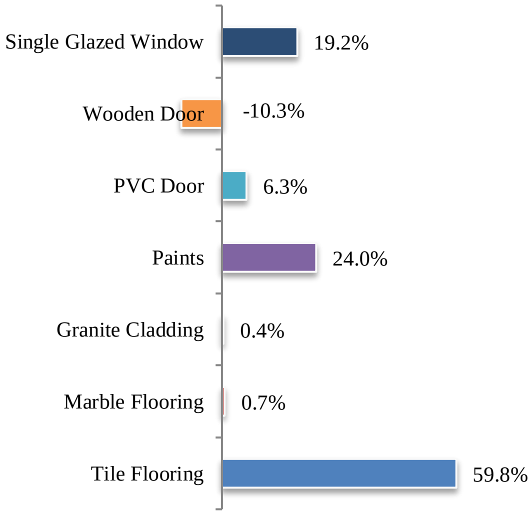

Figure 10: Embodied carbon emissions-finishing materials

The detailed information on embodied carbon and primary energy demand for the residential tower construction and the mass of the material was tabulated in Table 2.

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Table 2: LCA Inventory results of Residential Tower

Material	Mass in Kg	Embodied Carbon in Kg of CO2	Primary energy demand in MJ
R.C Concrete	8856365.8	1,228,620	7,854,540
Steel	401260.0	497,416	6,902,395
Concrete Block Work	928982.5	204,842	2,226,642
Plaster Work	70329.6	15,625	117,217
Tile Flooring	149688.0	41,180	735,760
IPS Flooring	171908.7	18,080	131,228
Marble Flooring	982.8	468	6,994
Granite Cladding	1404.0	262	3,905
Interior Paints	4659.0	12,237	300,929
Exterior Paints	770.0	1,605	36,808
Enamel Paints	1117.0	2,715	74,834
PVC Door	820.0	4,312	82,755
Wooden Door	5853.8	(7,129)	166,488
Single Glazed Window	3837.2	13,246	242,315
Plain cement Concrete	140676.0	7,207	37,322
CLSM Concrete	129333	8,997	121,225

Further, to extend the material analysis to broader spectra of construction industry emissions are evaluated based on the following functional units.

1. Volume (cu.m) as functional unit for concrete materials
2. Area (sq.m) as functional unit for finishing materials

The quantity of concrete is generally expressed in terms of volume in the construction industry. Hence, it is important to point out the embodied carbon emissions per cu.m of concrete. The emissions for the various types of concrete used in the case study is analysed and results is shown in fig 11 as kg of CO_2 per cu.m of concrete.

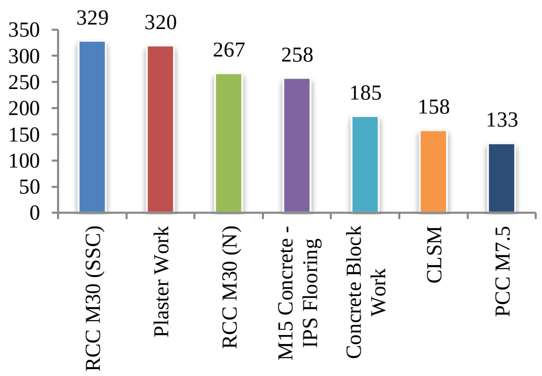

Figure 11: Embodied carbon emissions from concrete (kg of CO2 per cu.m)

The impact from the individual mix design components of concrete towards the embodied carbon emissions is shown in Table 3

Table 3: Embodied carbon break up -Concrete mix designs

Material	CLSM Concrete	M15 Concrete	PCC M7.5
Cement	56.3%	85.8%	88%
Crushed Sand	39.2%	10.2%	3%
Flyash	0.0%	0.0%	0%
Gravel	NA	1.3%	4%
Electricity	3.9%	2.4%	5%
Process water	0.6%	0.4%	1%

The influence of finishing materials is expressed in terms of area in the construction industry. The assessment of emissions for the various finishing materials is shown in fig 12 as kg of CO_2 per sq.m.

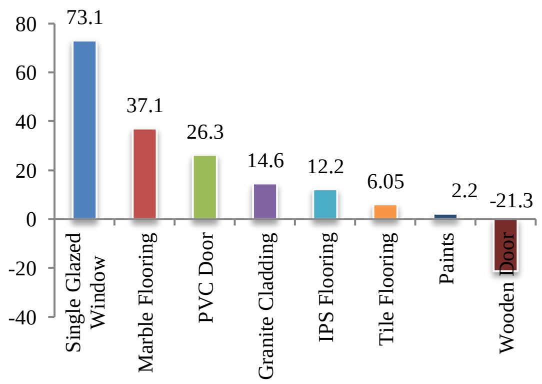

Figure 12: Embodied Carbon of Finishing materials (kg of CO2 per sq.m)

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To understand the overall embodied carbon emissions, it is important to quantify the emissions from fuel consumption of construction equipment's. Based on the pre- construction estimate, the embodied carbon of construction equipment's estimated using LCA tool is 14 MT of CO_2. The construction equipment's include wheel loader, transit mixer, tower cranes. Also DG sets are used in construction sites to cater electricity for site offices and the embodied carbon emissions of fuel used in DG sets are estimated as 20 MT of CO_2.

The residential tower with AAC Wall construction results in embodied carbon emissions of 1620 MT of CO_2 and 14,781 GJ of primary energy. This equates to 305 kg of CO_2 and 2.8 GJ of primary energy per usable floor area. By using AAC Blocks in superstructure walls, we can reduce 10.9% embodied carbon emissions compared to residential tower with RCC wall.

AAC walls in superstructure contribute to 20% of the total embodied carbon, whereas RCC walls contribute to 38% of the total embodied carbon.

The residential tower with brick wall construction results in embodied carbon emissions of 1817 MT of CO_2 and 18,117 GJ of primary energy. This equates to 342.7 kg of CO_2 and 3.4 GJ of primary energy per usable floor area. Brick walls in superstructure contribute to 28% of the total embodied carbon, whereas RCC walls contribute to 38% of the total embodied carbon

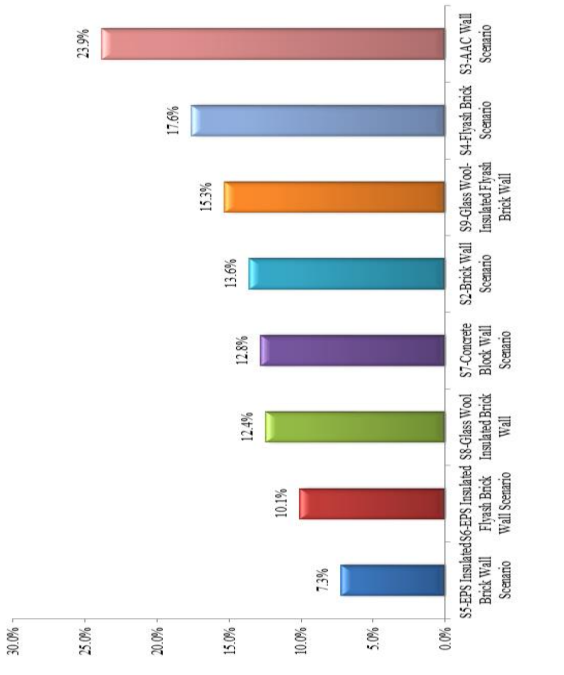

Figure 13: Reduction in Embodied Carbon emissions of different walls comparing to RCC Wall Scenario

Fig.13 shows reduction in embodied carbon emissions of different walls scenario compared with RCC Wall Scenario.

It shows AAC block saves 24% of emissions reduction where as flyash brick wall saves 17.6% of carbon emissions compared to RCC wall scenario. By using traditional bricks in superstructure walls, we can reduce 13.6% embodied carbon emissions compared to residential tower with RCC wall.

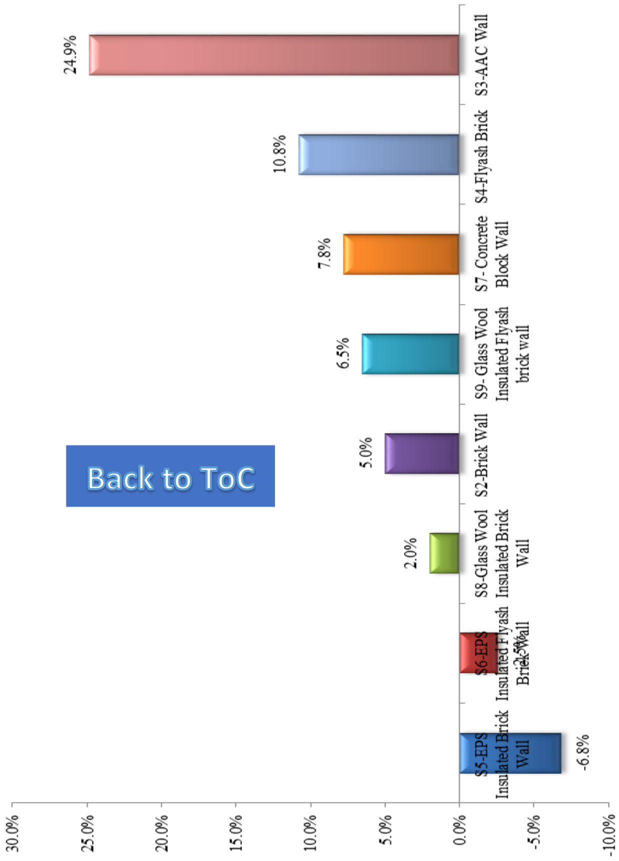

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Figure 14: Reduction in Embodied Carbon energy of different walls comparing to RCC Wall Scenario

Fig.14 depicts savings in embodied carbon energy of different wall materials with RCC wall.

Reduction in embodied carbon energy for AAC block is 24.9%, whereas for flyash brick wall is 10.8%. For insulated brick wall and insulated flyash brick wall there is no savings in embodied energy, it uses more embodied energy compared to RCC wall, which is a proven thing.

The similar graphs are applicable to all scenarios except in wall Super structure as shown in figure.15

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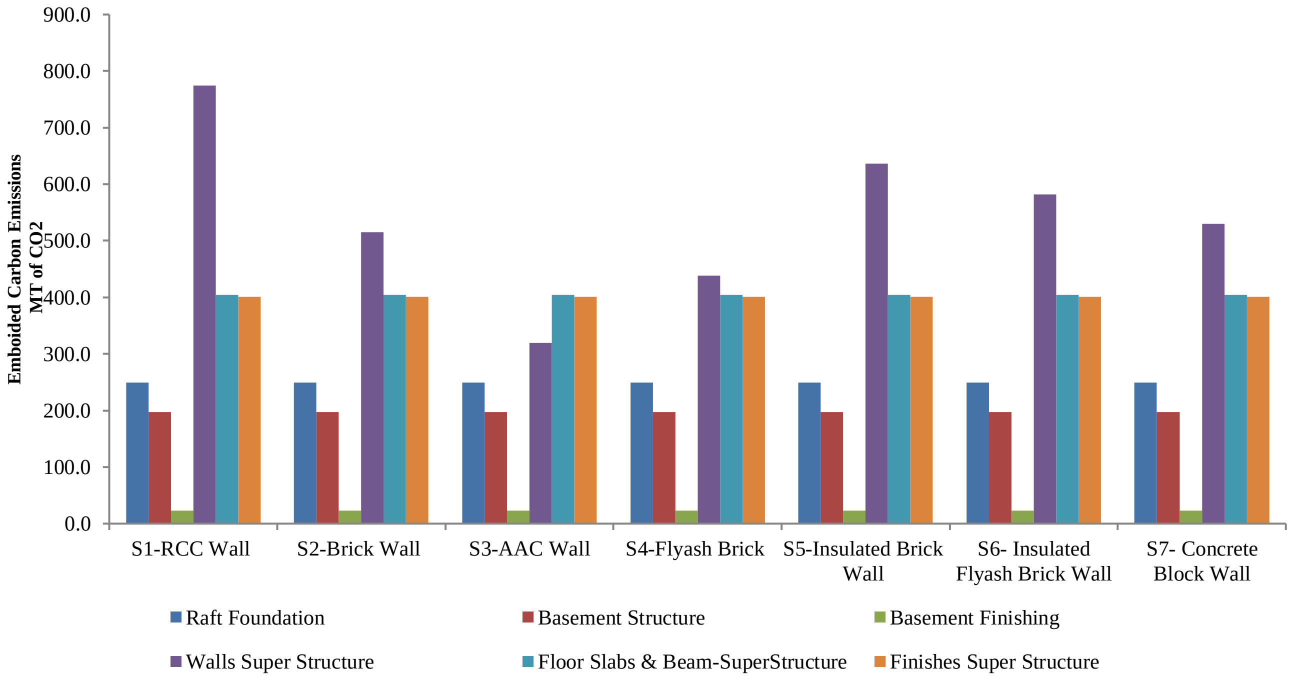

Figure 15: Embodied carbon-different scenarios an comparison

CONCLUSION

A LCA model of high-rise residential tower is examined with envelope options to determine the embodied carbon emissions and primary energy demand. Three scenarios with different wall material (Brick Masonry, RCC wall and AAC wall) have been assessed to support the selection of sustainable wall material.

The traditional brick wall masonry in the residential tower construction results in 23% more primary energy demand compared to AAC block masonry. The primary energy demand of brick masonry is higher due to burning of coal for the production of bricks. The coal usage in brick kilns releases several air pollutants and the specific energy consumption of brick kilns is higher in range of 1.2 to 1.75 MJ/Kg of fired product. Moreover, clay is natural resource depleted in production of bricks.

The high-rise residential construction with brick masonry consumes higher river sand and cement consumption which again increases the embodied carbon emissions and also the time spent for the construction process is more.

The self-compacting reinforced wall in high residential construction solves the issues related to time spent on construction process. But the high consumption of cement and steel results in increasing primary energy demand by 5.7% and the related embodied carbon increases by 12.8% compared to brick masonry. The production of concrete from batching plant and handling the concrete within the site (transit mixer and concrete pumping) consumes more fuel and thus increasing the embodied carbon emissions.

The RCC wall construction has less thermal insulation properties compared to brick wall masonry and leads to thermal comfort issues inside high-rise residential units. In addition, the aluminium formwork support is needed for the RCC wall masonry will also increase the embodied carbon emissions. Considering thermal insulation and thermal comfort as the key issues in high-rise residential construction, the suggested alternate wall material is aerated concrete block. AAC blocks have substantially lower thermal conductivity and excellent insulation properties than the RRC wall masonry and brick masonry typically 0.16 W/mk and low density in range of 550 to 650 kg/cu.m, four times lesser the RCC. The low density is achieved by the formation of air voids to produce a cellular structure. These voids are typically 1mm - 5mm across and give the material its characteristic appearance. So the AAC blocks are used as versatile lightweight construction material in residential tower construction. The use of AAC blocks in residential tower construction reduces the primary energy demand by 24.9 % and the associated embodied carbon emissions reduce by

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23.9% compared to RCC wall scenario. The use of flyash to greater extent nearly 60-70% in the mix design of AAC blocks reduces the embodied carbon to great extent.

In this paper, the embodied carbon (and energy) is studied in the context of buildings and construction materials. The consideration of embodied carbon needs to be integrated at the earliest design stage for energy efficient building design. In the literature, it also been shown that when considering the life cycle of a building, both embodied energy and operating energy need to be considered. The approach for estimating the operational energy of building is by using energy simulation method. As the operational energy is climate specific and more factors like orientation, occupancy pattern, efficiency of HVAC system are involved, detailed study on energy consumption for different Indian cities and the related operational carbon results will be discussed in detail in near future.

Acronyms

AAC Autoclaved Aerated Concrete

BHK Bedroom Hall & Kitchen

CLSM Consolidated Low Self Weight Material

LCA Life Cycle Assessment

SEC Specific Energy Consumption

RCC Reinforced Cement Concrete

PCC Plain Cement Concrete

PCC Plain Cement Concrete

GHG Green House Gases

LCI Life Cycle Inventory

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EMBODIED ENERGY DATABASE FOR BRICKS & BLOCKS IN INDIA USING PROCESS ANALYSIS METHODOLOGY

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Keywords: Embodied Energy, Building materials, Process Analysis, Bricks, Blocks

ABSTRACT

Embodied energy (EE) is the total energy required for extraction, processing, manufacturing and delivery of building materials to the building site. As EE is mostly derived from fossil fuels, it is also a good indicator of CO_2 emissions. A large growth in building stock is foreseen in India. As per an estimate by NITI Aayog, the residential floor space is estimated to grow four-times from 16 billion m^2 to 56 billion m^2, during 2017–2047. This will result in massive increase in the EE of buildings and associated carbon footprint. Thus, it is important to develop a better understanding of EE of buildings and undertake effective steps for reducing it.

Studies on estimating the EE of buildings in India suffer due to unavailability of good quality data on EE of several building materials, such as bricks. There are various kinds of bricks, differing in material composition (clay, fly ash, cement, etc.) and types (solid, perforated, hollow, etc.). Different technologies and processes are used in different regions of the country to produce bricks. Thus, the EE of bricks varies significantly across technologies and regions. This paper presents EE of bricks and blocks using process analysis methodology. The EE database is based on performance monitoring data from more than 30 brick manufacturing units.

The analysis shows that a) EE of bricks shows a large variation across types and regions (800–4750 MJ/ m^3 of bricks) b) Solid burnt clay bricks, which are largest in terms of market share, have the highest EE and shows large regional variations (2450–4750 MJ/m^3 of bricks) c) Several cement and fly ash-based bricks, compressed stabilized clay blocks and hollow burnt clay bricks have low EE (800–1600 MJ/m^3 of bricks).

INTRODUCTION

The building construction sector is undergoing a fast-paced growth in developing countries like India, due to increasing population, economic growth and rapid urbanization.

As per one of the estimates by NITI Aayog, the residential floor space in India, is estimated to grow four times from 16 billion m^2 to 56 billion m^2, during 2017–2047 (IESS, 2015). In the context of sustainable development, it is necessary to reduce the environmental impacts created during the life cycle of buildings.

The identification of appropriate measures/policies to reduce energy consumption during the life cycle of buildings, primarily requires proper estimation of Embodied Energy (EE) and Operational Energy (OE). EE of a building is the total energy required for the extraction, processing, manufacture and transportation of building materials used in the construction of the building. As most of the energy used comes from fossil fuels, it is associated with CO_2 emissions and hence EE is also a good indicator of carbon emissions. Studies on estimating EE of buildings in India suffer due to unavailability of good quality data on EE of several of the building materials, such as bricks. Masonry construction using bricks is the major form of building construction in India. Calculation of EE for such building requires good quality data on the EE of bricks.

Lack of good quality EE data for bricks and blocks, is primarily due to the nature of the brick manufacturing industry. The manufacturing industry of masonry bricks and blocks is spread throughout the country. The total number of manufacturing units is estimated to range between 2,50,000 to 3,00,000, majority of which belongs to the unorganized industrial sector. This makes it difficult to obtain good quality data on energy consumption. Solid burnt clay bricks, which are the largest in terms of market share, show regional variations in the manufacturing technology, raw material characteristics and energy consumption. Thus, there is a need for region specific data to assess EE, especially of solid burnt clay bricks.

OBJECTIVE & SCOPE OF STUDY

This paper focusses on creating the EE database for masonry units used for masonry construction. Masonry units comprise blocks or bricks. Bricks are traditionally made of size 230x110x70mm, with regional variations in dimensions. Blocks are larger in size and are commonly referred to by their nominal sizes such as 400x200x200mm, 600x200x200mm, etc.

Eleven types of bricks/blocks have been covered in this study. They are:

1. Solid burnt clay bricks
2. Perforated burnt clay bricks
3. Hollow burnt clay bricks
4. Autoclaved aerated concrete blocks (AAC)
5. Cellular light weight concrete blocks (CLC)
6. Pulverized fuel ash (fly ash) lime bricks
7. Pulverized fuel ash (fly ash) cement bricks
8. Solid concrete blocks
9. Hollow concrete blocks
10. Construction & Demolition (C&D) waste bricks
11. Compressed stabilized earth bricks (CSEB)

A brief description of the bricks/blocks considered in the study is provided in Annexure 1.

The data used in this study was collected during monitoring and site visits of production units, carried out during 2010–2017.

The EE database provides EE values for solid burnt clay brick at a regional level (4 regions) and single average values for other bricks and blocks at the national level.

The solid burnt clay bricks show large variations in their manufacturing technology, raw material characteristics and energy consumption across the country; so, region-specific EE values have been presented. Since the manufacturing processes of other bricks/blocks do not vary across the regions of the country, their EE have been provided at the national level.

METHODOLOGY

Earlier Studies

The accuracy and level of comprehensiveness associated with an EE analysis is dependent on which of the main analysis methods is chosen: process analysis, I–O analysis or hybrid analysis (Treloar, 1997). The method used depends mainly on the overall objectives of the assessment and the availability of required data. The process-based analysis is observed to be more appropriate for EE assessment of building materials particularly for the Indian construction industry (Praseeda, 2015). In this study, the EE of bricks and blocks have been assessed using process analysis, based on the system boundary definition suggested in International Federation of Institute for Advanced Study (IFIAS) workshop in 1974 (Dias and Pooliyadda, 2004).

Process Analysis Methodology for EE Assessment

The IFIAS workshop (1974) suggested that four boundary levels could be drawn for assessing EE for most of the materials. These four levels are:

Level-1 Direct energy spent during production process and transportation of product

Level-2 Direct energy of raw materials and its transportation

Level-3 Direct energy spent for manufacturing equipment and its transportation

Level-4 Direct energy spent in making machines which support the manufacture of equipment and its transportation.

The energy spent in levels 1 and 2 represents more than 90% of the total EE (Dias and Pooliyadda, 2004). Since it is practically difficult to assess the energy consumptions at levels 3 and 4, the first two levels (levels 1 and 2) have been considered as a system boundary of the EE assessment in this study. The total EE is the energy required directly for the main manufacturing process and the indirect energy embodied in the material inputs to the process (Treloar, 1998), as shown in Figure 1.

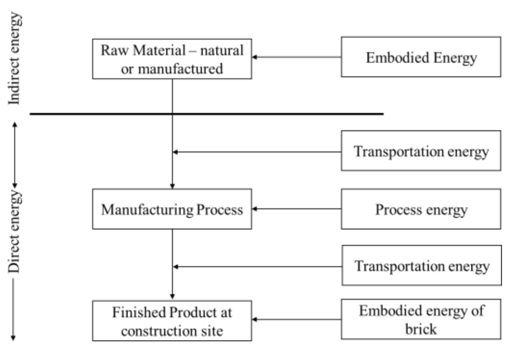

Figure 1: EE assessment framework adopted in the current study

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Table 1: Energy inputs considered while calculating process energy of bricks & blocks

Bricks/Blocks	Inputs considered while calculating the process energy
Autoclaved aerated concrete blocks	Electricity and diesel used for operating the plant machinery + fuel (Petcoke/coal) used to generate steam for autoclaves
Cellular light weight concrete	Electricity used for operating the plant machinery
Pulverized fuel ash-lime bricks	Electricity used for operating the plant machinery
Pulverized fuel ash-cement bricks	Electricity used for operating the plant machinery
Solid concrete blocks	Electricity used for operating the plant machinery
Hollow concrete blocks	Electricity used for operating the plant machinery
Compressed stabilized earth blocks	Electricity used for operating the plant machinery
C&D waste bricks	Electricity used for operating the plant machinery
Perforated burnt clay bricks	Electricity used for clay preparation and extrusion + fuel used in drying and firing of bricks in brick kiln (excludes solar energy for drying of bricks)
Hollow burnt clay block	Electricity used for clay preparation and extrusion + fuel used in firing and drying of bricks in brick kiln and dryer (excludes solar energy for drying of bricks)
Solid burnt clay bricks	Fuel used in firing of bricks in brick kiln (excludes sun energy for drying of bricks)

The EE of bricks/blocks considered in this study has been presented in terms of primary energy. The conversion factor used in the Indian context is 1 kWh = 11.22 MJ (Praseeda, 2015).

Instead of presenting EE values in MJ/kg, EE has been presented in MJ/m^3 in this study. This has been done to ease the computation of EE of buildings. It is easier to compute volume of walls (m^3) from the building drawings as well as bill of quantities (BOQ). A simple multiplication of the volume of walls with the EE (MJ/m^3), gives the EE contributed by bricks

The following points are to be noted regarding the methodology of EE assessment:

1. The energy inputs considered for calculating the process energy are presented in Table 1.
2. The EE of inputs of manufactured raw materials like cement and lime is considered as indirect energy as explained in Figure 1.
3. EE of AAC blocks, CLC blocks, Pulverized Fuel Ash Lime bricks, Pulverized Fuel Ash Cement bricks and Construction & Demolitions (C&D) waste bricks are estimated based on data collected through plant visits (during 2011-2017).
4. EE for Solid Concrete blocks, Hollow Concrete blocks and Compressed Stabilized Earth Blocks have been estimated based on the data on raw material composition and energy consumption in plant, obtained from literature (BMTPC, 1990; MSME, 2010; MSME, 2011).
5. EE for solid burnt clay bricks is based on energy monitoring carried out at 21 solid burnt clay brick manufacturing enterprises across seven states in the country by the team (during 2010–2017), along with the monitoring results from other studies (CPCB, 2016; TERI, 2016).
6. Transportation energy for bricks/blocks (except solid burnt clay bricks) is the average of the estimations done for two cities—Pune and Varanasi. To estimate transportation energy, specific energy consumption of diesel trucks-1.67 MJ/km-tonne (0.465 kWh/km-tonne) is used (TERI, 2007).
7. The transportation energy of burnt clay bricks (solid/perforated/hollow) includes the energy required to transport clay, coal and finished products for the given regions. The transport distances have been assumed based on the interactions with brick manufacturers.

Methodology for Estimating Region-Specific EE of Solid Burnt Clay Bricks

The methodology used for assessing region-specific EE for solid burnt clay bricks is explained in the following three steps (as shown in Figure 2) -

1. Regions: Based on the similarity in kiln-type distribution and energy consumption patterns, states have been grouped into four regions as shown in Table 2 and Figure 3. North-Eastern states have not been included due to the unavailability of monitored data.

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Table 2: Characteristics of manufacturing regions of solid burnt clay bricks

Regions	States	Contribution of kiln type in total production	Characteristics of regions
Region-1	J&K, Haryana, Punjab, Delhi NCR, West UP, Uttarakhand, HP	90% FCBTK and 10% IDZZK	Good quality clay/brick earth available in abundance in the plains. The production capacity of kilns is relatively large. Predominantly coal is used as fuel.
Region-2	East UP, Bihar, West Bengal, Jharkhand, Orissa	85% FCBTK, 13% IDZZK and 2% NDZZK	Good quality clay/brick earth available in abundance in the plains. The production capacity of kilns is relatively large. Predominantly coal is used as fuel.
Region-3	Rajasthan, Gujarat, Maharashtra, MP, Chhattisgarh	50% FCBTK and 50% Clamps	Good quality clay/ brick earth is available only in a few pockets. A mix of relatively large capacity (FCBTK) and small capacity (clamp) kiln.
Region-4	Karnataka, Tamil Nadu, Kerala, AP, Telangana	65% Clamps, 30% FCBTK and 5% Hoffman Kiln	Good quality clay/ brick earth is available only in a few pockets. A mix of relatively large capacity (FCBTK) and small capacity (clamp) kiln. Biomass fuels are used along with coal.

Note: FCBTK - Fixed Chimney Bull's Trench Kiln; IDZZK - Induced Draft Zig Zag Kiln; NDZZK – Natural Draft Zig Zag Kiln

2. Kiln distribution: For every region, brick kiln distribution and production according to the type of kiln has been estimated. This is based on the information collected from state-level brick kiln associations and information obtained from state government agencies/departments (such as, State Pollution Control Boards, Mining Dept., etc). For example, in Region-1, it is estimated that FCBTK (Fixed Chimney Bull's Trench Kiln) contributes around 90% while IDZZK (Induced Draught Zigzag Kiln) contributes around 10% of the total brick production in the region.
3. EE computation: Finally, region-specific EE data (in MJ/m^3) for solid burnt clay bricks is the weighted average of the two inputs—specific energy consumption of brick manufacturing enterprises and brick production percentage as per type of brick kiln for the region.

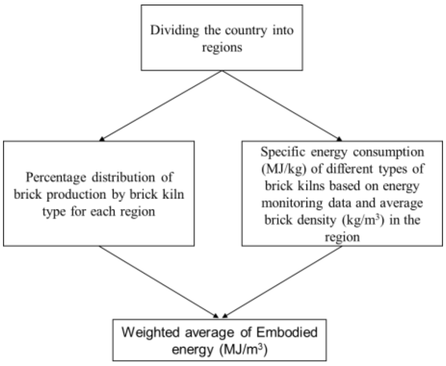

Figure 2: Methodology for estimating region-specific EE of solid burnt clay bricks

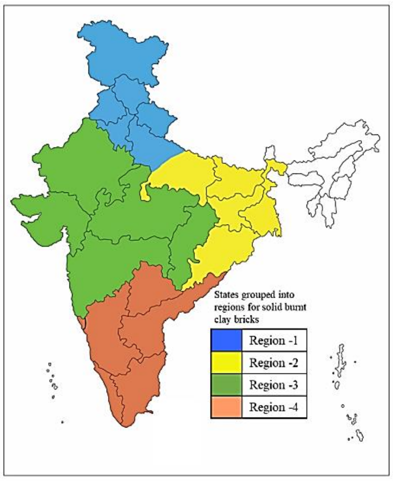

Figure 3: India is divided into 4 regions based on characteristics of solid burnt clay brick manufacturing enterprises

DISCUSSION & RESULT ANALYSIS

Using the methodology described in the previous section, the EE of bricks and blocks have been computed and presented in Table 3. Following points can be observed regarding EE values:

1. EE of bricks show a large variation across types and regions (800 to 4750 MJ/ m^3 of bricks). Hollow concrete blocks and Compressed Stabilized Earth Blocks have the lowest EE (~800 MJ/m^3), while solid burnt clay bricks manufactured in Region-4 has the highest EE (~4750 MJ/m^3).

Table 3: EE of bricks and blocks in India

Bricks/blocks		Symbol	Excavation / EE of Raw Materials (MJ/m^3)	Transportation of Raw Materials & Finished Products (MJ/m^3)	Process Energy (MJ/m^3)	Embodied Energy (MJ/m^3)
			Indirect Energy	Direct Energy		
Autoclaved aerated concrete blocks		A	717	230	559	1506
Cellular light weight concrete		B	897	128	106	1131
Pulverized fuel ash-lime bricks		C	848	658	177	1682
Pulverized fuel ash-cement bricks		D	634	406	177	1217
Solid concrete blocks		E	746	291	28	1065
Hollow concrete blocks		F	560	218	21	799
Compressed stabilized earth blocks		G	606	150	47	803
C&D waste bricks		H	1435	218	98	1751
Perforated burnt clay bricks		I	6	200	1743	1950
Hollow burnt clay block		J	4	125	1090	1219
Solid burnt clay bricks	Region-1	K	8	436	2127	2570
	Region-2	L	8	261	2219	2488
	Region-3	M	6	301	2255	2561
	Region-4	N	8	325	4414	4747

2. Solid burnt clay bricks, which have the largest market share, have the highest EE. Despite differences in technology, the EE values of solid burnt clay bricks in regions 1,2 and 3 are close to each other (~2500 MJ/m^3); but due to biomass fuel-based clamp and other types of brick kilns which have high specific energy consumption, the EE of solid burnt clay in Region-4 is high (~4750 MJ/m^3)
3. In case of burnt clay products (Fig. 4), the largest contribution to EE is process energy (86%–95%), while the contribution of transportation and indirect energy is small. The high process energy in burnt clay bricks is mainly due to energy used for firing of bricks in the kiln. Thus, in case of burnt clay bricks, measures taken to reduce the process energy through efficiency improvement of kilns and production of perforated and hollow products in place of solid bricks can help in reducing the EE of burnt clay bricks.
4. In case of cement and fly ash-based products (Fig. 4), the largest contribution to EE is due to indirect energy (mainly due to EE of cement and lime) and transportation energy. The process energy is small. Thus, reduction in indirect energy (e.g., efficient production process of raw materials), reducing material requirement (low density/hollow products) and avoiding long distance transportation of raw materials can help in reducing EE.

CONCLUSION

The paper presents EE of various types of bricks and blocks commonly used for building construction in India. This assessment has been carried out using process analysis methodology.

For computing the embodied energy of a building, it is necessary to have a database of EE of structural systems such as bricks and blocks used in the masonry construction. The EE figures of various bricks/blocks from this database, will be useful for architects, builders, green building rating agencies and other stakeholders in calculating the EE of various buildings.

The analysis shows that *a)* EE of bricks shows a large variation across types and regions (800–4750 MJ/ m^3 of bricks) *b)* Solid burnt clay bricks, which are largest in terms of market share, have highest EE and shows large regional variations (2450–4750 MJ/ m^3 of bricks) *c)* Several cement and fly ash based bricks, compressed stabilized clay blocks and hollow burnt clay bricks have low EE (800–1600 MJ/ m^3 of bricks)

There is a need for collecting more data from manufacturing units to further develop a region-specific embodied energy assessment for various types of bricks/blocks.

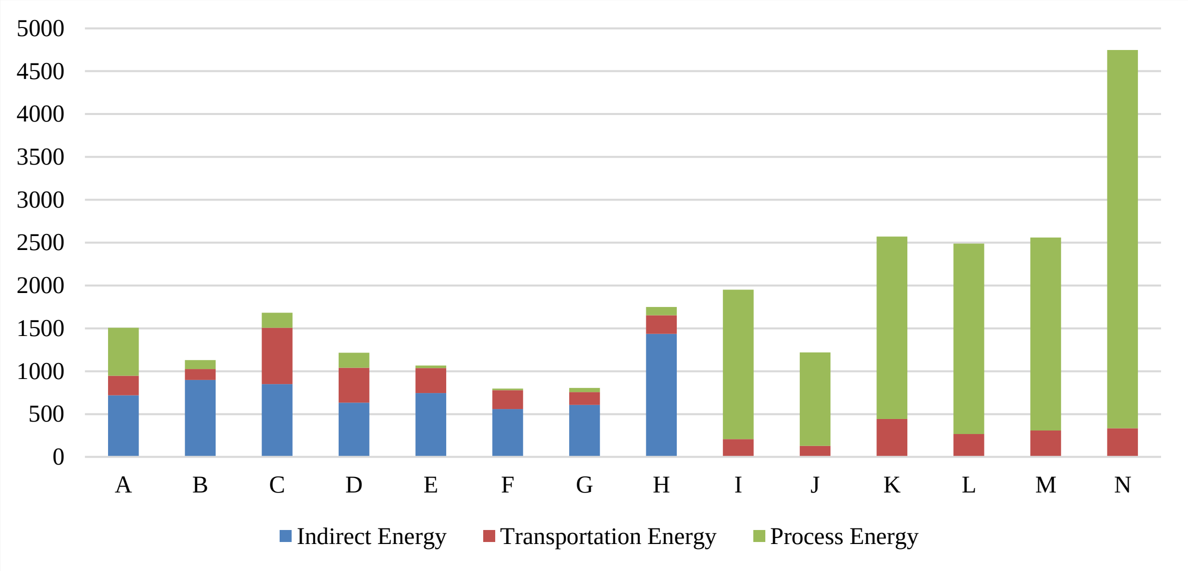

Figure 4: Contribution of indirect, transportation and process energy in the EE (MJ/m^3) for various types of bricks

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ANNEXURE -1

Bricks/blocks	Brief Description
Autoclaved aerated concrete blocks	It is a lightweight precast masonry block, that is produced by fly ash/sand, cement, lime, gypsum, aluminium powder/paste and water. These blocks are manufactured is a mechanized production setup. These blocks are steam cured in autoclaves.
Cellular light weight concrete blocks	It is a lightweight precast masonry block, that is produced by making a slurry of cement, fly ash, sand, water; which is further mixed with stable foam, in a concrete mixer. Usually, these blocks are water cured at ambient conditions.
Pulverized fuel ash-lime bricks	It is produced by blending fly ash, lime and an accelerator acting as a catalyst, and then compacting the mix in a press. In small scale plants. these bricks are usually water cured at ambient conditions.
Pulverized fuel ash-cement bricks	It is produced by blending fly ash, cement and an accelerator acting as a catalyst, and then compacting the mix in a press. In small scale plants. these bricks are usually water cured at ambient conditions.
Solid concrete blocks	It is produced by mixing cement, sand (fine aggregates) and stone chips (coarse aggregates, and then compacting the mix. In small scale plants. these bricks are usually water cured in ambient conditions.
Hollow concrete blocks	The manufacturing procedure, raw materials and setup is similar to solid concrete blocks except these blocks require different moulds A hollow concrete block has one or more large holes or cavities which either pass through the block (open cavity) or do not effectively pass through the block (closed cavity) and has the solid material between 50 and 75 percent of the total volume of the block.
Compressed stabilized earth blocks	It is a dense solid block produced by compacting a mixture of soil, sand, stabilizer (cement/lime) and water. These bricks are usually water cured at ambient conditions.
C&D waste bricks	These are dense solid block produced by compacting a mixture of cement (20-25%), crushed demolition waste (65-70%), admixture (5-15%) and water. As of now these bricks use special admixtures in their manufacturing, which reduces their curing time. These bricks are usually water cured in ambient conditions.
Solid burnt clay bricks	The primary material used in the production of fired clay bricks is clay or brick earth. The production process of solid bricks consists of: mining of clay, preparation of clay-mix, moulding of bricks, drying of green bricks and firing in brick kiln.
Perforated burnt clay bricks	The primary material used in the production of these blocks is clay. The production process of perforated bricks consists of: mining of clay, preparation of clay-mix, extrusion of bricks, drying of green bricks and firing in brick kiln. In practice, volume of perforations may range from 10 to 45% of the gross brick volume.
Hollow burnt clay blocks	The primary material used in the production of these blocks is clay. Hollow clay blocks are manufactured in factory setups which mainly includes extruders for brick moulding, artificial dryers, and tunnel kilns for firing of bricks. Volume of perforations are greater than 25% of the gross block volume, where the perforations are laid in the horizontal direction.

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SIMULATING NATURAL VENTILATION IN RESIDENTIAL BUILDINGS USING WATER TABLE APPARATUS

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Keywords: natural ventilation, water table apparatus, air flow pattern, air change rates, residential building.

ABSTRACT

Over the coming two decades tropical regions like Asia will be the main driver of 40% increase in world energy consumption. India is seeing a rapid uptake of energy-intensive methods for cooling buildings. Designing effective natural ventilation is essential for mixed-mode low energy cooling approaches. Analytical tools for designing natural ventilation flows for real buildings with elaborate geometry are either too simplistic to be useful or too complex to be accessible. The water table apparatus is an affordable tool to simulate air movement and visualize performance for architects, engineers and owners.

This paper demonstrates the use of the water table apparatus for natural ventilation to determine the quality of the air movement, distribution of air and the factors influencing them. The paper summarizes the construction of water table, validation of its results, and demonstration of its use as a design analysis tool. A scaled model of a residential apartment building is studied with parametrics for building orientation and window area. The simulated air-flow through the model is visualized with photographic documentation. Easily accessible graphic filters are used for post processing the information for quantitative analysis. Results of the air flow pattern are quantified in terms of temperature gradients, the effectiveness of natural ventilation, air change rates for each run. These results show the promise of the water table apparatus as an affordable and accessible analysis tool.

Keywords: natural ventilation, water table apparatus, air flow pattern, air change rates, residential building.

INTRODUCTION

The energy consumed by the building industry contributes to about 40% of the word's total energy consumption. In India, there has been a recent growth in the construction industry which had eventually led to a sudden increase in energy consumption. The total energy consumed by buildings in India is 33%, where the energy is consumed by commercial sector is 8% and that by the residential sector is 25% (ECBC 2009). Installation of air-conditioning equipment is rising rapidly in the country in both residential and non-residential buildings. Leading energy efficient building design solutions are being developed for non- residential buildings that include low energy solutions and mixed mode ventilation approaches. Residential buildings in India are largely of the multifamily multi- story typology. These buildings, with their high envelop to floor-area ratios, have potential for natural ventilation during certain times of the year. Architects and designers need to understand the effectiveness of natural ventilation and air movement as a result of their design decisions to achieve better building performance. However, architects design these buildings with little attention to natural ventilation flows. Currently available methods for analysis of ventilation flows, such as CFD modelling, are too complex to be accessible to most architects and their projects. This study demonstrates the use of the water table apparatus as an affordable alternative that provides useful results that can inform the design decisions for residential buildings in India.

The water table apparatus was built after reviewing some examples in literature, testing and modifying prototypes. Design calculations and dye concentration were finalized. The results of the water table were validated by comparing with the results of a smoke chamber test case that was published by Boutet (1987).

After validation, further experimentation of the water table is conducted for a single residential unit in a multi-story residential building using drawings for a real project. This paper documents the results of the base case design, and variations for orientation and window sizes. Analysis of the photographic documentation using graphic filters, time-lapse videos, calculations, shows that it is possible to make qualitative and quantitative observations about the performance of the design variations. The cost of the water table apparatus and the time required for the experimentation make this a useful tool for design analysis.

This methodology is used to evaluate wind induced natural ventilation in a building and is not applicable to

This methodology is used to evaluate wind induced natural ventilation in a building and is not applicable to temperature induced stack ventilation. Nevertheless, it is likely to be applicable to most of the multifamily residential construction in India.

LITERATURE REVIEW

There are three main methods used to understand and evaluate the ventilation air flow pattern: Numerical simulations, physical model studies and computational fluid mechanics. Physical models are most often studied using wind tunnels and smoke chambers. A few references are found on the use of salt water baths and water tables.

Open jet type simulator had been in use in the Architectural Association School of Architecture with the co-operation of the Department of Fluid Mechanics, University of Liverpool. Using a wind tunnel experiment, velocity ratios could be estimated (Koenigsberger 1975). Wind tunnels can be expensive to make and require measurement equipment that needs to be maintained and calibrated regularly.

A smoke chamber is a scaled down version of the wind tunnel simulator. The models are usually constructed using cardboard, paper and glass at a scale of 1” =1’. The model can be constructed to any scale within certain limitations. It is time consuming to construct the building model and to make modifications to change parameters. When the smoke chamber is at a reduced size, probes can be difficult to use. Analysis of the results is done from photographic documentation. The results obtained from a smoke chamber are two dimensional and need to be converted to a three-dimensional form (Boutet 1987).

Cunningham (2012) conducted research on the effects of the resistance pathways for air flow using a salt water bath. The intent was to provide quantifiable data to architects about the performance of natural ventilation and resistance pathways. The relation between stratification zone and height of the room, impact of a heat source was also studied.

Chiang Mai University in Thailand conducted the water table experiment to analyze the airflow pattern by passing colored water through horizontal and vertical slices (sectional) of the shallow building model. The depth of the model used in the experiment was 2 cm deep with 1 mm equally spaced openings and a thin layer of water was allowed to flow (3-4mm) across the table (Tantachamroon, 2015). The results were found to be not very accurate.

WATER TABLE APPARATUS

The water table (see figure 1) constructed in this study had a simplified design and dimensions of 1155mm x 750mm (30 mm deep) working base plane, 180mm x 750mm (95mm deep) input tank and 140mm x 750mm (125mm deep output tank (figure 1). It was designed to be economical and viable. Commercial plywood of 18mm thick was used for the basic framework and two types of 5mm thick acrylic sheet were used as a waterproofing layer. The acrylic working base plane of the apparatus constructed without undulations to ensure laminar flow. Commercially available adhesives and water-proofing sealants were used. A PVC Reservoir, 1020 mm x 650 mm x 330 mm (225 liters) was used for dyed water supply. A 0.5 HP self priming mini monoblock water pump was used. The piping, bends, inlet nozzles and control valves used are from reverse osmosis water treatment systems.

The input tank and output tank were lined with 5mm thick white glossy acrylic sheet and the working base plane was lined with 5mm thick acid-etched matt finish acrylic sheet to avoid glare during the photographic documentation.

To ensure the evenness of the working base throughout the experiment, a spirit level was used.

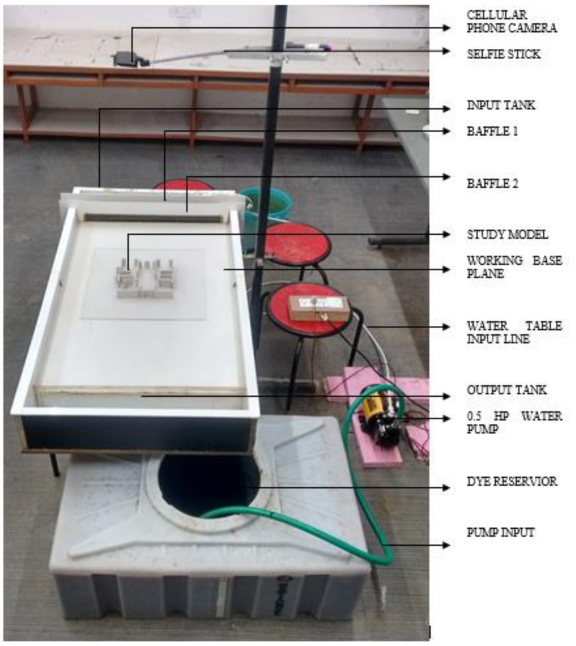


Figure 1:Water table apparatus experimental set-up

A cellular phone with an 8 MP, f/2.0 or autofocus camera on a selfie stick mounted on a vertical stand was used to record the videos of the experimental runs. The room is illuminated using artificial lights only to have a consistent illumination across the experiment runs.

The experiment is run by initially filling the water table with clear water. Then, the pump introduces the dye water via the input tank. The dye water uses Potassium Permanganate ($KMnO_4$) at a concentration of 1 g/litre. Baffles in the input tank help to achieve a uniform mixing of the dye water. The experiment runs through the initial stages and then reaches steady state in about 6 minutes. The total experiment run lasts for about 20 minutes, after which the pump is switched off, and all the water from the water table is drained to prepare it for the next run.

The velocity of air (simulated) relative to that of water (in the experiment) is calculated by equating the Reynolds number for the two scenarios. Reynolds number a dimensionless quantity is defined as the ratio of inertia forces to viscous forces of the liquid (Fox,2004).

$$\mathrm{Re} = \frac{\rho v l}{\mu} \tag{1}$$

Where, Re = Reynolds Number, ρ is the density of the fluid, v is the velocity of the fluid, l is the length or diameter of the object in the fluid, μ is the dynamic viscosity of fluid.

$$\mathrm{Re}_{(Air)} = \mathrm{Re}_{(Water)} \tag{2}$$

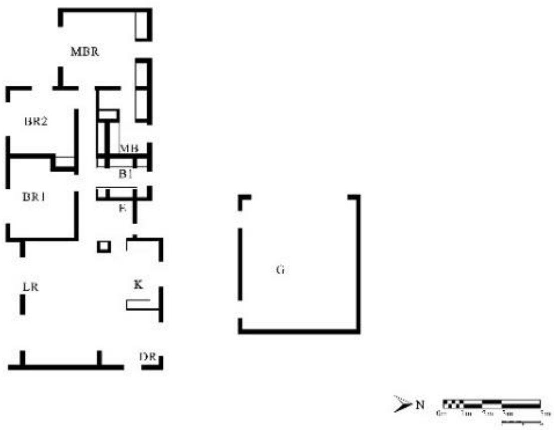
When, $\mathrm{Re}_{(\ Air)}$ is the Reynolds number of air,
$\mathrm{Re}_{(\ Water)}$ is the Reynolds number of water
And $\mathrm{Re}_{(\ Air)}$ and $\mathrm{Re}_{(\ Water)}$ are assumed to be equal,

$$\left(\frac{\rho v l}{\mu}\right)_{Air} = \left(\frac{\rho v l}{\mu}\right)_{Water} \tag{3}$$

$$v_{(Air)} = \left(\frac{\rho v l}{\mu}\right)_{Water} * \left(\frac{\mu l}{\rho l}\right)_{Air} \tag{4}$$

The water flow rate in the open channel, at 30 ºC was 0.076 l/s. The velocity of the water is calculated as per equation 4. The length (l) was 0.24m which is the length of the 1:50 scale building model facing the direction of the water movement. From equation 4, the velocity of the air is calculated as 0.0013m/s to that of 0.0034m/s respectively. This velocity of air is very low, and can be increased with modification to the appartus. The experimentation in this study is primarily for flow patterns, and is valid for low velocity scenarios. Higher velocity scenarios may need to be studied in future.

VALIDATION OF WATER TABLE APPARATUS



Legend							
MBR	Master Bedroom		MB	Master Bathroom		E	Entry
BR1	Bed Room 1		LR	Living Room		K	kitchen
BR2	Bed Room 2		DR	Dining Room		U	Utility
						G	Garage

Figure 2: Residence plan for validation (with legend)

The results of the water table were validated by simulating a residential building which had been tested in a smoke chamber (Boutet, 1987) and comparing the results. The flow pattern documented in the smoke chamber was compared with the results obtained from water table experiment.

The longer axis of the building was oriented in north–south direction. The entrance of the building was to the north. The plan consists of living, kitchen dining, master bed room, two bedrooms, two bathrooms. A garage was located adjacent to the building on the northern side. The north and the southern walls had maximum openings. The east and west walls had minimum openings. For the water table experiment, the extruded building plan was modelled at a scale of 1:50 using 5mm thick PVC sheet on a 5mm thick 500mm x 500mm wide transparent acrylic sheet. The recorded video was split into photographs at 20 seconds interval and line diagrams of the steady state flow were prepared to compare the results (Figure 4). The resultant flow in most of the spaces at BR1, BR2, MB, DR, K, B1 and G exhibited a similar pattern with both methods. MBR, LR, passages inside the building, adjacent space between the residence and garage exhibited slightly different flow pattern. The water table accuracy was sufficiently validated in comparison with the results from smoke chamber test.

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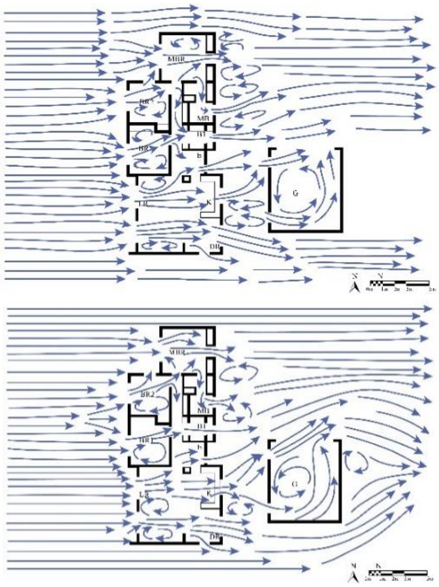

Figure 3: (Top) Flow diagram from smoke chamber test from Boutet (1987). (Bottom) Flow diagram from water table experiment

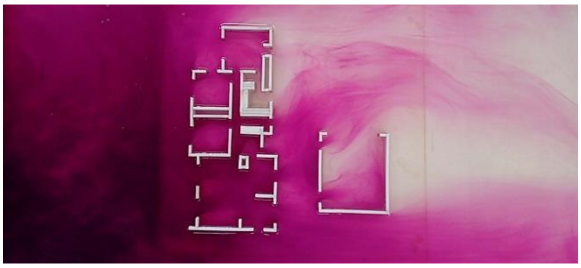

Figure 4: Water table experiment - Validation

PARAMETRIC ANALYSIS

Building selection

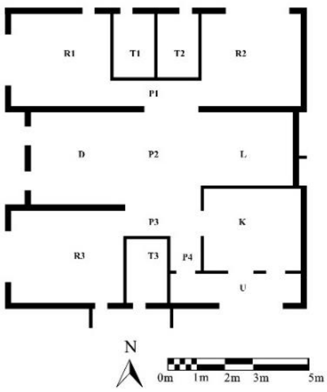

Figure 5:Plan of a residential building for experimentation

A typical apartment design of area 716 sqm was considered for the experiment trials. Base case (as designed) and various parametrics were simulated. The apartment (Figure 5) consists of a living room, dining room, three bed rooms (R1, R2, R3), kitchen, utility and passages (P1, P2, P3). The apartments have a square plan and are connected by a corridor. The western façade of the selected apartment had maximum openings and the northern and western façade had minimum openings. The eastern façade had the entrance to the apartment from the corridor.

Qualitative analysis

At the beginning of the experiments the flow pattern is typically different, and it changes as the water flow encounters the building edges. The steady state of the experiment run, when the flow patterns were observed to be repetitive for an extended duration, was used for the analysis. A line diagram depicting the steady state flow pattern for each experiment run was drawn.

Experiment 1 Base case

Experiment 1 was a baseline trial (0^o orientation) (Figure 6). The access to fluid movement (ventilation) was observed to be high at the windward side of the building R1, D, R3, P1, P2, P3, P4, U and minimum access in R2, L, K (Figure 6). T1, T2, T3 had a negligible access to ventilation. R2 was observed to have internal air movement from R1 and D through P1 and P2 respectively (Figure 6). Continuous circular air movement were observed in R1, R2, R3, K spaces (Figure 6 and Figure 7). Positive pressure was created in the windward side of the building. Negative pressure was created at the leeward side of the building model and eddies were observed.

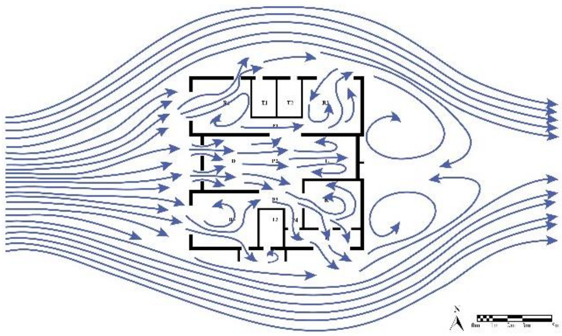

Figure 6:Flow pattern for experiment 1- Base case 0 ^{o} degree orientation

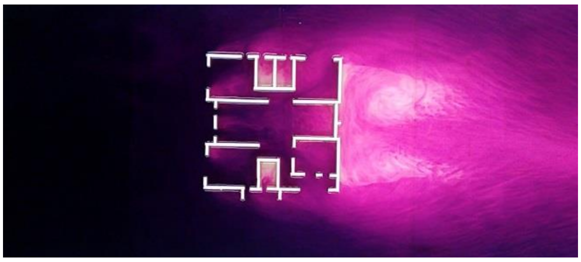

Figure 7: Experiment 1- Base case 0 ^{o}degree orientation

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Experiment 2 Orientation 45 degree

Experiment 2 was a trial at 45⁰ degree orientation (Figure 8). The access to flow was observed to be uniform throughout all the rooms in the building except in R2, T1 and T2. R2, T1 and T2 were observed to have minimum access to flow. R2 was observed to have internal air movement from R1 and D through P1 and P2 respectively (Figure 8 and Figure 9). Room D received direct access to flow from the openings as well minor amount of flow access was observed to enter from R3, K and U. Good access to the flow in passages P1, P2, P3 and P4 were noticed. Circular air movement were observed in R1, R2, R3, K spaces (Figure 8). Positive pressure was created in the windward side of the building. Negative pressure was negligible at the leeward side of the building model and smaller eddies were observed. The orientation of the model at 45⁰ degree demonstrated an even flow across major spaces in the building.

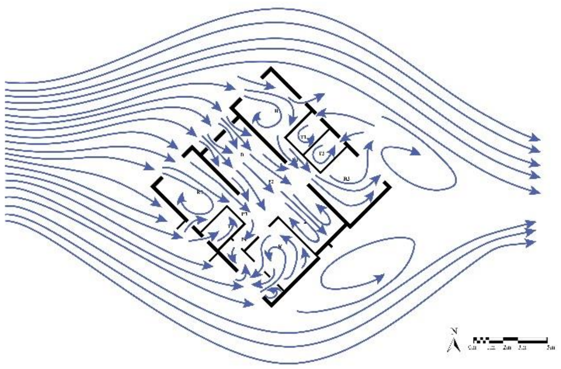

Figure 8:Flow pattern for experiment 2- 45 ^{0}degree orientation

Figure 9:Experiment 2- 45 ^{0}degree orientation

Experiment 3 Reduced inlet_0 degree

Experiment 3 reduced the inlet sizes (windows on the windward size) by 50% with 0⁰ degree orientation (Figure 10). The position of the openings was maintained as constant. The access to flow was observed to be uniform throughout all the rooms in the building. Good access to flow and absence of eddies were observed in all the rooms. Linear air movement were observed in all the spaces. Positive pressure was created in the windward side of the building. The rooms R1, T1, T2, R2 received a part of the wind from Northern side (Figure 10). T3, U, K, P4 received winds from the southern side. At the leeward side of the building negative pressure was not evident. It was observed that the winds from the northern side and the southern side converge into the spaces T1, R2 and U, K, P4 respectively (Figure 10 and Figure 11).

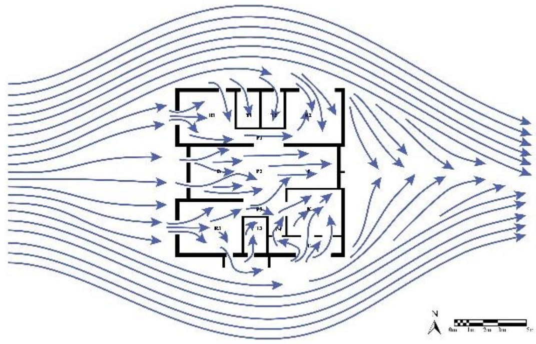

Figure 10:Flow pattern for experiment 3- Reduced inlet 0 ^{0}degree orientation

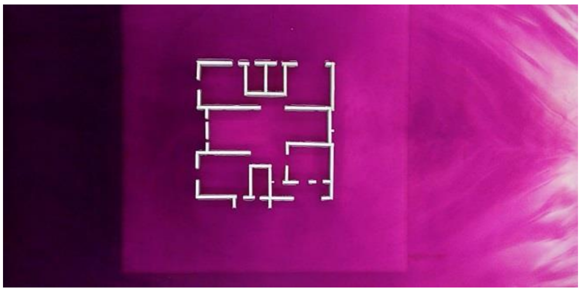

Figure 11: Experiment 3- Reduced Inlet 0 ^{0}degree orientation

To summarize, the flow patterns observed during the steady state had to be observed for repetitive flow pattern and are overlaid to define the line diagram. It is possible to observe the flow pattern on the windward side of the building, within the building and on leeward side of the building in both the photographic documentation and the line diagrams. The effect of positive and negative pressure areas was observed during the experimental runs.

The photographic documentation also helped in visualizing the flow pattern in each space inside the building. The raw video footage and the time lapse videos were particularly helpful in understanding changes in flow over time within an experiment. The intensity of the concentration differentiated spaces with maximum, minimum and low access to ventilation. This could be observed from the difference in the colour concentration of the dye in the model spaces.

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During the steady state, the change in the location of pressure areas, reduction in the size of the pressure areas with respective to the parameters, linear flow, circular air movement, eddies were observed for every parameter.

Quantitative Analysis

From the qualitative observations, four categories were formulated namely: good access to ventilation (for an entire room), minimum access to ventilation (for an entire room), dead spots (within rooms) and even distribution (within rooms).

In experiments (E1, E2, E3) every room was analysed and the percentage of the area was calculated under each category, through visual judgement of the movement of coloured water in the model. At the steady state frames, the percentage of area was calculated by tracing an outline polygon. The calculated results are shown in Table 1 and 2.

Comparing both the results in Figure 12 and Figure 13, it can be observed that experiment E3 (Inlet reduction) has the best performance with 90% access to ventilation, 10% minimum access to ventilation, 90% uniform ventilation, 8% non- uniform ventilation and 0% dead spots. This result justifies the literature that maximum velocity is obtained when the outlet opening is larger than the inlet opening as the positive pressure is created in the windward direction and the negative pressure is created inside the building (Boutet 1987).

The results from experiment E1 (base case 0^0 degree) demonstrated the least effective performance with 59% access to ventilation, 41% minimum access to ventilation, 28% uniform ventilation, 50% of non-uniform ventilation and 22% dead spaces.

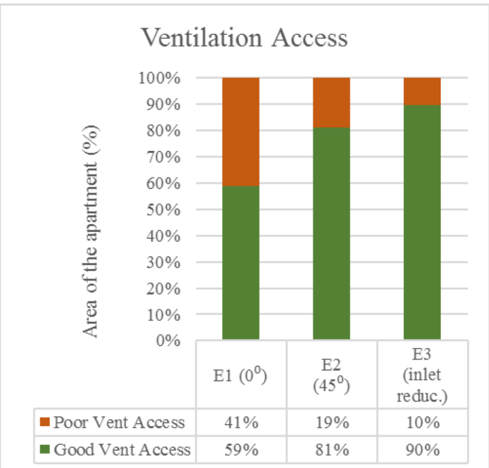

Figure 12: Ventilation access

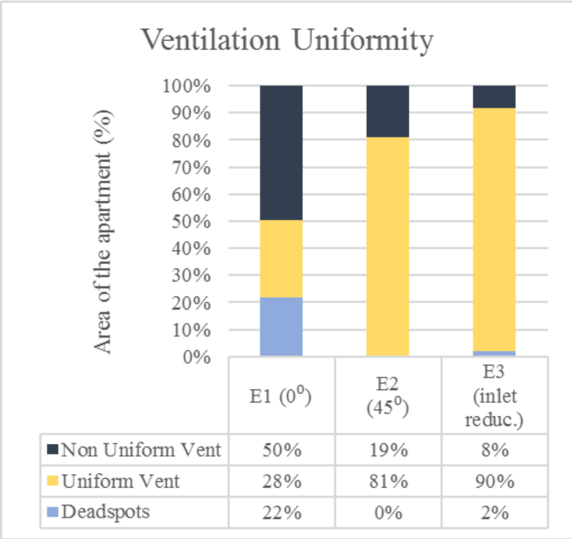

Figure 13: Ventilation uniformity

Table 1: Ventilation Access

		Good access to ventilation			Min Access to ventilation		
Room	Area	E1 0^0 T1	E2 45^0	E3 Inlet reduc	E1 0^0 T1	E2 45^0	E3 Inlet reduc
R1	13.9	13.9	13.9	13.9			
R2	13.9			13.9	13.9	13.9	
R3	15.7	15.7	15.7	15.7			
D	15.9	15.9	15.9	7.16			8.74
L	10.3		10.3	10.3	10.3		
K	12		12	12	12.0		
U	5.78	5.78	5.78	5.78			
T1	4.2			4.2	4.2	4.2	
T2	3.97			3.97	3.97	3.97	
T3	3.97		3.97	3.97	3.97		
P1	3.5	3.5	3.5	0.24			3.26
P2	8.48	8.48	8.48	8.48			
P3	3.8	3.8	3.8	3.8			
P4	1.6	1.6	1.6	1.6			
Total	**117**	**68.7**	**94.9**	**105.0**	**48.3**	**22.1**	**12.0**
% Total		**59%**	**81%**	**90%**	**41%**	**19%**	**10%**

Table 2: Ventilation accessibility

		Dead spots			Even distribution		
Room	Area	E1 0^0 T1	E2 45^0	E3 Inlet reduc	E1 0^0 T1	E2 45^0	E3 Inlet Reduc.
R1	13.9		0	0		13.9	13.9
R2	13.9	3.8	0	0			13.9
R3	15.7		0	0		15.7	15.7
D	15.9		0	0	15.9	15.9	7.16
L	10.3	5.9	0	0		10.3	10.3
K	12	7.77	0	0		12	12
U	5.78	0.78	0	0		5.78	5.78
T1	4.2	2.7	0	0			4.2
T2	3.97	1.9	0	0			3.97
T3	3.97	2.6	0	0		3.97	3.97
P1	3.5		0	0	3.5	3.5	0.24
P2	8.48		0	0	8.48	8.48	8.48
P3	3.8		0	0	3.8	3.8	3.8
P4	1.6		0	0	1.6	1.6	1.6
Total	**117**	**25.5**	**0.0**	**0.0**	**33.3**	**94.9**	**105.0**
% Total		**22%**	**0%**	**0%**	**28%**	**81%**	**90%**

Calculation of ACH

The Air Change rate was calculated for experiment E1 baseline. Dye concentrations were calibrated from 0% to 100% for 10% increments. In this study, the ACH was calculated for the living room and the dining room considered as a single entity. The calculation of ACH for the simulated results were calculated for various frames at 2-minute intervals. The concentration at each frame was visually compared with the calibration standards to analyse the percentage of concentration. Equations 8 and 9 derived from Dockery (1981) were used to calculate the air-change rates.

$$dc = PaC_o dt + \frac{S}{V} dt - (a+k)Cdt \qquad (8)$$

Assuming $Pa = 1$, $\frac{S}{V} = 0$, $k = 0$

$$dc = (aC_o - aC)dt$$

$$\frac{dc}{dt} = a(C_o - C)$$

$$a = \frac{dc}{dt*(C_o - C)} \qquad (9)$$

Where, a is Air change rate per hour, dc is change in concentration, dt is change in time, C_0 is the outside concentration, C is the inside concentration Pa is penetration factor/ fraction of the outdoor contaminant entering the indoors and K is rate associated with process of removal other than air exchange, S is the indoor – source emission rate, V is the indoor volume

Table 3: Calculation of ACH

S. No.	Trials	Time (mins)	Frames	Co	C	dc	dt	a=dc/ dt* (Co-C)	ACH
1	E4	00:02		0.51	0.27	0.01	2	0.02	1
		00:04		0.52	0.36	0.01	2	0.03	2
		00:06		0.53	0.47	0.01	2	0.09	5
		00:08		0.54	0.5	0.01	2	0.14	9
								Total Average ACH	4

Table 3 shows the average ACH for the selected time frames (00:02 :00 to 00:08:00) is calculated as 4.

Calculation of temperature gradient

The simulation for a particular time frame was converted to a black and white image and processed to 5 levels using the posterisation filter in Photoshop Cs5.1. The areas for each of the five levels of concentration within the room were calculated by tracing an outline polygon (Figure 14).

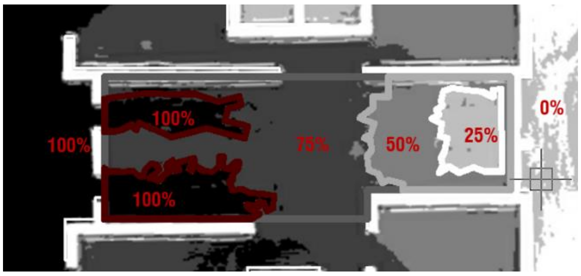

Figure 14: Posterization and plotting percentage of concentration

Using a straight line curve where the concentration represents the mixed air temperature, with the internal temperature is assumed as 30 degree and external temperature as 20 degree Celsius, air temperatures at various points in the room were calculated. The concentration varies from 0%, 25%, 50%, 75% and 100% and the calculated mixed air temperatures are 30ºC, 27.5ºC, 25ºC, 22,5ºC, and 20ºC respectively.

The calculations could be repeated for the other simulations at various time frames and concentrations using equations 10 and 11.

.

$$y = mx + c \qquad (10)$$

when y is the mixed air temperature, m is the slope, x is the % of concentration, c is the intercept on y axis $c = 30$.

$$m = \frac{y2 - y1}{x2 - x1} \qquad (11)$$

Where x_n are the concentrations, and y_n are the temperatures for the 100% and 0% conditions.

CONCLUSION

The effectiveness of air movement in a space has been demonstrated and understood by using a water table apparatus. The results thus obtained are visual, similar to false color monochrome imaging.

A water table can be used for the following:

1. To study performance of designs for effective natural ventilation.
2. To calculate the percentage area of space that is well ventilated.
3. To identify dead spots that are not ventilated.
4. To identify areas that have uniform and non-uniform flow.
5. To calculate Air changes per hour (ACH).
6. To calculate mixed air temperature achieved based on concentration of dye.

The water table can thus serve to be a suitable tool for an architect's office and in design schools to study natural ventilation and make design decisions.

Further the research can be carried out by comparing the results with CFD simulations. Higher velocities can be studied by modifying the apparatus. The method can be used to understand the effect of natural ventilation due to the introduction of wing walls and fins. The effect of natural ventilation inside and outside the building due to adjacent the buildings could also be studied.

NOMENCLATURE

Re	= Reynolds Number
ρ`	= density of the fluid
v	= velocity of the fluid
l	= length or diameter of the object facing the direction of the fluid flow
μ	= dynamic viscosity of fluid
b	= breath of the water table channel
h	= depth of the cross section
a	= air change rate per hour
dc	= change in concentration
dt	= change in time
C_0	= outside concentration
C	= inside concentration
Pa	= penetration factor/ fraction of the outdoor contaminant entering the indoors
K	= rate associated with process of removal other than air exchange
S	= the indoor – source emission rate
V	= the indoor volume
y	= temperature,
m	= slope
x	= % of concentration
c	= intercept on y axis

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MODEL FOR ASSESSING IMPACT OF ENERGY CONSERVATION BUILDING CODE 2017

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Keywords: Energy Conservation Building Code (ECBC), peak demand shaving, impact assessment model, energy performance benchmark, energy use intensity, building labeling

ABSTRACT

The updated Energy Conservation Building Code (ECBC) has been updated and launched in 2017. Informed by extensive analysis of energy conservation measures, revised energy performance benchmarks have been proposed in this updated code. However, in national context, the impact of these recommendations is unknown.

This paper presents a model that evaluates the impact of updated performance benchmarks to the code at national level. The model simulates the proposed energy performance benchmarks; ECBC, ECBC+ and Super ECBC (S-ECBC), to evaluate their impact relative to the Business as Usual (BAU) case. A Predictive Compliance Model (PCM) indicating gradual market transformation has been compared as well. The outcomes include cumulative savings for national building stock, peak shaving potential and financial impact of avoided power infrastructure resulting from demand abatement.

Outcomes are categorized by Building Typology, Climate Zone and State. Maximum potential for energy use savings and peak demand shaving is expected from Office typology, Composite climate zone and the state of Maharashtra. While S-ECBC scenario delivers maximum energy efficiency potential, it does not offer cost-benefit. The ECBC scenario succeeds in providing cost-benefit along with energy efficiency potential.

This model can shape strategic policy decisions. The outcomes can identify critical sectors or states for policy implementation. The financial outcomes can inform incentives for building technologies. This model may be replicated at state level for setting Minimum Energy Performance Standard (MEPS) and ratcheting the energy performance benchmarks.

INTRODUCTION

Building Codes and regulations have the potential to improve and standardize the construction practices. These, however require constant revisions and updates to keep current with improvements in technology. Recently, the building energy efficiency code for India was updated. While the updated code is expected to mitigate the building energy use, its impact is unknown. This paper models the impact of the updated ECBC in the national context.

Aware of building energy use and its impact, the government assesses ECBC uptake as part of its five- year plan review. In 2014, an expert group was setup by the Planning Commission to review the progress on 12th five-year plan and National Action Plan on Climate Change (NAPCC). Considering market transformation towards ECBC compliant stock, the committee projected abatement of 131 $mtCO_2e$/year in 2030 (Planning Commission, 2014).

Similar studies, evaluating the impact of code implementation have been undertaken. In the United States, the Building Energy Codes Program (BECP) under the Department of Energy (DOE), has assessed the impact of implementing of various code revisions within an analysis frame of 1992-2040 for residential and commercial buildings. The study uses prototype buildings for evaluating respective Energy Use Intensity (EUI). This information is applied to historical data and forecasted building stock information (US DOE,

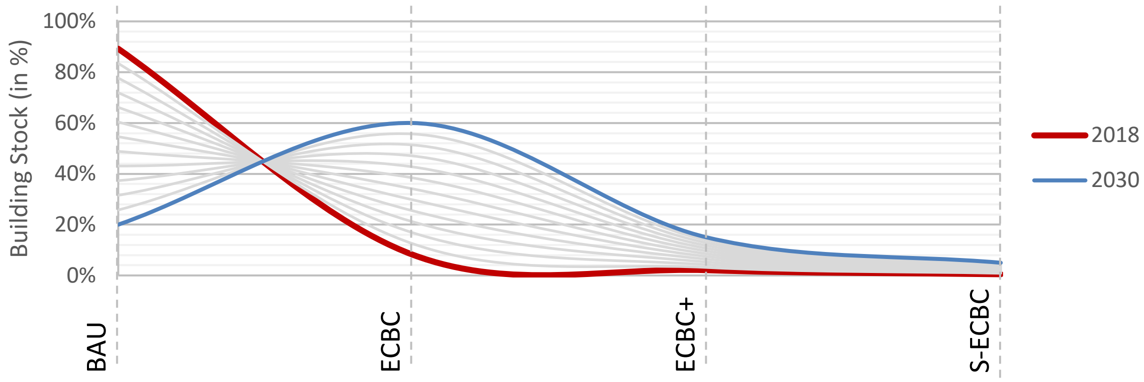

Figure 1 Predicted Compliance Model (PCM)

Table 1 Performance benchmarks for Office typology in Composite climate

METRIC	UNITS	BAU	ECBC	ECBC+	S-ECBC
Energy Use Intensity (EUI)	kWh/m^2-yr	203.0	164.3	147.8	97.6
Peak Energy Demand (PED)	W/m^2	135.4	116.7	113.2	110.4
Peak Cooling Energy Demand (P$_C$ED)	W/m^2	70.3	52.6	50.5	38.8

METHODOLOGY

The model uses a bottom-up approach, wherein performance parameters for respective building typologies across climate zones have been compiled through energy simulation analysis for prototype buildings. These outcomes are applied to building stock estimates and trends. Building stock information has been compiled from extensive market research. The source for building stock information is based on demand and accounts for socio-economic factors. The impact assessment outcomes have been categorized by typology, climate zone and state.

Scenarios and Performance Parameters

5 performance scenarios have been modelled for all building typologies across climate zones. These are

1. BAU: The Business as Usual (BAU) case is representative of the current building stock. The BAU case assumes prevalent construction practices.
2. ECBC: The ECBC case outlines minimum effort required to meet ECBC compliance. This case includes energy efficiency measures modelled onto the BAU case based on life cycle analysis approach.
3. ECBC+: The ECBC+ case outlines energy performance beyond code requirements.
4. S-ECBC: The Super ECBC case outlines near zero performance or best available technology scenario representative of maximum achievable energy efficiency.
5. PCM: The Predicted Compliance Model assumes a distribution consisting of BAU, ECBC, ECBC+ and S-ECBC stock. This model reflects a steady market transformation from BAU dominant stock to code compliant stock within the analysis time frame. Figure 1 outlines the annual variability of building stock distribution modelled for the analysis period.

For each of these cases, performance benchmarks of Energy Use Intensity (EUI) in kWh/m^2-yr, Peak Energy Demand (PED) in W/m^2 and Peak Cooling Energy Demand (P$_C$ED) in W/m^2 have been compiled from energy simulation studies of prototype buildings across typologies and climate zones (Somani et al, 2015). These prototypes were simulated for all respective cases except the PCM case. The PCM case inputs have been computed by weighting stock distribution. For reference, Table 1 indicates

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performance benchmarks for all scenarios for Office typology in Composite climate zone.

Building stock forecasting

Prior to 2008, building stock was growing at 8% (Sathaye, et al, 2005). Following the economic downturn of 2008, the real estate growth declined (CRISIL Research). Latest available information indicates that as of 2017, vacancy of commercial real estate in key economic zones of National Capital Region (NCR), Navi Mumbai, Bangalore, Hyderabad, Pune, Kolkata and Chennai have increased (JLL-CII). Considering this downward trend, conservative demand estimates from RICS study have been used (RICS Research, 2011). As the effect of updated ECBC will start showing in 2018, the analysis uses stock estimates from 2018 onwards. The analysis does not model existing stock before 2018.

In addition, to the stock trends, the model also accounts for surviving stock. The analysis uses a normally distributed stock population with average life expectancy of 30 years. The distribution assumes that more than 50% of the stock exceeds its service life. Figure 2 outlines the surviving stock model used in the analysis.

Building stock classification and distribution

The building stock has been categorised by typology, climate zone and state-wise. However, building stock categorization data is unavailable. In absence of robust data, stock categorization has been estimated from market reports.

Research by RICS estimates real estate demand on a per capita basis (RICS, 2011). Considering that building stock correlates with population, population trends have been utilized for estimating stock distribution by climate. Since commercial buildings fulfilling the scope of ECBC are largely restricted to urban areas, the stock distribution follows urban population statistics. Data for urbanized cities has been compiled from Ministry of Finance for Tier 1, 2 and 3 cities and their respective population from 2011 census data. This data has been used to prorate building stock to cities. Further, available weather data facilitates mapping these cities to respective climate zones. The cities have also been identified with their respective states.

Building performance analysis for 19 building sub-types has been compiled. However, due to lack of categorised building stock data, these have been aggregated to 6 typologies. Stock distribution data has been referenced from the LBNL study that classifies building stock into retail, education, hospital, office, hotel and industrial sectors (Sathaye et.al, 2005). Percentage distribution of stock in 2030 by typology and climate zone is outlined in Figure 3. State-wise stock distribution in 2030 is outlined in Figure 4.

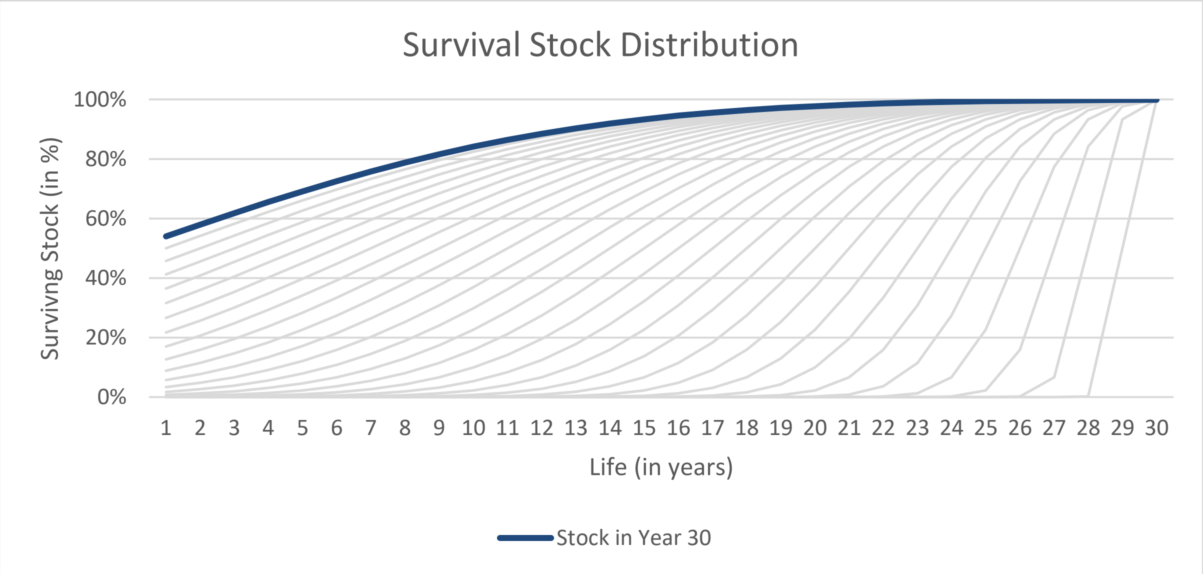

Figure 2 Survival stock distribution model

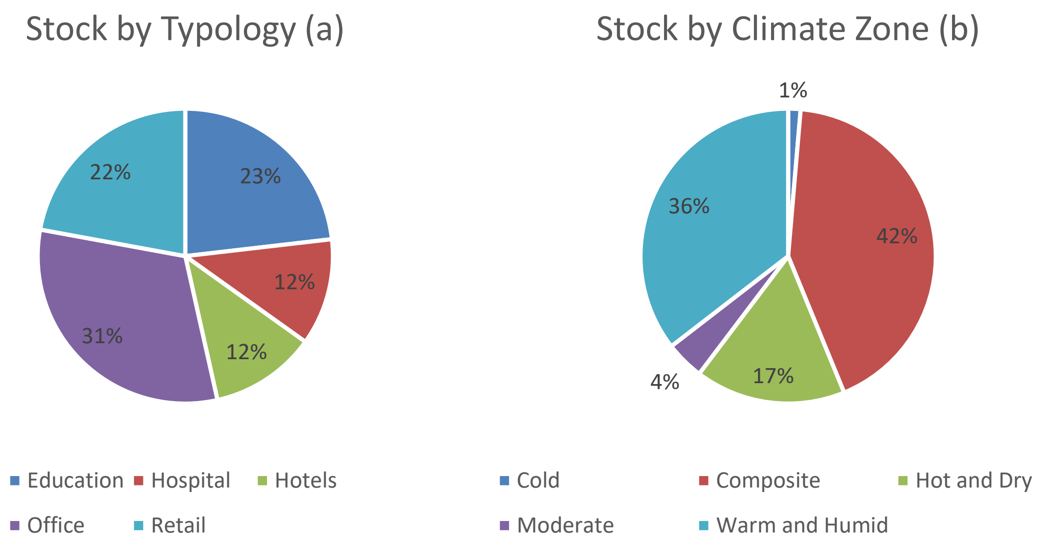

Figure 3 Distribution of surviving stock across (a) typologies and (b) climate zones in 2030

MODEL SIMULATION

Performance Simulation

Except PCM, all scenarios model 100% building stock with respective benchmarks. For example, ECBC scenario models 100% stock with ECBC performance benchmarks. The PCM scenario however is modelled to reflect anticipated market transformation. As indicated in Figure 1, this scenario dynamically models annual building stock distribution indicative of the uptake of ECBC and available technology measures. The PCM case assumes a normally distributed stock in 2030 representative of a mature market.

Using equations (1) to (8), benchmark performance and stock information inputs provide energy use, emission and energy demand metrics. The performance benchmarks for PCM case are dynamic as these are computed annually by weighting for different stock cases. Equation (9) outlines PCM case evaluation.

Financial Simulation

In addition to performance metrics, the model also evaluates financial savings in national context. The model includes cost parameters for incremental cost of construction, energy use and setting up thermal power based infrastructure. Incremental cost is computed from a database of products spanning envelope materials, HVAC and Lighting equipment. Considering complexity of HVAC systems reasonable assumptions have been applied while arriving at incremental cost. To add to this, the model allows updating financial parameters, including respective cost escalation rates and discount rates. The cost of constructing stock in respective year and demand savings offset by energy efficiency are computed as Capital Expenditure while the cost of energy use for stock is computed as Operating Cost.

MODEL EQUATIONS

National Energy Use and Savings

$$Cumulative\ Energy\ Use_{case} = \sum_{i=2018}^{2030} \sum_{j=1}^{5} \sum_{k=1}^{5} \left(EUI_{case}^{i} \times Stock^{i,j,k}\right) \tag{1}$$

$$Cumulative\ Energy\ Use\ Savings_{\ case} = Cumulative\ Energy\ Use_{BAU} - Cumulative\ Energy\ Use_{case} \tag{2}$$

National GHG Emissions and Abatement Potential

$$Cumulative\ GHG\ Emission_{\ case} = Energy\ Use\ Savings_{\ case} \times GHG\ Emission\ Factor \tag{3}$$

$$Cumulative\ GHG\ Emission\ Abatement\ Potential_{\ case} \\ = Cumulative\ GHG\ Emission_{\ BAU} - Cumulative\ GHG\ Emission_{\ case} \quad (4)$$

National Peak Energy Demand and Abatement Potential

$$Peak\ Energy\ Demand_{\ case} = \max_{i=2018 \rightarrow 2030} \sum_{j=1}^{5}\sum_{k=1}^{5}\left(PED_{Case}^{i,j,k} \times Stock^{i,j,k}\right) \quad (5)$$

$$Peak\ Energy\ Demand\ Abatement\ Potential_{\ case} \\ = Peak\ Energy\ Demand_{\ BAU} - Peak\ Energy\ Demand_{\ case} \quad (6)$$

National Peak Energy Demand and Abatement Potential

$$Peak\ Cooling\ Energy\ Demand_{\ case} = \max_{i=2018 \rightarrow 2030} \sum_{j=1}^{5}\sum_{k=1}^{5}\left(P_C ED_{Case}^{i,j,k} \times Stock^{i,j,k}\right) \quad (7)$$

$$Peak\ Cooling\ Energy\ Demand\ Abatement\ Potential_{\ case} \\ = Peak\ Energy\ Demand_{\ BAU} - Peak\ Energy\ Demand_{\ case} \quad (8)$$

PCM Case

$$Metric_{\ PCM} = \sum_{Case=1}^{4}\sum_{i=2018}^{2030}\sum_{j=1}^{5}\sum_{k=1}^{5}\left(Metric_{case}^{i,j,k} \times Stock\ Weight_{Case}^{i,j,k}\right) \quad (9)$$

National Savings

$$Energy\ Use\ Savings_{case} = \sum_{i=2018}^{2030}\sum_{j=1}^{5}\sum_{k=1}^{5}\left(Cumulative\ Energy\ Use\ Savings_{case}^{i,j,k} \times Fuel\ Cost^{i,j,k}\right) \quad (10)$$

$$National\ Cost\ of\ Stock_{case} = \sum_{i=2018}^{2030}\sum_{j=1}^{5}\sum_{k=1}^{5}\left(Stock_{Case}^{i,j,k} \times Construction\ Cost_{case}^{i,j,k}\right) \quad (11)$$

$$Demand\ Abatement\ Savings_{case} = \max_{i=2018 \rightarrow 2030} \sum_{j=1}^{5}\sum_{k=1}^{5}\left(PED_{case}^{i,j,k} \times Setup\ Cost^{i,j,k}\right) \quad (12)$$

$$Net\ Savings_{case} = Demand\ Abatement\ Savings_{case} + Energy\ Use\ Savings_{Case} \\ + National\ Cost\ of\ Stock_{case} \quad (13)$$

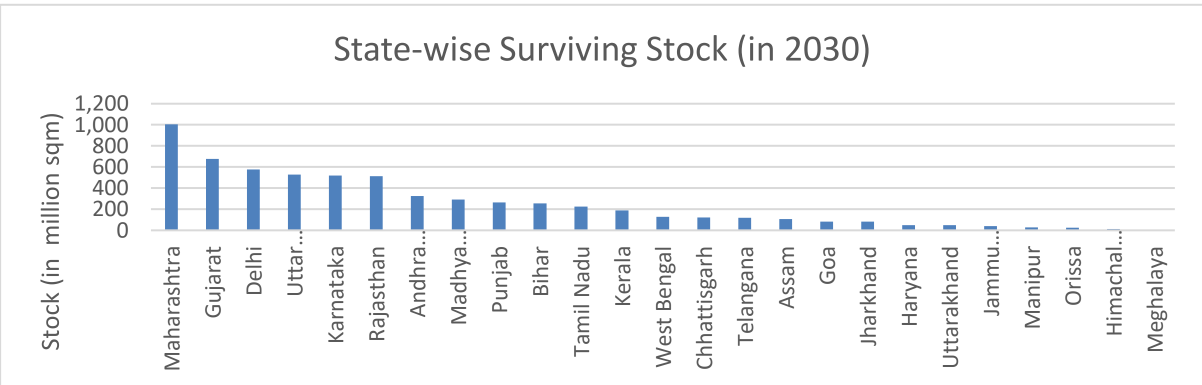

Figure 4 State-wise surviving stock in 2030

RESULTS

Among all typologies, Office and Retail sectors have significant energy savings potential. With respect to climate zone, composite and warm humid climate present significant savings opportunity. Among states, Maharashtra, Gujarat and Karnataka present significant potential for energy savings and demand abatement. Figure 5 and Figure 6 outline energy savings potential by typology and climate zone respectively. Figure 7 outlines energy savings and peak demand abatement potential state-wise.

S-ECBC scenario outperforms the other scenarios for energy savings and demand abatement potential. Figure 8 outlines the energy savings potential while Figure 9 and Figure 10 outline the peak energy and peak cooling demand abatement potential. While it is expected that the S-ECBC outperforms other scenarios on energy efficiency, the ECBC scenario outperforms all scenarios considering cost of investment and returns on savings. PCM scenario also provides cost-benefit within the analysis horizon. Figure 11 outlines cost-benefit for the scenarios.

To aid interpretation, state-wise outcomes for energy use savings and, peak energy and peak cooling demand abatement potential are depicted on a political map. Figure 12 showcases the map visualization of state-wise results for easy readability.

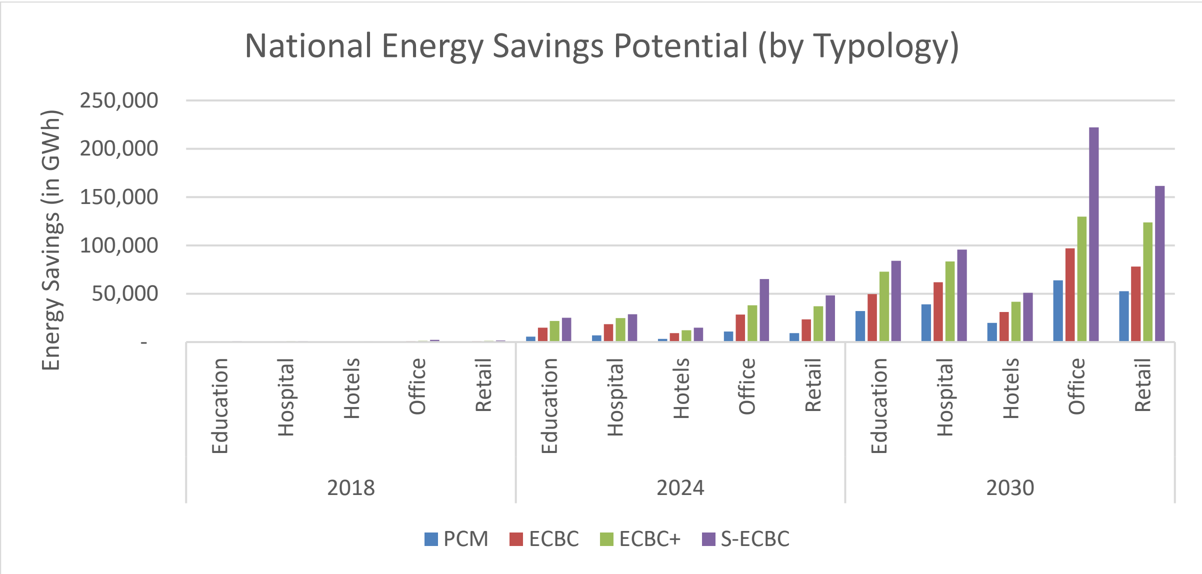

Figure 5 Energy savings potential by typology

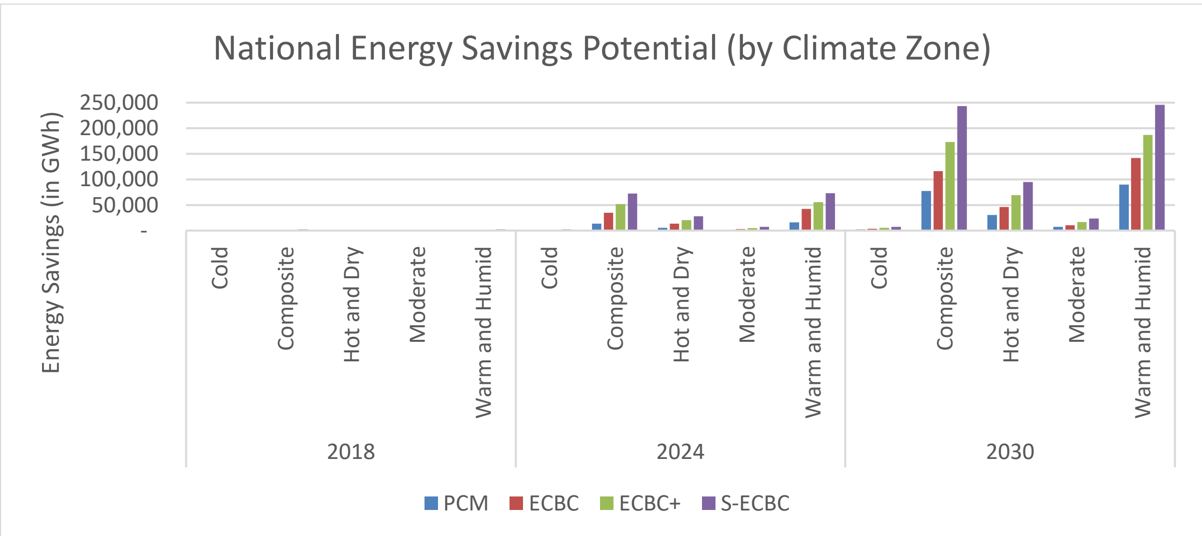

Figure 6 Energy savings potential by climate zone

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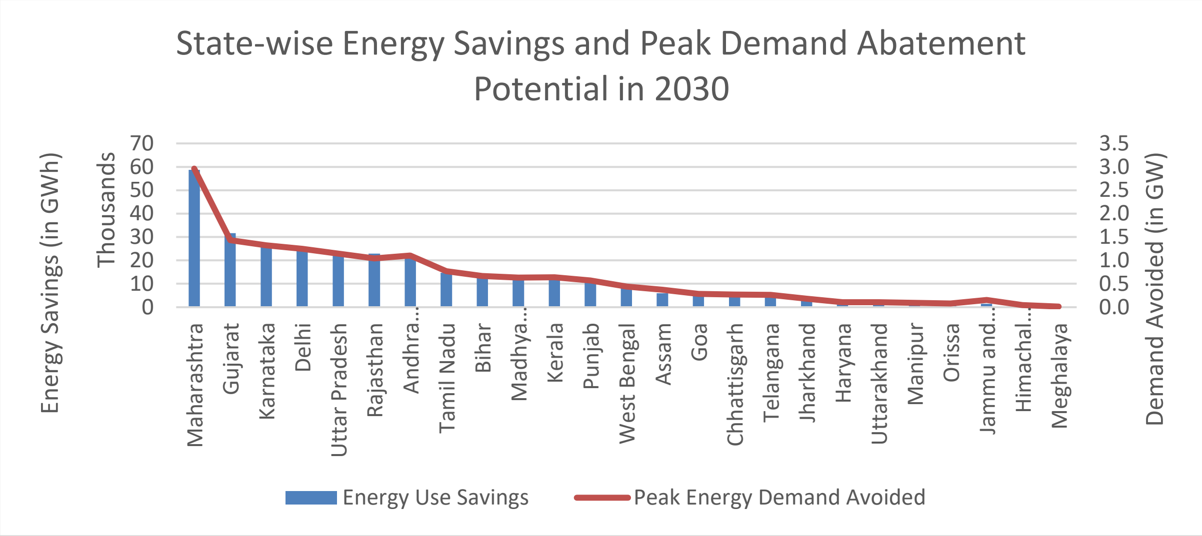

Figure 7 State-wise Energy savings and Peak demand abatement potential

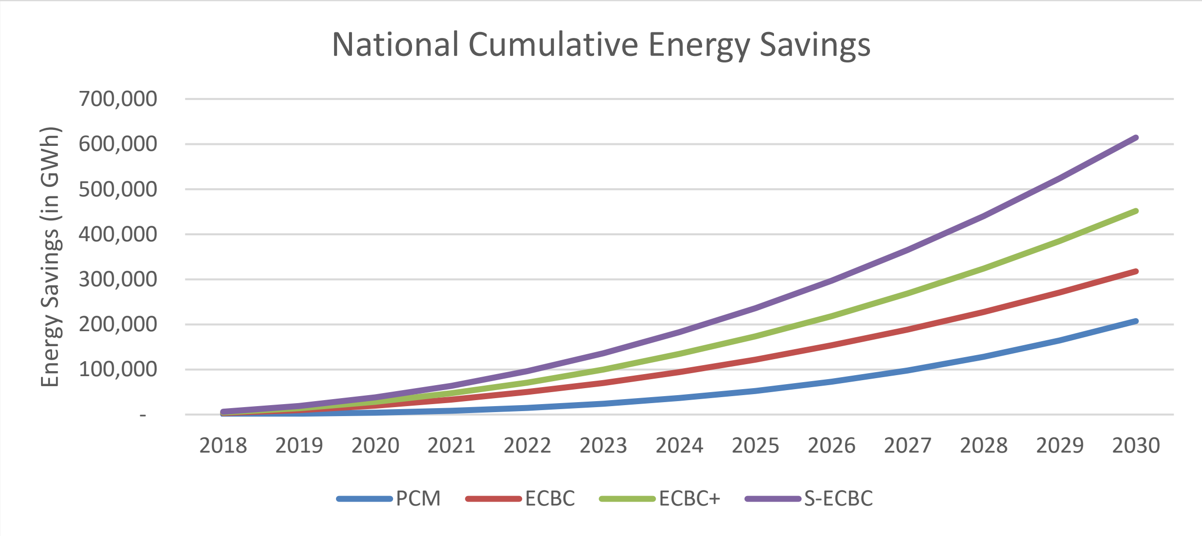

Figure 8 Scenario comparison for national energy savings potential

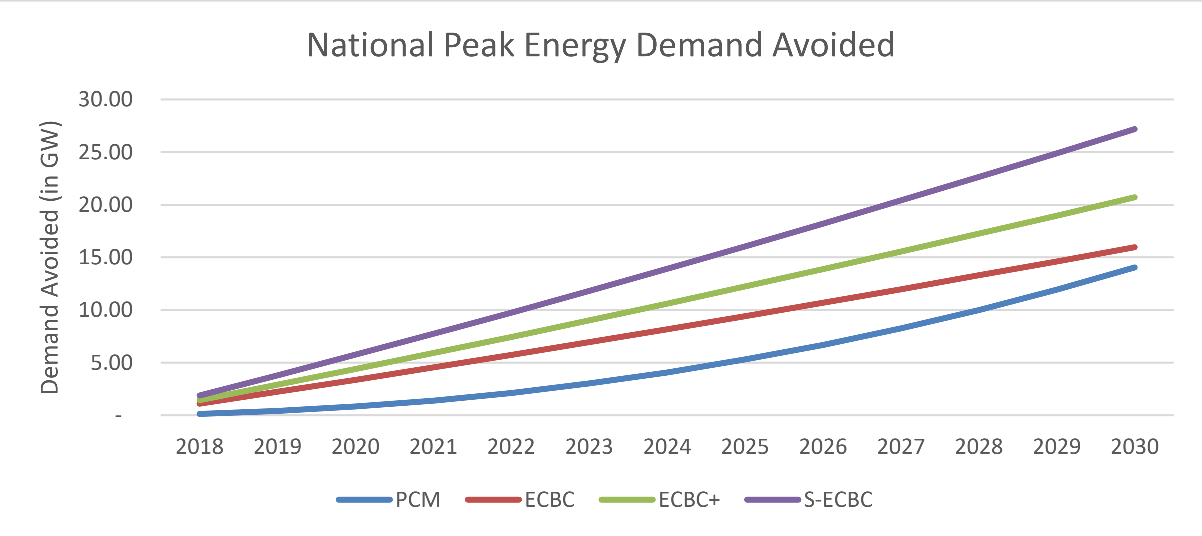

Figure 9 Scenario comparison for national peak energy demand abatement potential

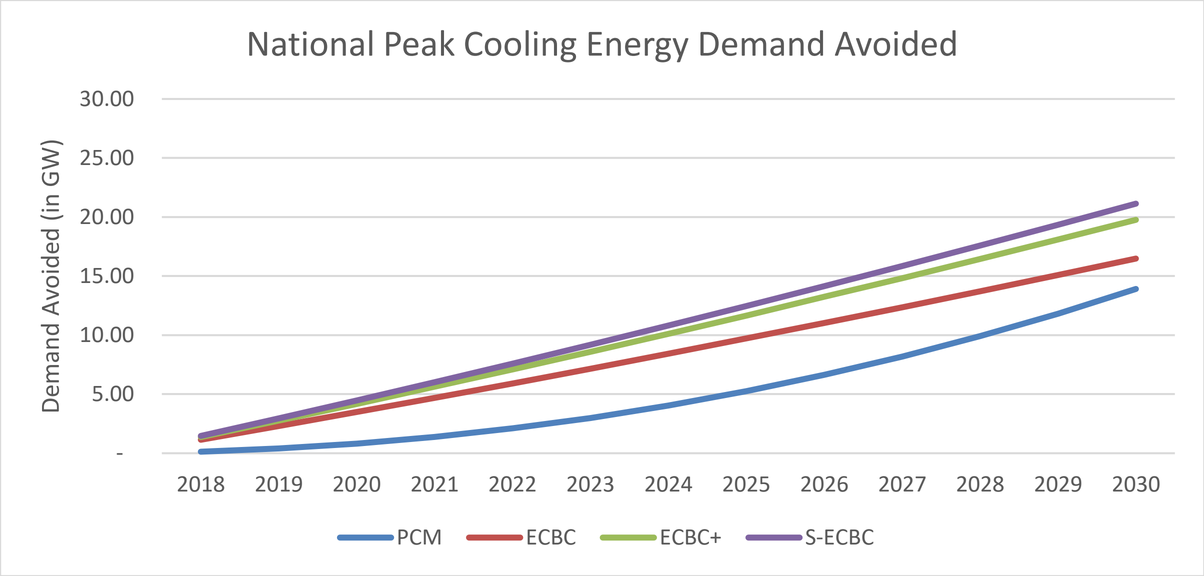

Figure 10 Scenario comparison for national peak cooling energy demand abatement potential

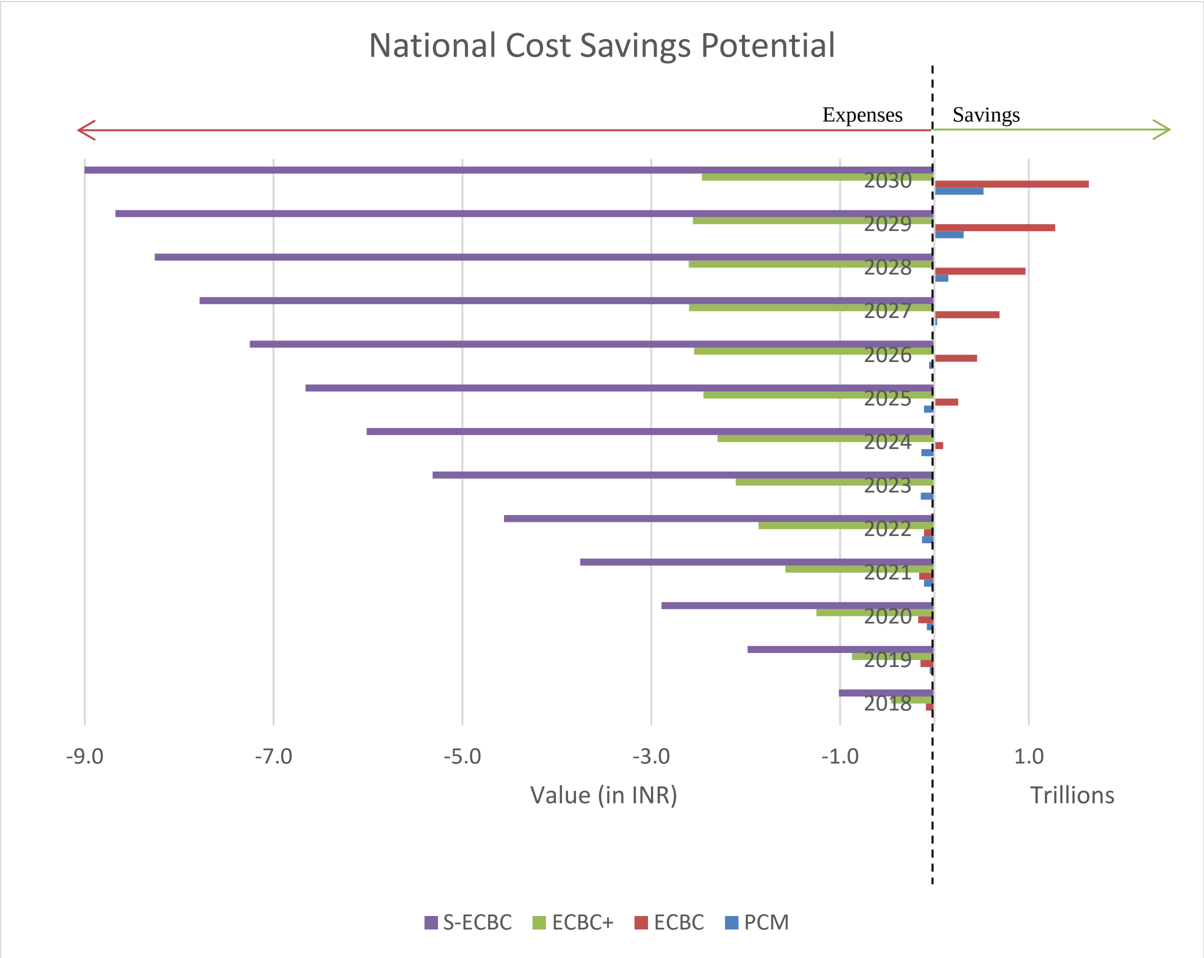

Figure 11 Scenario comparison for financial savings potential

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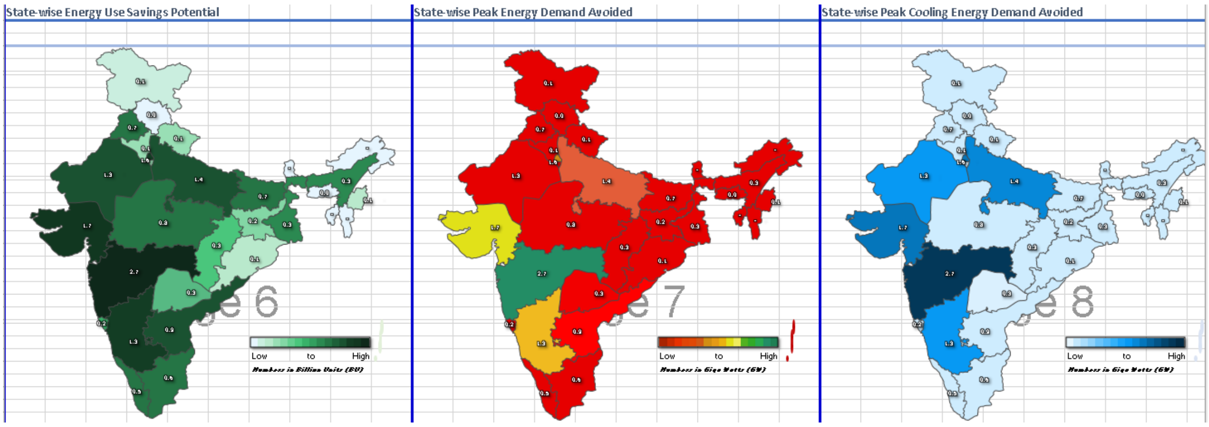

Figure 12 Visualization of state-wise outcomes of savings and demand abatement potential

CONCLUSIONS

The model assesses the impact of the updated ECBC using established metrics for the national context.

The model identifies states that have high potential for energy savings and demand abatement. This model can assist in prioritizing states that require policy implementation for energy efficiency adoption. For example, it may be interpreted through the model outcomes that 7 of the top10 states have notified or adapted ECBC for implementation.

The model also identifies typologies and climate zones that have high potential. This information may be used to focus on specific sectors and climate zones.

The financial outcomes can inform incentives for building technologies. The outcome on net savings indicates that the ECBC requirements are financially viable. The PCM scenario provides savings as well, confirming the viability of anticipated market transformation.

While the model helps in goal setting, it can also aid in tracking and measuring policy performance and achievement of milestones.

This model may be replicated at state level for setting MEPS and ratcheting the energy performance benchmarks.

There is however lack of building census data to carry out such analyses. Compared to the assessment presented in this paper, existing assessment studies (US and China) indicate relatively reliable building stock information. Research indicates that this data is critical to identify survival behaviour of buildings (Bradley, et.al, 2005). In the absence of reliable data, the model does not account for historical stock. A detailed study identifying building characteristics such as use type, area, location, etc. is required for reliable forecasts.

NOMENCLATURE

$case$	refers to scenarios ECBC, ECBC+, S-ECBC and PCM.
i	refers to respective year (2018 to 2030)
j	refers to 5 Climate Zones of India
k	refers to 5 Building Typologies
$EUI_{case}^{i,j,k}$	Energy Use Intensity for respective *case* in year *i*, for climate zone *j* and building typology *k*.
$Stock^{i,j,k}$	Survivng Stock in year *i*, for climate zone *j* and building typology *k*.
$PED_{Case}^{i,j,k}$	Peak Energy Demand for respective *case* in year *i*, for climate zone *j* and building typology *k*.
$P_CED_{Case}^{i,j,k}$	Peak Cooling Energy Demand for respective *case* in year *i*, for climate zone *j* and building typology *k*.
$Metric_{case}^{i,j,k}$	Metric refers to either, Energy Use, GHG Emission, Peak Energy Demand, etc. for respective *case* in year *i*, for climate zone *j* and building typology *k*.
$Stock\ Weight_{Case}^{i,j,k}$	For exmaple, in year *1*, 50% stock is *BAU case*, then for *BAU* scenario in year *1*, the weight is 0.5

$Fuel\ Cost^{i}$	Cost of electricity per unit in year i.
$Construction\ Cost^{i}_{case}$	Cost of constructing a building.

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FUTURE CITIES – HOT AND SMART: URBAN HEAT, IMPACTS, RISK AND RESILIENCE IN INDIA

Komali Yenneti

Keywords: Smart Cities, India, Urban Heat, Resilience, Energy

ABSTRACT

India is in the midst of a 'smart cities' revolution. The 'Smart Cities Mission', a government-backed programme of urban renewal, is considered to hold promise to make the country's cities more liveable, sustainable, and resilient. But how can this be achieved when the cities are facing a series of complex interconnected challenges related to urban warming? The social and environmental consequences of increasing urban heat across most Indian cities are starkly apparent. Cities are getting hotter, with severe implications for energy demand for cooling, public health, comfort and labour productivity. Yet, the issue of urban heat receives little attention. In this paper, the impact of urban heat to the needs of energy production and use, and to the society, especially with respect to human health and the risk of vulnerable people and communities to adverse thermal conditions and the capacity of households to adjust are provided and discussed in detail. The paper also presents the recent developments and knowledge on urban heat mitigation techniques and technologies, and reviews the role that specific technologies could play in enabling 'smart sustainable cities'. As the smart cities approach is driven by a belief in the application of technologies for the efficient management of urban growth, urban heat mitigation technologies seem like ideal tools to resolve major challenges of urban sustainability. In fact, a systematic focus on urban heat mitigation, is essential to provide a robust, adaptive and resilient pathway towards greater urban sustainability.

Key words: Smart Cities; India; Urban Heat, Resilience; Energy; Society

INTRODUCTION

India is in the midst of a 'smart cities' revolution. The 'Smart Cities Mission' is considered to hold promise to make the country's cities more liveable, sustainable, and resilient. But how can this be achieved when the cities are facing a series of complex interconnected challenges related to urban warming? Cities have become hubs of dense population and economic activities that demand large disproportionate fractions of ecosystem services, causing serious urban environmental issues like air pollution, poor water quality, and depletion of natural resources. At the same time, urban sprawl and sealing of urban surfaces with impervious paving and buildings as compared to vegetated areas have been resulting in cities themselves becoming urban heat islands (UHI) characterised by higher ambient temperatures as compared to the adjoining rural areas (Sharma and Joshi, 2016; Thomas et al., 2014).

Higher temperatures and frequent extreme heat events have serious energy, health and well-being, environment and economic impacts, as well as pose a significant risk to sustainable urbanisation and resilience of cities. Experimental studies conducted in several Indian cities document that the UHI effect increases energy consumption for cooling purposes and the peak electricity demand (Akpinar-Ferrand and Singh, 2010), increases mortality and morbidity rates, especially among the elderly, children and low- income communities (Azhar et al., 2014; Desai et al., 2015), affects outdoor and indoor thermal comfort conditions (Anupriya, 2016), and intensifies the concentration of greenhouse gas emissions (GHGs) (Yadav et al., 2017).

Advanced mitigation technologies and scientific models exist to counterbalance the impact of UHI (Santamouris et al., 2016). It is critical to effectively utilise experimental evidence and scientific models on local climate change mitigation in planning policy and regulations to address serious urban sustainability challenges, to guide sustainable urban development, and to achieve national objectives and global commitments on climate change.

The objective of this paper is to present an in-depth knowledge on the characteristics of urban climate change in India, its impact on various domains of human life and economy, and the technologies and strategies to counterbalance it. The rest of the paper is organised as follows: Sections 2 discusses climate change and extreme heat events in India. Section 3 presents the recent developments in experimentation identification of the UHI in India and its dynamic characteristics. Section 4 evaluates the impact of urban warming on

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EXTREME TEMPERATURES AND HEAT EVENTS IN INDIA

During the 21st century, India has experienced an increase in surface temperatures, and a higher frequency, persistence and spatial coverage of heat waves (Akpinar-Ferrand and Singh, 2010). The mean annual temperature has increased by about 0.6°C over the last 110 years in line with rising temperature across the globe (Mohan, 2015). The annual daytime maximum temperatures have increased by 0.4°C, while overnight minimum temperatures have warmed by nearly 1.2°C (MSPI, 2015). Further, in a major shift, the period 1901-2003 has seen a significant warming trend of the all-India mean annual temperature of 0.05°C/10 years (Kothawale and Kumar, 2005), while the recent period (i.e., the post-industrialisation period) 1971-2014 has witnessed a relatively accelerated warming of 0.22°C/10yr (MSPI, 2015), which is largely due to the unprecedented increase in maximum temperatures during the last two decades (figure 1). Very warm months that occurred just over 2 percent of the time during the period 1951 to 1980 occurred nearly 7 percent of the time during 1981 to 2010, and over 10 percent of the time over the past 15 years (MSPI, 2015). Looking at recent years more broadly, India's top five warmest years since 1901 have been recorded only in the last 15 years (i.e., 2016, 2015, 2010, 2009, and 2002) (Kapoor, 2017). The 10-year mean temperature for 2004–2014 was the highest on record at 0.56°C above average (MSPI, 2015). The temperature series are also marked by considerable spatial variability. Dash et al. (2007) divide India into seven zones and find that while all regions have experienced an increase in maximum temperatures over the last century, the increase in maximum temperatures have not been uniform: 1.28^{0}C in the west coast, 1^{0}C in the north-east, 0.98^{0}C in the western Himalaya, 0.88^{0}C in the north central, 0.68^{0}C in the north-west, 0.68^{0}C in the east coast, and 0.58^{0}C in the interior peninsula.

Climate change projections suggest that the annual average temperatures in India are projected to rise by 0.6 to 1.5°C by 2030, 1.4°C to 3.0°C by 2050 and 2.9°C to 4.3°C by end of the present century from the 1961-90 baseline (Bal et al., 2016; Mallet, 2012). These changes are likely to result in a climate characterised by higher average, maximum and minimum temperatures, particularly in spring and summer, a more frequent occurrence of extreme temperatures (for example the number of days over 35°C), increase in the number of very hot days and warm nights, and a decline in cool days and cold nights. This is all noteworthy when we consider that the duration and frequency of very hot days (greater than 35 degrees) have increased across many parts of India (figure 2). For example, the heatwave that engulfed the States of Andhra Pradesh and the neighbouring Telangana in May 2016 has seen heat records tumble like Jenga blocks. During the heat wave, various states and regions, including Madhya Pradesh, Andhra Pradesh, Telangana, Odisha, and New Delhi have experienced temperatures at least 10^{0}C above normal for that time of year, and in some places such as Churu in Rajasthan, temperatures soared to 51^{0}C. The other extreme heat events include the heatwave in 2015, when around two-third of India has recorded temperatures above 45^{0}C for a period of over two weeks (Burke, 2015), and the unprecedented heatwaves in 2009 and 2010, when Northern India has experienced maximum temperatures above 47^{0}C and 48^{0}C for three consecutive days respectively (Bhaduri, 2010). In India, heat wave is a period of abnormally high temperatures, more than the normal maximum temperature that occurs between March and June, and in some rare cases even extend till July. The daily maximum temperature data from 103 stations uniformly distributed over the country for the period 1911-2009 indicate that many areas of the country have experienced more than eight heat wave days on an average per season (Mohan, 2015) (figure 2).

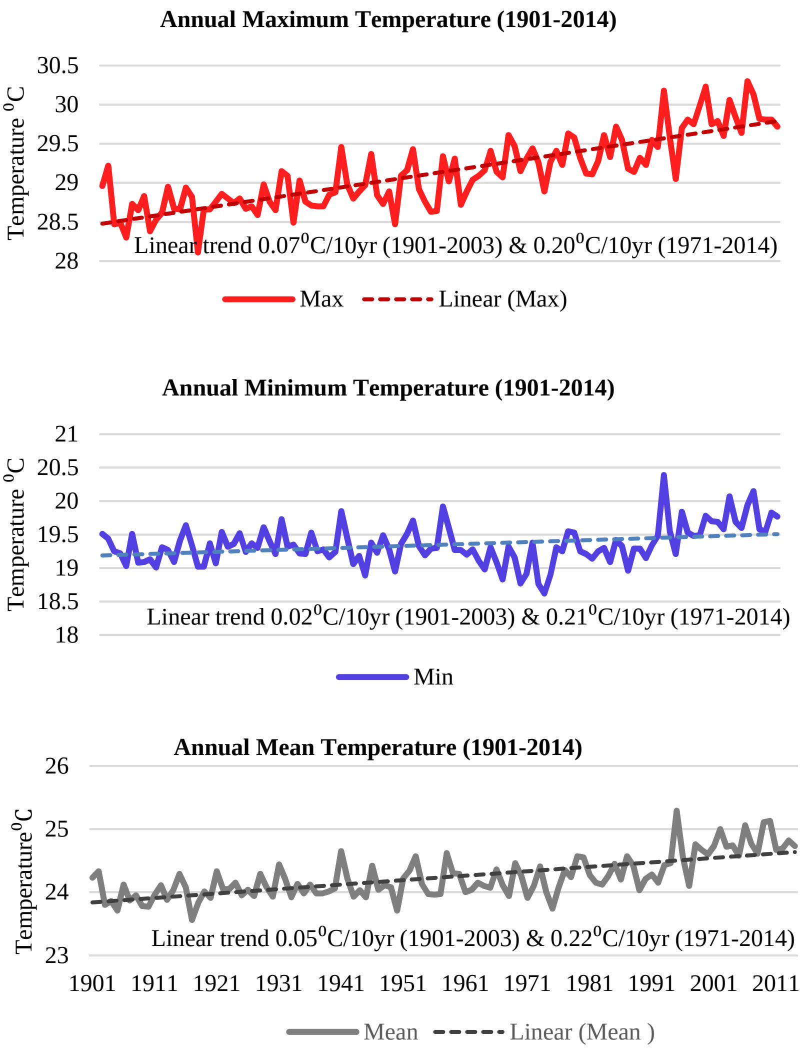

Figure 1 Variation of all-India mean, maximum, and minimum temperatures during 1901–2014 (Source: data from MSPI, 2015)

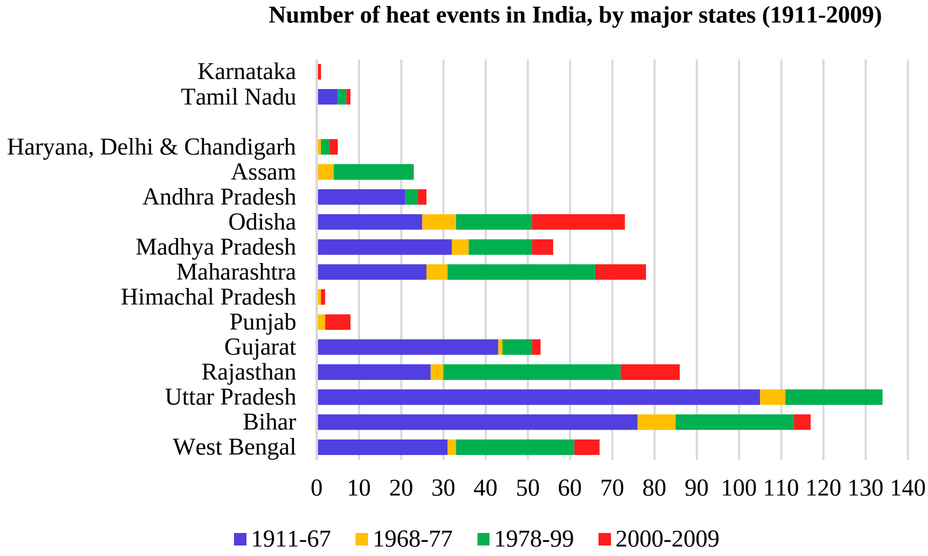

Figure 2 Number of Heat Waves in India (by major States) (Source: data from MSPI, 2015) Note: The data for Andhra Pradesh is for the period before the bifurcation of the state.

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MAGNITUDE OF URBAN HEAT ISLAND EFFECT IN INDIA

India is on the brink of an urban revolution. Over the last two decades, India's urban population has increased from 217 million to 377 million and is expected to increase to 600 million by 2031 (Sharma et al., 2015). This rapid growth in urban population, along with industrial and economic development, has come with greater urban sprawl, increase in density of urban form and conversion of vegetation to urbanized regions with highly built-up areas and infrastructure, resulting in the formation of heat pockets through an urban heat island (UHI) effect (Shastri et al., 2017). While most studies argue that UHI is a pronounced effect of urbanisation, a few studies report that global climate change resulting from the increase of the anthropogenic greenhouse gases (GHGs) in the atmosphere intensifies urban warming (Akpinar-Ferrand and Singh, 2010). Depending on the scenario, the most recent estimates for India suggest an increase of 1.4 to 4.3^{0}C between 1990 and 2100 (IPCC, 2014). Though the relative contribution and the relationship between the phenomena of local and global climate change is rather less known, recent studies predict that for several urban areas of the world, the impact of urbanisation on urban warming will be similar to that of two times the CO_2 concentration in the atmosphere (Santamouris, 2015b).

The intensity of UHI is characterised by a maximum difference in temperature within a city or between a city and its suburbia and/or its surrounding rural areas (Santamouris, 2015b). In simple terms, UHI is the characteristic 'island' of heat in urban areas sorrounded by 'sea' of cooler rural areas. The areas of maximum temperature can expectedly be found within the densest part of the urban area. UHI affects highly the thermal structure of the urban atmosphere and also results in extreme hot nights in some urban areas (Amirtham, 2016; Pandey et al., 2012a). The intensity and magnitude of UHI depends on the urban land use, the morphological, structural and physical characteristics of the cities (e.g., density, urban layout, materials on building façades and road surface), the magnitude of anthropogenic heat storage and release by buildings and pavements, and the synoptic weather conditions (Borbora and Das, 2014; Thomas et al., 2014).

UHI manifests itself in two basic forms (i) the Surface UHI (SUHI) and (ii) the Atmospheric UHI (AUHI) (Sharma and Joshi, 2014). SUHI is the phenomenon of temperature difference between surfaces of urban and surrounding rural areas. SUHI is studied using land surface temperature (LST) retrieved from thermal satellite sensors. AUHI encompasses difference in pattern of air temperature between urban or central business district (CBD) and rural settings. AUHI is measured through automobile transects and weather station networks. AUHI further falls in one of the two categories viz., Canopy layer or Boundary layer. Canopy layer UHI influence the atmosphere extending from surface to mean building height or tree canopy, while the Boundary layer UHI accounts for air beyond canopy layer.

UHI is extremely well documented and intensive experimental studies exist for several cities in India. Details of some studies and the main results are given in table 1. The magnitude of the UHI in India for all studies employing standard measuring equipment varies between 2.0 and 10.4, while measured intensity for all studies employing mobile traverses varies between 2.12 K and 2.9 K. The reported UHI intensity for all studies employing non-standard measuring methods, including micrometeorological stations and satellite thermal imageries, varies between 0.75 K and 12 K. For all studies using standard measuring stations, the average intensity is 2.4 K and the standard deviation is 0.29 K, while for all studies employing non-standard measuring stations and satellite imagery, the average intensity values are 4.17 K and 4.65 K respectively. The corresponding standard deviations are 2.61 K and 3.23 K respectively. Studies using mobile equipment and other non-standard methods present a significantly higher UHI intensity than that of corresponding studies using standard measuring stations. Furthermore, surface UHI manifests significantly higher values than that of atmospheric UHI. Mobile equipment and standard measuring equipment are frequently employed to measure ambient UHI, while satellite imagery methods are used to measure surface UHI.

The UHI phenomenon in India exhibits high spatial and temporal variability, and depends on many parameters like the experimental protocol selected, duration of the experiment, the accuracy of the measuring equipment and others (Santamouris, 2015a). The maximum UHI intensity always occurs during summer, except in cities with humid climates where the maximum occurs during the dry season (e.g., Chennai).

Table 1 Characteristics of the heat island in Indian cities (source: compilation of authors)

NO.	CITY	INTENSITY OF UHI	CHARACTERISTICS OF THE USED CLIMATE DATA	REFERENCE
Atmospheric UHI (AUHI)				
1	Mumbai	Mean annual maximum – 2.8 K	Data from two urban and two rural reference stations	(Maral and Mukhopadhyay, 2015)
2	Guwahati	Maximum daytime intensity – 2.12 K; night time intensity – 2.29 K	Data from two urban and two rural reference stations	(Borbora and Das, 2014)
3	Chennai	Mean maximum intensity during winter –3.35 K, during summer – 2.48 K	Data from vehicular traverses covering major areas of the city	(Devadas and Rose, 2009)
4	Kochi	Maximum intensity observed during winter, daytime - 4.6 K; night time – 3.7 K	Data from vehicular traverses covering all local climate zone classifications	(Thomas et al., 2014)
5	Nagpur	Mean maximum annual intensity during winter – 2.36 K; during summer – 2.14 K	Data from vehicular traverses conducted within the city	(Kotharkar and Surawar, 2015)
6	Pune	Maximum intensity – 2.0 K	Data from vehicular traverses over 9 routes and covering 170 locations within the city	(Deosthali, 2000)
7	Thiruvanant hapuram	Maximum intensity – 2.4 K	Data from mobile transect from urban centre to suburban area	(Ansar et al., 2012)
8	Chennai	Maximum daytime intensity in summer – 10.4 K Maximum night time intensity in winter – 4.1 K	Data from 30 micrometeorological stations	(Amirtham, 2016)
9	Delhi	Average daily maximum - 8.3	Data from 28 micrometeorological stations	(Mohan et al., 2013)
Surface UHI (SUHI)				
10	Bangalore	Maximum intensity 2-2.5 K	Data from *Landsat* and MODIS thermal imagery	(Ramachandra and Kumar, 2010)
		2-7 K (varies within different land cover classes)	Data from *Landsat* thermal imagery	(Ambinakudige 2011)
11	Chennai	Maximum intensity -12 K	Data from *Landsat* ETM+ thermal imagery	(Faris and Reddy, 2010)
12	Delhi	Maximum intensity during summer – 8 K	Data from *Landsat* thermal imagery	(Babazadeh and Kumar, 2015)
		Daily maximum intensity observed during summers and at night time– 6 K	Data from MODIS imagery	(Pandey et al., 2012a)
		Maximum intensity observed during night time – 4 K	Data from ASTER and Landsat 7 ETM+ thermal imagery	(Mallick et al., 2013)
13	Chandigarh	Average maximum annual intensity – 5.2 K	Data from MODIS imagery	(Mathew et al., 2016)
14	Hyderabad	Maximum intensity – 2 K	Data from *Landsat* 5TM thermal imagery	(Franco et al., 2015)
		Maximum intensity in the night – 1 K	Data from ENVISAT-AATSR thermal imagery	(Badarinath et al., 2005)
15	Bhopal	Maximum intensity varies between 3 K	Data from NOAA and *Landsat* TM thermal imagery	(Gupta et al., 2009)
16	Ahmedabad	Daily maximum intensity close to 9 K	Data from *Landsat* ETM thermal imagery	(Joshi et al., 2015)
17	Noida	Maximum intensity close to 8 K	Data from *Landsat* NDVI and NDBI thermal imagery	
18	Lucknow	Mean annual difference – 0.75 K	Data from Landsat NDVI and UTFVI thermal imagery	(Singh et al., 2017)

SOCIO-ECONOMIC IMPACTS OF URBAN HEAT ISLAND EFFECT

The focus of this section is on the impacts of the UHI effect on human life, and the relationship between extreme temperatures and impacts on the community assets and values.

Health and Mortality

The Indian Meteorological Department (IMD), the National Disaster Management Authority of India (NDMA), and other national and regional institutions now recognise that high temperatures and extreme heat events cause serious risk to public health. The impact of extreme temperatures on human health in India is mainly investigated during the recent heat waves. As reported in De and Mukhopadhyay (1998), during the summer of 1998, India experienced a 75-year record-breaking heat wave, with maximum temperatures of 48°C or above for more than 2-weeks, which led to more than 2500 deaths across the cities of Bhubaneswar, New Delhi and Chandigarh. A similar record-breaking heat waves occurred in 2002, 2003, and 2015, killing thousands of people in a number of cities in the States of Andhra Pradesh and Telangana (Desai et al., 2015). The heat wave of 2015 caused more than 2000 deaths in Hyderabad, Khammam, Guntur and other cities in Andhra Pradesh and Telangana. Azhar et al. (2014) have reported an excess 1300 all-cause mortality associated with the May 2010 heat wave for Ahmedabad. A study by Chaudary et al. (2000) has shown that the average annual loss of human life due to heat wave in India is 153. These findings show that significant increase in premature heat-related mortality poses a threat to public health in many cities of India. The historic data also reveal that there has been an increasing trend of heat-waves and temperature-related mortality in India over the past two decades, whereby several cities in India have been severely affected (figure 3).

Heat-related illness is a serious concern for governments, and those most at risk include vulnerable members of the community such as the elderly adults, babies and young children, pregnant women, and people with existing medical conditions. The relationship between temperature and mortality exhibits a U- or V-shaped curve, with a specific temperature thresholds above which mortality increases. Existing studies show that heat related mortality increases by at least 10 per cent at temperatures of 40°C and above (Desai et al., 2015). The threshold temperature over which mortality increases rapidly changes as a function of the climate of each zone, and other local parameters, including age and the socioeconomic characteristics of the population (Santamouris, 2015b). According to a report titled ‘Ageing in the Twenty-First Century: A Celebration and A Challenge’ by UNFPA and HelpAge (2012), the elderly population in India is expected to rise from 90 million in 2011 to 173 million by 2026. These trends will lead to an increase in mortality risks of temperature extremes in India. Studies, of similar nature, report that elderly surgical population is at risk of developing complications and prolonged hospital stay when peak outdoor temperature ranged above 30°C (Gautam et al., 2011).

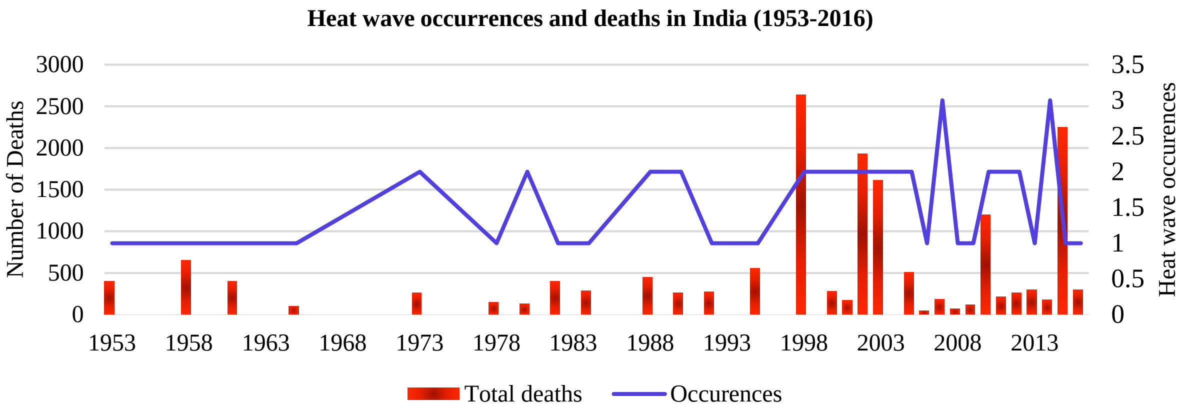

Figure 3 Heat wave occurrences and deaths in India (source: Data from EM-DAT)

Energy consumption and peak electricity demand

Urban warming has a significant impact on the energy consumption of cities and peak electricity demand. Existing studies find a positive correlation between the increase of ambient temperature and the energy demand rise in India. It is estimated that energy consumption in cities with population greater than

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100,000 increases by 3 per cent to 8 per cent per degree of temperature rise (Kumar, 2014). Furthermore, the upward trends in average temperatures will increase the number of cooling degree days, leading to continued growth in energy demand for space cooling. Air conditioners sales have increased by 20 per cent annually in recent years (Peterson, 2015). About 3.3 million air conditioners were sold in India during the 2013-14 fiscal year, adding to the 25 million total units in the country (Peterson, 2015). According to different estimates, energy consumption for air conditioning under baseline scenario (i.e., without efficiency programs) will be 195 TWh in 2020, 552 TWh in 2030 (McNeil and Iyer, 2008), and ~750 TWh to ~1350 TWh in 2100 (Akpinar-Ferrand and Singh, 2010). The figures may be higher or lower in cooling or heating dominated areas, respectively, though with an average summer temperature higher than 32^{0}C, the additional energy increase for cooling is much higher than the corresponding increase of the heating demand, and may depend on a number of factors, such as the thermal quality of the building stock, the degree of penetration of the air conditioning, the assumed indoor comfortable temperature and the specific characteristics of the local electricity network. Nonetheless, the increase in the level of peak demand will have serious economic implications for the energy suppliers in terms of their need to upgrade or build additional infrastructure to expand the network capacity. Increasing energy consumption and peak electricity demand can mean more frequent occurrences of failures due to network overload. India's stressed and fragile electricity networks that can't guarantee supply to the increased peak electricity demand during the warm period, while ensuring electricity security and stability at all times of the year, have been a serious concern for the policy makers.

Thermal comfort and low-income communities

Humans are most comfortable at an ambient temperature of about 28^{0}C. The further we are away from that temperature, the more thermally uncomfortable we feel (either cold or hot). The relation between thermal comfort – both outdoors and indoors - and ambient temperature is very strong and most studies assessing thermal comfort conditions in Indian cities conclude that higher urban temperatures substantially lower the specific comfort levels (Pawar et al., 2015), though some find that thermal comfort is determined by a range of meteorological factors (e.g., air temperature, humidity, radiation and air movement), personal factors (e.g., insulation and clothing value), and rate of metabolism, which in turn is affected by age, gender and body shape (Indraganti and Rao, 2010). Nicol (1974) have conducted a sample survey on outdoor thermal comfort in Roorkee, and find that people felt extreme discomfort when temperatures exceeded 32^{0}C and wore light clothing. Studies on the indoor thermal comfort find the same. A study based in Hyderabad find that, in naturally ventilated indoor environment, ambient temperature above a threshold temperature of 29^{0}C is likely to affect thermal comfort and normal daily life (Indraganti, 2010).

The problem is more intensified in the poor and low-income housing characterised by low thermal protection standards, poor construction practices, high infiltration levels and poor indoor environment quality and where necessary, the resources to maintain buildings under proper comfort conditions may not be available (e.g., better housing conditions and access to air conditioning). Migrant labourers often settle down in informal settlements characterised by high population density and associated public health risks. These densely populated areas, with no or substandard basic facilities like drinking water, sanitation, and energy, are highly prone to extreme temperatures. This is a real concern in India's major cities, and an important agenda on the government policies. However, a little research has been carried out to investigate the impact of high temperatures on the low-income communities in India, in particular indoor environmental quality and thermal comfort (Nix et al., 2015).

Economy and productivity

Urban warming has a significant economic impact and affects work and productivity. The loss of productivity during extreme heat waves is particularly among the outdoor working population, such as the construction workers, pavement vendors, and industrial labour, though indoor workers aren't completely immune to high temperatures. Heatwaves have a significant impact upon Indian economy and workplaces, with research calculating that a 4^{0}C increase will result in an economic losses equivalent to 1.8 per cent of annual Gross Domestic Product (GDP) (Saha, 2016). A study on steel industry workers in Southern India show that 1% of workers have taken sick leave during extreme heat events (Krishnamurthy et al., 2017). 10% went to work but were less productive, while 26% took more time to complete a task. Studies of similar nature find 18-35 per cent productivity loss in outdoor workers when the temperature exceeded the threshold limit value of 28°C (Chinnadurai et al., 2016). When the sample is extrapolated to the entire working population, a 4^0C temperature increase could cut 3.6 per cent of India's daylight work hours by 2025 and over 5 per cent by 2050 (Saha, 2016; Sarkar, 2016). The results of the existing studies on the economic cost of extreme heat events vary considerably, with estimations anywhere between US$1.8-8 billion (Sarkar, 2016). These losses put the cost of heat stress on par with the cost of chronic health conditions. Given that labour productivity is one of the keys to economic growth, rising temperatures can be viewed as a substantial and increasing threat to the Indian economy.

Higher ambient temperatures and extreme heat events affect various other sectors of the economy, including transport, social behaviour, and major events. For example, the 2015 heat wave that swept the cities in Telangana and Andhra Pradesh killed five million chicken within a span of two weeks in Hyderabad city alone, triggering a loss of US$8 million loss to the poultry industry, pushing prices of chicken and eggs in the retail market, and causing huge losses to the hotel industry (Sikdar, 2015). During the 2016 heatwave, as much as 25 per cent of the country – 330 million population – could have been affected by power shortages (Ferdano, 2016). The heatwave has significantly affected the country, resulting in power outages, transport disruptions, traffic signals malfunctioning, and roads lifting and cracking. In parallel, anti-social behaviour can result in direct economic costs through damages afflicted on people and property (e.g., collective crime, assault, domestic violence, burglary, prostitution), public funding of crime prevention and policing, as well as for maintaining the justice system such as courts and correctional facilities. However, as anti-social behaviour is related to human actions – whether by individual or group, and their relationship to external social and environmental factors, it is difficult monetise. Moreover, research into temperature-related behaviour effects on India's economy is found to be extremely limited.

URBAN HEAT ISLAND EFFECT MITIGATION TECHNOLOGIES & STRATEGIES

To counterbalance the impacts of extreme temperatures on cities, appropriate mitigation technologies have been developed. This section presents the developments and achievements regarding two major promising clusters of urban heat mitigation technologies: a) mitigation technologies that decrease absorption of solar radiation and release of sensible heat to the atmosphere and keep urban surfaces cool. Important applications in this category include cool roofs and cool pavements, and b) mitigation technologies that increase evapotranspiration in an urban environment. Examples include urban greenery, green infrastructure and water-based systems.

Evaporative techniques - use of water

The use of water in reducing ambient temperature has been known for many centuries. It is characteristic that water-based urban landscape, such as lakes, rivers, and wetlands contribute to 'urban cooling islands' and may decrease the city's ambient temperature by 1-2 K (Manteghi et al., 2015). Apart from natural water bodies, a variety of passive systems like pools, ponds and fountains, and active or hybrid water components like evaporative wind towers, sprinklers and water fountains have been implemented in urban public spaces around the world for decorative and climatic reasons (Santamouris et al., 2016). A number of studies have evaluated the impact of both passive and active water-based technologies on urban heat mitigation (Martins et al., 2016; Nishimura et al., 1998). The main characteristic of these studies is that water contributes to reduce the ambient temperature several degrees through convective processes. However, the mitigation potential of water-based systems is strongly dependent on the physical and geometric characteristics of the water system, the considered urban area, and the local climatic conditions, including humidity, ambient temperature, wind speed, turbulence and solar radiation (Santamouris, 2015b). The knowledge on the mitigation potential of water-based techniques and technologies is however quite limited in India.

Urban green technologies and techniques

Various forms of urban green technologies and techniques, such as nature reserves, urban parks, street trees and hedges, open spaces, and green infrastructure decrease urban temperatures and cool ambient air through shading, evapotranspiration and alteration of wind movement (Akbari and Kolokotsa, 2016). Urban greenery also decreases the sensible heat transmission to the air or to building envelope, improve outdoor and semi-outdoor thermal comfort and human health, mask noise, prevent soil erosion, reduce outdoor air pollution, enhance water quality, increase property values, contribute to mental balance of urban citizens, and make cities more attractive. Urban greenery may be part of the urban landscape, parks, streets and open spaces, or may be integrated into the exterior envelope of buildings through green roofs and green facades (Cuce, 2017; Vijayaraghavan, 2016). Detailed performance analysis conducted for the city of Bangalore suggest that increasing the street tree and canopy cover by 14 per cent to 40 per cent can lower afternoon ambient temperatures by as much as 5.5 K (Vailshery et al., 2013). The results of an experimental investigation for a typical urban area in Ujjain city show that green roofs not only reduce high daytime temperature in summer, but also reduce energy load for air conditioner (Pandey et al., 2012b). Based on a review of urban green space planning for climate adaptation in Indian cities, Govindarajulu (2014) conclude that in tropical and subtropical climate zones with sunny summer skies, like that of India, urban greenery is by far the most effective and economical cooling strategy. Yet, green infrastructure technology - green roofs and green walls - is very much in its infancy and there are several barriers to their widespread adoption in India.

Use of reflective materials

Increase of the albedo of cities contributes highly to mitigate UHI effect and reduce extreme temperatures. Advanced materials with very high reflectivity in the visible or infrared, or across the whole spectrum of solar radiation together with a high emissivity value have been developed and are commercially available. Reflective materials may be used either in the envelope of buildings (cool roofs and cool facades), or in the outdoor space of cities (cool pavements). Cool materials help to mitigate temperatures, reduce cooling-energy use in air conditioned buildings, increase comfort in unconditioned buildings and improve air quality and comfort (Akbari and Matthews, 2012). Though several experimental and theoretical studies have been performed to identify the impact of cool materials on UHI, building energy and comfort across the world, research in India remain limited. An experimental study in Hyderabad and Nagpur find that cool roof contributes to reduction of average and peak summer indoor temperatures up to 2 K and 5 K respectively (Garg et al., 2016). While cool roofs can offer significant opportunities to save energy and cool cities in India, the lack of sufficient technical knowledge, relevant policies and building codes with cool roof credits or requirements can create challenging conditions.

The common reflective materials applied to the buildings are white and may be single ply or liquids. Typical liquid products are usually white paints, elastomeric, acrylic or polyurethane coatings, while single ply products are EPDM (Ethylene Propylenediene Tetrolymer Membrane), CPE, (Chlorinated Polyethylene), PVC (Polyvinyl Chloride), TPO, (Thermoplastic Polyolefin), and CPSE, (Chlorosulfonated Polyethylene). The standard reflective materials used for paved surfaces are fly ash (concrete additive), chip seal, slurry coating, reflective synthetic binders and light-colour coating. During the recent period, an extended and ground-breaking research has been carried out to develop coloured thermochromics materials that become more reflective at higher temperatures (Synnefa et al., 2007). Through these materials, building owners do not require compromising on the aesthetics. Important research has also been carried out to develop very high reflective materials for pavements, including water retentive or permeable systems, infrared reflective coating, heat reflecting coating, colour changing coating and photovoltaic based pavements (Santamouris, 2013). However, more R&D is required to develop these materials as viable economic cool materials.

Combined mitigation technologies

Various performance analysis of projects that combinedly used water for evaporation, urban greenery systems and reflective technologies suggest that the mitigation potential from the combined use of different technologies and systems is quite higher than the sum of the contributions of each individual technology. It is evident that the combined use of greenery and reflective materials increases reduction in maximum temperature by 0.95 K, while the corresponding increase in the average temperature drop is 0.3 K. The use of reflective materials and greenery in combination with water-based and solar control mitigation techniques will reduce the average and maximum ambient temperature between 0.8-1.3 K and 1.4-3.1 K respectively. The combined use of water, greenery, shading and reflective pavements is found to drop the average and peak temperature between 0.6-2.4 K and 1.4-5.8 K respectively. The average maximum temperature reduction with just one technology is close to 1.89 K and increases up to 2.26 K when two or more technologies are used together. Urban greenery, in particular, trees, followed by grass and green roofs present an effective and economic mitigation potential. Trees and hedges result in peak temperature reduction close to 1.66 K. Reflective materials installed on roofs of buildings and pavements present a maximum temperature reduction close to 1.3 K.

CONCLUSIONS

Urban Heat Island (UHI) is the most documented phenomenon of climate change and intensive experimental studies exist for most of the large and medium size cities of the world. It is evident that UHI is a major climatic phenomenon in India, and its intensity varies between 0.5 K and 12 K. The magnitude of the UHI effect is a function of the urban layout, materials' characteristics, synoptic weather and climate conditions, local meteorological factors, physical, structural and morphological characteristics of the cities and anthropogenic heat released (Santamouris, 2015b). Although scientific knowledge on the characteristics of UHI in India is continuously increasing, the lack of clarity on the experimental methods used to collect relevant scientific information, the accuracy and representativeness of the results, and the overall validity of the scientific conclusions given opens a serious discussion on the authenticity of the existing studies (Santamouris et al., 2016). The main uncertainties relate to the monitoring techniques used to measure the magnitude of UHI, the duration and season of the monitoring, the number of stations used and the way the results are reported. The non-homogeneity of the existing protocols and procedures makes the understanding, the classification and the comparison of the reported data quite difficult, even impossible.

UHI has a serious impact on the human health and well-being (Desai et al., 2015), energy consumption (Yadav et al., 2017), and economy and productivity (Krishnamurthy et al., 2017). Urban warming is associated with an increase of the concentration of urban pollutants, in particular tropospheric ozone, city’s carbon foot print, energy consumption of buildings during the summer period, cooling energy consumption and the corresponding peak electricity demand (Santamouris, 2015a). The understanding of the relationship between urban warming and impacts can help in assessing the additional impacts of UHI effect and identifying the relevant mitigation technologies and strategies.

To counterbalance the impacts of higher urban temperatures on cities, appropriate mitigation technologies have been developed. Appropriate mitigation techniques include any intervention designed and applied by human beings to reduce the strength of the sources and enhance the potential of the temperature anomaly sinks. The implementation of mitigation technologies (for example, cool roofs, cool pavements, green roofs, and urban green zones) can partly or fully counterbalance the impact of the urban heat island effect and local climate change. The average maximum temperature reduction with just one technology is close to 1.89 K and increases up to 2.26 K when two or more technologies are used together. Urban greenery, in particular, trees, followed by grass and green roofs present an effective and economical mitigation potential. Trees and hedges result in peak temperature reduction close to 1.66 K. Reflective materials installed on roofs of buildings and pavements present a maximum temperature reduction close to 1.3 K. The average maximum temperature drop for water-based projects, especially when sprinklers and cooling towers are used, is close to 4.5 K. Despite of intensive knowledge and a wide-variety of real scale application based mitigation strategies that can enhance the sinks of temperature anomaly exist, the linkage of such evidence to government and industry decision-making is not well developed. It is critical to effectively utilise experimental evidence and scientific models on local climate change and its mitigation in planning policy and regulations to address serious urban sustainability challenges, to guide smart sustainable urban development, and to achieve national objectives and global commitments on climate change.

POLICY IMPLICATIONS

Local governments can mitigate heat by preparing for and responding to heat events, through emergency response plans and outreach to vulnerable neighbourhoods, opening cooling centers, and providing other services. However, emergency response alone will not save all of a community’s most vulnerable residents. Emergency response also fails to address other aspects of urban heat, including energy disruptions, air pollution, and economic costs of work place productivity and infrastructure failures. Long-term mitigation strategies are needed to keep residents, buildings, and communities cool and save energy, health and economic costs.

This paper analysed different natural and built environment mitigation strategies and technologies – urban greenery, green roofs and walls, water-based technologies, cool roofs, cool pavements – to help local governments reduce the effect of increased heat on their communities and citizens. Individually, each mitigation strategy can reduce high temperatures; taken together, citywide adoption can drastically reduce the urban heat island (UHI) effect itself, while providing many additional co-benefits. By drawing on analytic criteria, local governments can compare mitigations strategies and determine which will work best for them.

Local governments face challenges in mitigating urban heat, such the complexity of the choices available, limited resources and authority, the need to coordinate among many local agencies, and in some cases skepticism about climate change. As such, the mitigations strategies proposed and analysed in this paper can provide a decision framework for local governments to help overcome these barriers.

ACKNOWLEDGEMENT

We would like to acknowledge the funding from the Faculty of Built Environment, University of New South Wales, the CRC for Low Carbon Living and the support of the Australia-India Institute, University of Melbourne.

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BUSINESS & INDUSTRY

INNOVATIVE METHODS FOR PUBLIC PROCUREMENT OF ENERGY EFFICIENCY SERVICES

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Keywords: Energy Efficiency, Public Procurement, Energy Efficient product and Services, Life cycle cost evaluation

ABSTRACT

Public procurement represents purchase of goods and services with public money. In India this expenditure accounts for about one fifth of national gross domestic product (GDP). Public sector is often considered to have a leadership role when it comes to reducing negative environmental impacts, promoting more sustainable products and services. Public procurement policy generally ensures transparency, accountability, enhances efficiency and economy.

Energy is the key indicator as well as backbone for the growth of any country. Energy conservation and energy efficiency have potential to bridge the gap between demand and supply of energy, mitigation of climate change impact and enhanced energy security of the country. Public Procurement of energy efficient product and services includes a wide range of government procurement activities with the overarching goal of lessening the negative impacts on environment, government expenditure.

Procurement of energy efficient product and services is remains a challenge to government on account of rigid rules and regulations, evaluation of bids on single criteria of lowest cost offer, absence of life cycle cost approach. Innovative methods are proposed in the paper which include combination of single parameter bid evaluation of highest energy savings offer along with fixed cost of maintenance services. Proposed methods provide business case to the organization by procuring energy efficient product and services within the existing framework of rules and regulations. Proposed methods provide additional business avenues to ESCO for facility management and more opportunities to maximize the profit by using smart automation.

Key words: Energy Efficiency, Public Procurement, Energy Efficient product and Services, Life cycle cost evaluation

INTRODUCTION

Procurement is the acquisition of appropriate goods or services or both at the best possible cost of ownership to meet the requirements of buyer in terms of quality, quantity, time and location. When goods or services are purchased by public authorities – the Central or State governments, ministries or departments, public sector undertakings (PSUs) or state-owned enterprises, it is called "Public Procurement" and in most cases money spent is the public money used to procure goods and services . Public procurement accounts for a substantial part of the economy with 10-15 percent of the national budgets in developed countries, and up to 20 percent in developing countries, Public procurement in India account for more than Rupees 10 lakh crore of business. This constitutes about 30% of India's GDP and about 15% of the budget.

Public procurement of general goods and services are based on least cost (L1) criteria while procurement of energy efficient products and services are substantially complex in nature. Combination of product cost and energy cost during the project period is the deciding factor for procurement bids. Generally , value added services associated with energy efficient product and service are not taken account in bid evaluation.

This paper illustrated some innovative business models for public procurement of energy efficient product and services. In this paper, potential market of performance contract and its challenges are discussed with a focus on Public Procurement Policy at Central and state level. Section-I describes basic ESCO based performance contract business model. Section II illustrated business models used by Energy Efficiency Services Limited (EESL) in procuring energy efficient product and services. Section-III describes innovative business model suggested to Public Health Engineering Department, Government of Rajasthan, for procurement of Energy efficient pumps and services. Section IV compared various business models and compiles cons and pros of these models. Section V concludes analysis and conclusions of business models.

SECTION-I

ESCO BASED PERFORMANCE CONTRACTING

An ESCO is a professional services business providing a broad range of comprehensive energy efficient solutions, including design and implementation of energy savings projects, energy infrastructure outsourcing and risk management. ESCOs perform in-depth analyses of physical properties, design energy efficient solutions, install proper equipment's, and maintain the systems to ensure energy savings. The Bureau of Energy Efficiency (BEE), Ministry of Power (MOP), India defines ESCOs as an organization engaged in a performance based contract with a client firm to implement measures which reduce energy consumption and costs in a technically and financially viable manner.

The methodology of Energy Performance Contracting differs from traditional contracting where former is results-driven, ensuring quality of performance, while later is invariably price-driven. In practice, under a performance contract, an ESCO takes financial and performance risk of project and provides a comprehensive retrofit solution. The payment to ESCO is the key difference between performance contracting and conventional contracting.

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PUBLIC PROCUREMENT CHALLENGES

Myopic financial planning and management in public departments that is predominantly undertaken on an annual basis may leave little scope for purchasing of efficient products as the upfront cost of these products may be higher and benefits in terms of financial savings may accrue over the useful life which may not be considered at the time of allocating funds for procurement.

Financial viability of energy efficient project is also a major challenge. This may be on account of higher interest rate of debt received from financial institution or may be on account of higher rate of returns on equity of the ESCO. Smaller size and high transaction costs of ESCO project further deteriorate the viability. Abnormal debt to equity ratio further restrict financing of project. Lack of valued credit rating of ESCO restrict ESCO to secure proper financing.

Longevity of project and external factor of site may led to diminish concentration of client on performance contract. Energy efficient products may change faster than Energy Efficiency Certification.

Prevailing statutory rules of public procurement, contracting and financing, further restrain contractors to participate in competitive bidding. Selection of agency on the basis of least cost criteria limits execution of performance contract for energy efficiency project. Fruits of ESCO projects are not realised due to lack of regulatory provision for matured ESCO contracting on account of lack of confidence and uncertainty belief of client in energy savings and monetary savings. Very few agencies having expertise in Energy Savings Performance Contract (ESPC).

Indian ESCO industry is still in evolving stage. The overall energy efficiency investment market size in India has been estimated to Rs. 74,000 crores with the potential to save about 54 billion units of electricity annually. Currently available Public procurement business models adopted in ESPC Procurement are given in Table-1.

Table-01

Model	**Description**
Shared Savings	Under this model, the ESCO finances the project either through its own funds or by borrowing from a financial institution or third party
Guaranteed Savings	In this case, the user/ client finances the design and installation of the project by borrowing funds from a third party such as a bank or through leasing the equipment. Payment to ESCO is based on the guaranteed performance.
Lease Rental Model	The supplier installs the equipment and may maintain it. The lease payments are financed by verified savings and the ownership is generally transferred at the end of a lease period.
BOOT Model	A BOOT (Build-Own-Operate-Transfer) model may involve an ESCO designing, building,

	financing, owning and operating the equipment for a defined period of time and then transferring this ownership over to the client.
BOO Model	Build-Own-Operate
ROT Model	Replacement/Refurbishment-Operate-Transfer

Energy Performance Contracting Process

Stage 1: Walk through Energy Audit and Business Proposal

Stage 2: Contract ESCO for Investment Grade/Detailed Energy Audit

Stage 3: Development of a Detailed Project Report (DPR)

Stage 4: Finalize the EPC Contract with ESCO and Coordinate Financing

Step 5: ESCO Implements Energy Improvements

Step 6: Measurement, Monitoring and Verification

SECTION-II

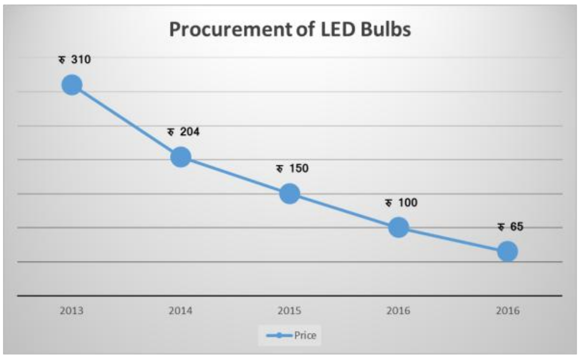
EESL'S BUSINESS MODELS IN PUBLIC PROCUREMENT

Various innovative business models have been adopted by EESL for Public procurement of energy efficient products and services.

UJALA

UJALA (Unnat Jyoti by Affordable LEDs & Appliances for All) formerly known as a DELP (Domestic Efficient Lighting Programme) is a flagship initiative of EESL to transform the market of energy efficient equipment. EESL collated aggregations of demand across states and procure LED Bulbs in large quantity to reduce the LED bulbs price in market.

Figure 1 illustrated reduction in LED prices from Rs. 310 (7w LED bulb) to Rs. 65 (9w Bulb)-with bulk procurement within a period of 3 years. EESL included BEE 5 star 1200 mm ceiling fan, 20 W LED tube light and 5.2 ISEER rated 1.5 ton air-conditioners in the UJALA scheme. Using the same methodology, EESL planned extension of UJALA scheme in other countries.



SLNP

Street Lighting National Programme (SLNP) was started by EESL in 2015. EESL assured 40-60 percentage energy saving in SLNP by retro-fitting conventional street light with LED street lights and CCMS panel for monitoring purpose to reduce operation and maintenance cost. EESL has installed more than 24 lakhs LED street lights across India. Reduction in price of LED Street light during 3 phases of procurements, on account of bulk procurement, is shown in the figure-2.

In order to increase the energy efficiency in agriculture pumps, water supply and sewerage pumping stations EESL has started AgDSM for farmers & MEEP for Atal Mission Rejuvenation Urban Transformation (AMRUT) cities.

SECTION-III

INNOVATIVE BUSINESS MODEL OF PHED, AJMER

EESL has supported an ESCO project for the replacement of inefficient water pumps in pumping stations of Ajmer Region in Public Health Engineering Department (PHED), Government of Rajasthan,. The project is covering replacement of 32 water pumping stations of Bisalpur Water Supply project (BWSP) for Ajmer District. Public Health Engineering Department has implemented various ESCO projects in PHED at Udaipur, Rajsamand, Jodhpur, Bharatpur and Bhilwara. Operation & Maintenance (O&M) of transmission line and pumping stations were carried out by the ESCO where transmission line are very small and not have very high complexity as in the PHED BWSP.

It was envisaged that retrofitting solution would take care the water demand of the locality considering the water supply demand of 2027. Inclusion of O&M of longer and bigger size complex transmission line system and Water Treat Plant was a major challenge. Also, it was very difficult to achieve the replacement of all working and standby pumps and operation & maintenance of WTP and transmission lines under the ESCO project. Viability of the project was a major challenge considering project requirements and sharing of energy savings at least 10 percent to the department.

An innovative business model is proposed addressing most of these issues. In the proposed model, O&M of pumping stations and transmission lines were made as part of the scope of work. The O&M cost for transmission lines were made separately from the energy savings to make the project attractive ad more financial viable. In previous ESCO Models of PHED, the replacement of pump set is not necessary but in proposed model, the replacement of all working pump is made mandatory to reduce the life cycle cost of pump sets and to meet the future water demand of locality as most of pumps of the project have completed more than 20 years life. Other feature of innovative models are as given below:

- **Maximum Information Sharing**:

The proposed model detailed out maximum sharing of information to bidders on project site, configuration of pumping stations, boundary conditions, technical specifications, scope of work, general terms & conditions of project. Clarity on mandatory replacement of working pumps and single parameter bid evaluation criteria based on maximum energy savings to the department, are defined in the model. Mandatory replacement of pumps are incorporated considering the facts that most of pumps have passed their life as these are more than 20 years old and are not be suitable to meet future water demand of 2027.

- **Enhanced competition**:

In order to increase the competitiveness in the bidding process Joint Venture (JV)/ consortium of manufacturer, ESCO and registered contractors in addition to enlisted PHED contractors are permitted to participate in the bidding process. Importers of pumps are also permitted for bidding to enhance the competitiveness. Considering that the project is a service contract which includes ESCO contract, O&M contract of pipelines and WTP (Water Treatment Plant) and each of these contracts have different qualification criteria for experience. Therefore, in the proposed model, bidders meeting any two out of three qualifications are permitted for bidding.

- **Simplicity**:

In the proposed model, Energy Savings calculations are simplified by using the methodology based on reduction in Specific Energy Consumption (SEC) and floating energy charges. Although, electricity tariff for PHED installations is based on energy charges (kWh) and fixed charges (kVA) and in ESCO projects tariff based on both parameters may result in reduction in electricity bills, however for simplicity in the proposed model, only tariff based on energy charges, is proposed. The selection criteria is based on single parameter, of maximum sharing of energy savings to the department. Although the contract includes O&M of transmission pipelines and WTP, but bid evaluation criteria doesn't include cost of O&M as an evaluation parameter.

- **Transparency**:

Effort has been made to bring transparency in the selection criteria and payment mechanism. Single criteria of maximum sharing of energy savings to the department is kept in the model. Provisions of Rajasthan Transparency Act in Public Procurement (RTPP) and Rules were also retained in the model. Provision of floating energy charges for calculation of sharing of energy savings and payment to agency is included in the model. Provision of payment of a fixed cost against the O&M of pipelines and fixed charges against event based O&M are incorporated in the model. These payments are based on the previous year payment by the department on O&M, both on general O&M and event based O&M of pipelines.

- **Benefit to the Department**:

In the proposed model, time line for the replacement of all working pumps within two years from letter of award (LoA), however the agency shall start to pay minimum guaranteed savings (10%) after one year of award. If agency will not be able to replace all working pumps within 2 years of award, then agency will have to pay an additional penalty of 5% (maximum) of guaranteed saving. Mandatory replacement is also include capacity enhancement of pumps meeting the water demand of 2027. Provisions of installation of energy and flow meters at each pumping station is also a major benefit to the department for computation of energy savings and monitoring of performance of the pumps.

- **Selection of competent agency:**

In the proposed model provisions of competency criteria are retained in terms of financial capability (turn over, net worth) and technical capability of the bidder. However considering the dynamic nature of bidding capacity and unavailability of correct information about the number of projects and their worth, the eligibility criteria of bidding capacity are deleted. As the project covering ESCO project, O&M project of pipelines and O&M of WTP, eligibility criteria of experience of HT pump installation and O&M of HT pumps have been retained.

Energy Saving Scenario in PHED, Ajmer

Annual energy consumption of last year of all water pumping stations in PHED, Ajmer is approximately 41 million Kilowatt-Hours. EESL proposed the energy saving of approximately 12.30 million Kilowatt-Hours that is 30% of energy consumption. PHED shall retain the guaranteed energy saving that is 10% of the baseline energy consumption which is approximately 4.10 million Kilowatt-Hours of actual energy consumption in last year.

Energy Saving Share to ESCO	
Particulars	**Value(in mln-KwH)**
Existing Energy Consumption	41.00
Post-implementation energy savings	12.30
Energy Saving Retained by PHED 10% of the Baseline Energy Consumption	4.10
Balance Energy Saving (In kwH)	8.20
Balance 90% Energy Saving share to ESCO	7.38
After Sharing Balance Energy Saving to ESCO retained by PHED	0.82
Total Energy Saving Share to ESCO	7.38
Total Energy Saving retained by PHED	4.92

Financial Aspects

To make the project financially viable, we introduced a new model in which vendor shall generate the fund from Energy saving for the O&M of water pumping station and replacement of old pump sets. PHED will provide a fixed amount for O&M of the transmission lines. For the evaluation of the bids, Energy saving to PHED is used as a single parameter that is after the 10% of guaranteed energy savings to PHED. The O&M of transmission line is not used as a criteria for the bid evaluation. For the regular O&M of the transmission pipe line 32.00 million is provided annually. The project cost is estimated as Rs. 249.74/- million only. The expected annual monetized energy saving is Rs. 92.95 million Rupees. The expected net sharing of monetized energy saving to PHED is Rs. 36.90 million annually. Total payment to vendor is Rs. 87.35/- million annually. Payback period of the project is approximately 76 months. The Financial aspects of project is shown in the below table:

Financial Model of ESCO Project	
Particulars	**Value(in INR Million)**
Investments	**249.74**
Equity%	20.00%
Return on Equity (Pre-tax)	21.4%
Debt%	80.00%
Interest on Debt	11.00%
Annual Maintenance Charges	2.00%
Equity Contribution	49.95
Debt Contribution	199.79
Monetised Value of Energy Savings to ESCO	55.35
PHED already paid Operation & Maintenance Charges to Other Agencies with 5% inflation	32.00
Yearly Repayments to Implementing Agency	87.35

For the calculation purpose tariff rate is take as Rs. 7.5/- per kWh.

Implementation of the SCADA System

SCADA system is also introduced in the project to reduce the maintenance and operation cost of water pumping stations. We proposed the monitoring and operation system is installed in the regional office of Ajmer. Only monitoring system shall be implemented in the Head Quarter of PHED in Jaipur. A website is also designed for the communication of daily report of the pumping station.

SECTION-IV

COMPARISONS OF BUSINESS MODELS

In the proposed model, provision of mandatory replacement of working pumps has incorporated and liberty was given to the agency for replacement/ refurbishment of standby pumps. Mandatory replacement of pumps is based on the future water demand of 2027. Further, the time line for the replacement of working pumps is within two years from the letter of award (LoA), while in other similar ESCOs projects, there is no provision of mandatory replacement of working pumps and liberty was given to agency for either refurbish or replace pumps during the entire project period of 11 years.

Other models have only retrofitting solutions and do not cover other benefits accruing on account of energy efficient retrofitting through the innovative model. Mandatory asset enhancement followed with guaranteed 10 percent energy saving will provide more acceptance of client or user to the proposal.

SECTION-V

CONCLUSIONS

This is the first project in which ESCO as well as regular O&M both is considered as a key factor for the financial viability. In the proposed model, provision of mandatory replacement of working pumps is incorporated and liberty is given to the agency for replacement/ refurbishment of standby pumps. Mandatory replacement of pumps is also based on the future water demand of 2027. Further, the time line for the replacement of working pumps is within two years from the date of award, while in other similar ESCOs projects, there is no provision of mandatory replacement of working pumps and liberty was given to agency for either refurbish or replace pumps during the entire project period of 11 years.

Due the procurement of the new pump sets with latest technology and SCADA optimize the operation & maintenance cost of the project. SCADA system also helps in the reduction of wear & tear of the pump sets due to cavitation, high voltage, high current, frequency and power factor. SCADA system will increase the safety of employee as well as the equipment.

ACKNOWLEDGEMENT

We would like to express our special thanks of gratitude to Dr. Sandeep Verma (Principal Secretary, PHED), Sh. Arun Srivastav, Superintending Engineer and Mr. R.N. Khati (Assistant Engineer, PHED) as well as who help us on understanding the PHED department's methodology used for procurement. They also helped us in doing a lot of Research and we came to know about so many new things regarding water pumping stations and statutory Rules and Regulations of PHED.

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ENERGY AND RESOURCE EFFICIENCY OPPORTUNITIES ACROSS THE VALUE CHAIN

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Keywords: Supply chain sustainability, energy efficiency, SMEs

ABSTRACT

Value chain sustainability is important to create long-term environmental, social and economic value for all stakeholders involved in bringing products and services to market. Such efforts lead to numerous benefits such as reduced carbon footprint, reduced energy, reduced resource consumption, and very importantly reduced costs and enhanced efficiency for the principles themselves.

This paper shows that empowered suppliers can uncover opportunities for developing sustainable products and services, thereby contributing to a greener supply chain. This is done through sharing results from two separate EU SWITCH Asia supported projects in India; one that worked with small and medium enterprises (SMEs) linked with the automotive value chain and the other with SMEs in the food and beverage supply chain of large retailers.

Some examples of energy and resource efficiency interventions carried out by the SMEs are described to show the potential of improvements and the low cost at which process improvements can be done.

While large automotive companies are willing to engage with their direct suppliers, interest to support SMEs at second or third tiers diminishes considerably. In the retail sector, relationships with suppliers are transactional and price driven. Relationships with SME suppliers are mostly seen as short-term relationships.

In conclusion the following recommendations are offered for those seeking to green their value chains: focus on longer-term relationships, build trust, get close to the key stakeholders, and champion the cause.

INTRODUCTION

Value chains in businesses can range from being simple and linear to very complex, multi layered and therefore even difficult to map. Some businesses invest time and effort to bring sustainability into their value chains. They do this to create, protect and grow long-term environmental, social and economic value for all stakeholders involved in bringing products and services to market. Businesses that have strengthened sustainability of their value chains report benefitting through reduced carbon footprint, reduced energy, and reduced resource consumption. Examples from leading companies show that good supply chain management can increase shareholder value (The Global Compact). Additional benefits reported by companies through strengthening sustainability of their value chains include:

- Better risk anticipation and management
- Lower disruption to supply
- “Informal” or “social” license to operate within communities
- Reduced costs and enhanced efficiency and productivity
- Improved working conditions can reduce turnover of employees and improve process quality and reliability
- Environmental responsibility improves efficiency and profitability
- Corporate brand and values, and customer and consumer confidence and loyalty are protected and enhanced
- Process and product innovation. Empowered suppliers uncover opportunities for developing sustainable products and services.

Therefore many progressive companies have begun to try to understand their value chains and to promote sustainability in their own value chains. One of the important thematic areas for this is energy. Another key thematic area of focus is Resource Efficiency. The following sections describe opportunities for enhancing energy and resource efficiency that were identified and in some cases even capitalised through two different projects. The experiences and opportunities from Indian industry described here are based on actual fieldwork and direct experience. Additionally a few international examples from literature are also reported to demonstrate the huge potential that lies within the value chains.

METAL FINISHING CLUSTER

Over 100 metal finishing companies in 6 locations across India were serviced as part of a 4-year project called ACIDLOOP for short. This project was supported under the SWITCH Asia programme of the European Union.

The main object of ACIDLOOP project was to promote resource efficiency amongst the metal finishing SMEs and also to demonstrate the benefits of applying closed loop technologies for recovery of resources amongst waste streams. The project carried out several capacity building exercises at the SMEs as well as provided direct consulting for promoting resource efficiency. Details of the project can be obtained at www.acidloop.in .

Of all SMEs supported directly by the project, 39 SMEs were part of automotive supply chains. Metal finishing is an important function within the automotive manufacturing process. While large sized parts and components are produced and finished by the automotive principals or their large (tier 1) suppliers, hundreds of small yet significant components are finished by metal finishing SMEs. This metal treatment provides much needed performance enhancement such as corrosion protection and can also be important to enhance aesthetics of the component. It is important to point out that metal finishing processes potentially have many environmental issues through the use of water, chemicals and energy and the production of waste water and also forms of solid waste. The project team mapped out the customers of the SMEs and thereby attempted to engage with the automotive principals of the 39 SMEs. The hypothesis was that

- Customers of automotive SMEs exercise significant influence
- Metal finishing SMEs are relevant for environmental compliance of automotive manufacturers.

While all automotive manufacturers conform to all regulatory requirements within their metal finishing operations, as do most of the tier 1 and some tier 2 suppliers, the situation for small metal finishing enterprises that are often at tier 3 or tier 4 level is very different. The project team had to learn that the situation on compliance at metal finishing SMEs is sometimes quite poor, while most SMEs were struggling to survive using old and dated processes, their highest priority was to meet their customer demands on quality and delivery.

Engaging the Customers.

The project team considered the influence of the customer as a huge opportunity to drive resource efficiency within the metal finishing SMEs in India. Despite several efforts to engage with automotive principals, there was little to no interest to work with the project on the ground and to support the metal finishing SMEs. This was the case even through no financial support from the OEMs was sought – only the convening power of OEMs to facilitate cluster formation and setting demands for higher resource efficiency within their value chains.

The Key on-ground findings:

- For OEMs the tier 3or 4 suppliers are too far away
- Most focus on tier 1suppliers

Relegated to the “bottom” of the value chain, metal finishing SMEs bear the brunt of cost pressure from the entire value chain and the least technical support for process improvements from automotive principals.

Results

As a cluster level average, the project led to specific reduction in energy use by 23%, material resource use by 27% and water use by 33%. A large number of savings accrued from implementation of no-cost or low-cost improvements, thus building the business case of RECP for MSMEs.

As energy is a key and expensive resource for many of the metal finishing SMEs, measures to save energy were of much interest to the entrepreneurs and several energy saving measures got implemented. The heat losses from the top and sides of un-insulated hot tanks led to high heating time at start up, inability to maintain required temperature, continuous operation of heaters and evaporation losses. Tank side insulation was achieved by using rock wool or double wall insulating jacket. Top surface insulation was done using polypropylene balls. In some cases, the top surface was covered with wooden boards during non-working hours. Issues with compressor use were improper pressure setting, improper location of compressor, old technology or poor maintenance causing leakages. In most cases, the leakages were fixed, pressure setting was reduced where applicable and the compressor was moved close to the point of use. Different interventions such as proper insulation, controlling furnace mouth size, emissivity coating were made to reduce energy consumption in ovens and furnaces. Collectively

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such simple low/no cost measures implemented have yielded 2,289 t of CO_2 emission reduction. While this emission reduction figure, may initially not appear significant, it actually represents a 25% reduction in the emissions caused by the cluster SMEs.

Baseline specific consumption (resource use per unit of production) data from start of project (~2012) was compared to consumption data from post-implementation period (~2015) to determine the saving in resource use. Results of savings achieved by the SMEs are compiled location wise and also at the overall project level in the graphic below.

Reduction per kg product in consumption of		
material	energy	water
		
27%	23%	33%

Figure 1: Resource savings achieved by ACIDLOOP companies

As is evident from Figure 1, the level of savings achieved varied greatly. The range of savings realised was analysed further and found to be influenced mainly by commitment of individual entrepreneurs, their priority areas; while some focussed on water, others worked to save energy; and regional issues such as shortage in the local cluster. Aurangabad cluster companies face major issues of poor availability of water for their processes, hence as a whole the cluster focussed on water saving options and thereby achieved a 40% specific water saving.

This distribution of specific resource savings is presented in Figure 2. While a handful of companies achieved around 50% savings of material and resource use, most companies achieved 10 to 30% specific resource use reduction.

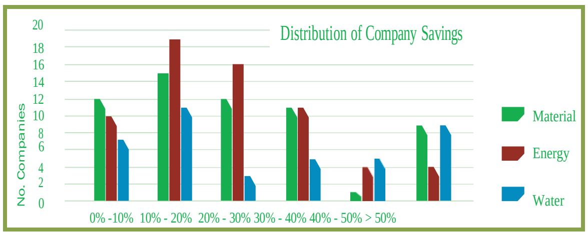

Figure 2: Distribution of savings achieved

The project was able to achieve significant savings in the specific resource consumption through the improvement actions taken by metal finishing SMEs at their own costs. The fact that most of the options suggested by the project team were low or no cost options helped the SMEs embrace the resource efficiency approach.

These results indicate that huge opportunities lie within the value chain for reducing resource consumption in a cost effective manner. These opportunities can be further harvested if the customers of the SMEs demand improvements in resource efficiency in addition to the conventional demands of cost reduction, quality and delivery performance.

By considering the entire value chain; additional opportunities for resource consumption and materials saving can be identified. For example OEMs could cluster the SMEs and consider common sourcing of chemicals thus reducing logistics and packaging, a common effluent treatment plant would not only improve compliance but also reduce costs for the SMEs.

Examples

A few select examples of the types of interventions carried out at the SMEs are presented here as simple showcases. The business case for the improvement option is also described for each example, as this is important to get buy-in from the entrepreneurs both for implementation as well as for replication.

Compressed air system optimisation – example 1: from a small electroplating company in Pune. High pressure compressed air at 7 kg/cm^2 was produced for use in auxiliary equipment that in fact required only 4 kg/cm^2 pressure. The project team identified leaks in pipeline and also noted that compressors were placed far from the equipment requiring compressed air. Company technicians had set high pressure at generation stage to compensate for loss of compressed air through leaks, rather than to plug leaks. ACIDLOOP project team explained the high cost associated with compressed air leaks and that motivated the company to move the compressors closer, repair the pipeline for leaks and could then reduce the set pressure on the compressor. These improvements resulted in smaller of the two compressors being put off, and lower energy consumption by the operational one. Though this intervention required no investment the company saved Rs. 50,287 from electricity savings annually.

Compressed air pressure adjustment - example 2: this is from a Mohali based company that was also operating their compressor at higher than required set

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pressure. In order to clearly demonstrate the energy savings by reducing the set pressure, ACIDLOOP team carried out a trial by installing a power logging instrument at the air compressor. The power and energy values were logged over short time interval and then the set pressure reduced from 12 kg/cm^2 to 8 kg/cm^2 and power logging continued. The reduced pressure did not adversely impact the performance of equipment drawing compressed air. Collected data is plotted in the form of a graph in Figure 3, that clearly demonstrates the savings. The company standardised the set pressure at 8 kg/cm^2 to derive electricity cost saving of Rs. 112,000 annually at compressor, with immediate payback.

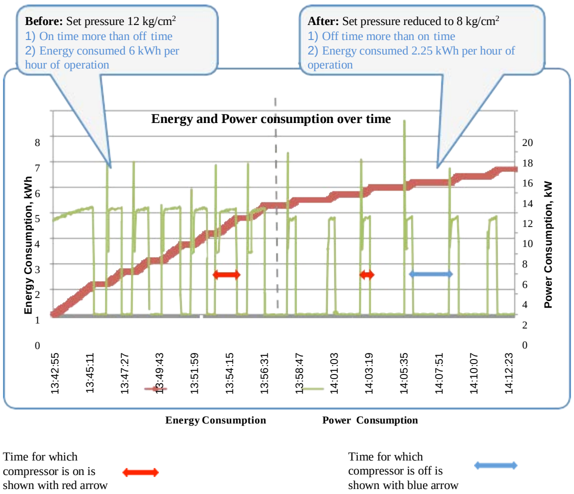

Figure 3: Power consumption change due to pressure reduction

Heat insulation of tank – example 3: from another electroplating company in Pune, wherein degreasing process tank was heated using a 2 kW heater. This heater normally operated all 8 hours of the shift as heat was continuously being lost from un-insulated tank walls. Upon suggestion of ACIDLOOP team the company fabricated a double walled insulated jacket for the tank at cost of Rs 5,000. Post insulation, the heater could be switched off for nearly 4 hours per shift and because of uniform temperature in the tank the degreasing process became more effective. Over a year the company saved Rs. 21,600 with a payback period of 2.8 months.

Innovative tank insulation – example 4: Another interesting example on thermal insulation is from a powder coating company in Aurangabad. This company was informed about the benefit of top lids on heated process tanks and decided to fabricate wooden lids using waste wood from packaging and started to hours to attain the set temperature each day, but after covering overnight, the so-called cold start up time reduced to 1 hour. The company observed that the tanks lost only 5°C compared to a significant drop overnight earlier. Energy savings accrued to Rs. 275,900 while utilising waste material to fabricate a simple yet effective solution.

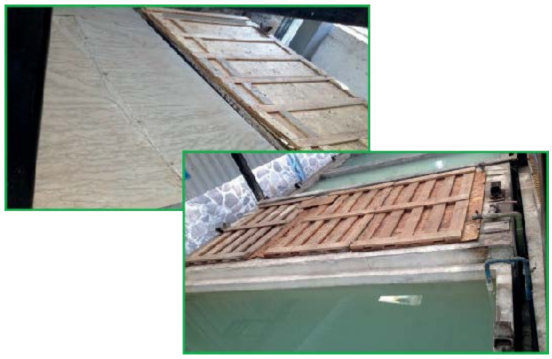

Figure 4: Innovative cover for heat loss reduction

Door opening adjustment – example 5: again demonstrates that simple change in work practices can lead to energy savings. This powder coating company from Aurangabad processes a variety of parts. The powder coating oven door opening was set for the largest requirement leading to heat loss from the openings. ACIDLOOP team explained the heat loss through thermo graphic studies and the company

apply these lids onto the process tanks soon after they were done for the day, as can be seen in Figure 4. Earlier the process tanks took around 4 now aligns the parts along the conveyer axis and correspondingly has minimised the oven opening. The images in Figure 5 show the visual as well as thermal images from before in the first row and the improved situation in the second row. The company saved diesel used for firing the oven worth Rs. 183,900 with no investment.

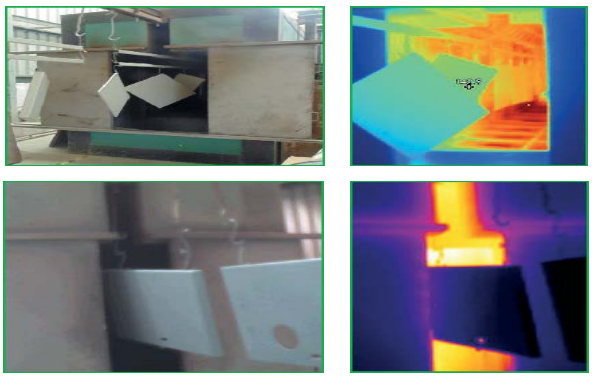

Figure 5: Heat loss reduction through oven opening size reduction

While most examples in this paper are selected to exemplify energy savings, one example to show material efficiency has been included to demonstrate the wider scope of ACIDLOOP project.

Paint gun selection – example 6: from a fabrication company in Mohali. Spray gun with high paint wastage was in use. Transfer efficiency was improved through use of High Volume Low Pressure paint gun and the corresponding operator training. Paint consumption came down for the same output; additionally paint booth cleaning time was reduced. The company saved paint worth Rs. 160,000 annually through an investment for Rs. 12,000, thus realising a payback period of 1 month.

The various examples above show that with some technical inputs (knowledge and support) SMEs are able to reduce wastage of energy and other resources without any financial support. The cost savings that accrue from simple process improvements helps the SMEs met the annual cost reduction pressures exerted by OEMs in their value chain.

FOOD AND BEVERAGE RETAIL VALUE CHAIN

Four large retailers of India along with some of their food and beverage supplier SMEs were supported through another SWITCH Asia project called GREEN RETAIL India for short. In this case the project team had the hypothesis that retailers are the most effective players in influencing change at all levels, as they are at the crossroads between both areas of the value chain; supply chain and consumers. The key on-ground findings from the project work are:

- Retailers willing to engage in Greening the supply chain
- Retailers implementing and benefiting from sustainable practices in-store

But as the relationships with suppliers are transactional – price driven, they oftentimes have short-term relationships with their supply chains and do not partner with them over time.

Some retailers have a perception that Indian consumer is not willing to pay more for sustainable products. Therefore no long term-strategies are in place for developing sustainability in the value chains. Studies on consumer behaviour (National Geographic and Globe Scan, 2016) indicate in fact that Indian consumers are most likely to pay more for a sustainable product. Indian consumers seek an assurance of a truly sustainable product (Green Purchasing Network, 2013-14).

Results

Some of the interventions with the retailers at the store level yielded significant energy savings, as shown for a particular store from Kolkata in Figure 6 below.

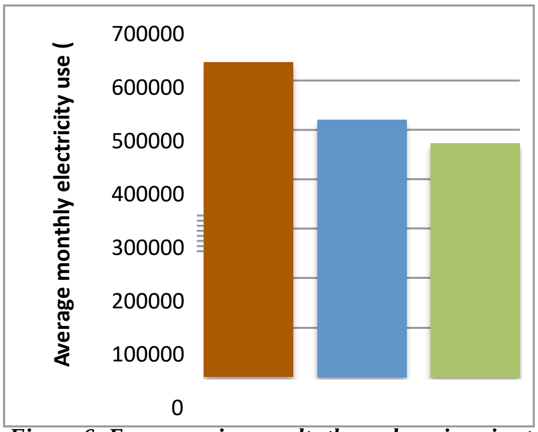

Figure 6: Energy saving results through various in store initiatives over three years

The energy consumption was reduced by 19% in one year of project interventions and further by 8% in the subsequent year through additional measures being implemented.

Moving upstream in the value chain with the support of the retailers would certainly throw up several additional resource saving opportunities. Retailers could engage with SME suppliers for developing common delivery services (particularly for cold chains) thereby reducing fuel costs and achieving timely deliveries. Retailers actively engaging downstream with consumers would help them identify sustainable products (for example reducing packing waste, or providing organic produce) which would not only help differentiate them from other retailers but also bring down operations costs.

Examples

An SME from Mumbai that produces and supplies snacks and savouries to retailers achieved a decrease in Electricity consumption by 625 kWh/month which is equivalent to savings of Rs 5000/month while also leading to emission reduction of 570 kg of CO_2/month through compressed air leak reduction, lighting optimisation. Simple combustion optimisation in boiler/fryer and improving insulation in boiler helped the company to enhance production by 10 kg/hr for same fuel consumption.

International examples also show large savings potential as well. Wal-Mart modified their yogurt packing system (Tom Blanck, CSCP, CPP Principal CHAINalytics; 2011 APIC Intl. Conf., Pittsburgh, USA) to capture multiple benefits as summarised in Table 1.

Table 1: Changes made by Wal-Mart in one yogurt production line

Pre-formed cup	**Form, fill & seal (FFS)**
7.3 g	5 g
Cups made and stamped offsite	Formed at yogurt line
Shipped	No need
Circular shaped	Cube shaped
Single sales unit	Multi pack – less handling

The journey of improving packing system optimisation was not an easy one – not was it possible for the principle (Wal-Mart) to undertake this journey alone. Strategic partnerships with value chain partners were forged and cross-functional teams involved in order to utilise the full potential. Technology supplier offering new packing systems alone could not provide to Wal-Mart the optimised solution that the is described in Table 1, if the production team and customer interfacing team inputs were not considered.

The benefits achieved are significant from business as well as sustainability perspectives. Not only at the business end but also from energy savings and sustainability point of view, this project delivered significant impact, as can be seen in Table 2.

Table 2: Savings realised

RESULTS	**Business**	**Sustainability**
Inbound	Primary packing material saving of 31%	Materials savings 363 t
	Freight savings 60%	Pallets eliminated 3,000
		CO_2 savings 32 t
Outbound	Operational cost savings >30%	Material savings 1,900 t
	Freight savings 28%	Pallets eliminated >15,000
	Corrugated savings 33%	CO_2 savings 2,000 t
	Pallets cost saved $90,000	Energy 6,447 kWh

CONCLUSION

There are many opportunities to save energy and resources in the value chain. This also leads to improved sustainability. Businesses need to foster longer-term relationships with their value chains, and also invest time and effort to build trust. They must promote closeness to the key stakeholders and Champion the Cause for sustainability in the value chain, as the example from Wal-Mart shows. Indian automotive OEMs and large retailers can actively engage with their value chains to tap into the large potential of energy and resource conservation. A collaborative and long-term approach is likely to yield not only environmental but monetary benefits for the principals and strengthen their own business sustainability.

ACKNOWLEDGEMENTS

This paper is based on the work carried out under two European Union (EU) SWITCH Asia Programme supported projects. The author gratefully acknowledges the financial support from the EU for these two projects, as also the technical contributions by other partner organisation in the project consortia.

Some of the results and examples presented in this paper also appear in similar or different form in reports pertaining to the cited projects.

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ENERGY EFFICIENCY FOR CLIMATE RESILIENCE IN ASIAN CITIES

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Keywords: Urban climate resilience

ABSTRACT

With over one billion city dwellers in Asia, building adaptive capacity and decreasing vulnerability to climate change in urban areas has become critical. Cities already contribute up to 80% of GDP, yet they strive to generate more and more economic opportunities. At the same time, urban spaces face the pressure of a fast growing population and increased consumption of natural resources, which threatens the overall development process in the long run.

In such a context, it is critical to reverse the resources consumption tendency. Governments have become increasingly aware of threats related to water mismanagement, however the role of energy efficiency in contributing to building urban climate resilience is largely underestimated. In addition to reducing GHG emissions, energy efficiency can deliver multiple benefits, such as palliate the heat island effect, curb air pollution and generate positive impact on health, increase economies of scale, alleviate poverty and augment disposable income, improve the transportation sector. Most importantly, while delivery of other basic services majorly depends on a government-subsidized approach, energy efficiency presents a strong case for economically and financially viable opportunities.

The paper outlines how energy efficiency contributes to making Asian cities resilient to shocks and stresses and what major climate resilience benefits the government may expect from incentivizing it through the example of the transport sector.

INTRODUCTION

Energy efficiency, despite not being looked at in priority when thinking of climate resilience in cities, plays nevertheless a major role: the energy sector is not only a major contributor to global greenhouse gas (GHG) emissions but also conditions sustainable urban planning. In its 2014 report, the Intergovernmental Panel on Climate Change (IPCC) highlighted the three pillars of “deep de-carbonization,” as:

1. Energy efficiency and conservation
2. (transport, buildings, manufacturing);
3. Low-carbon electricity (nuclear, solar, hydro, wind geothermal), or coupling fossil fuels with carbon capture and storage (CCS); and
4. Switching to lower carbon fuels.

IPCC directly connects the success of climate resilience to clean energy. In the context of developing Asian countries, industries, buildings, urban transport and other urban infrastructure sectors are highly energy dependent. Asian cities, being major economic hubs, are the largest contributors to global GHG emissions. Targeting energy savings can reduce these emissions and make economies more competitive. In fact, energy efficiency is often times a business case while targeting efficiency in the water, transport or another urban service delivery sectors brings a less direct return on investment. By targeting energy efficiency, a city may positively influence a number of other sectors. This approach will be demonstrated on the example of the transportation.

BACKGROUND

Summary: Cities are drivers of economic growth. In most of the developing Asian countries, economic growth is not yet decoupled from energy consumption. GDP growth requires greater energy use to perform economic activities on a business-as- usual scenario. Cities are also at the forefront of Green House Gases (GHG) emissions and hence are major contributors to climate change. However, importantly, cities are also major victims of climate change due to high concentration of people and activities in a smaller area. It is therefore an urgent priority for Asian cities to shift towards clean energy to help mitigate climate change at the earliest.

Cities have become drivers of economic growth. Hundred largest metro areas account for 20% of Asia’s global GDP ($21.9 trillion) in 2014[1]. Many cities contribute as much as 200 to 500 % in national GDP versus their population share.

[1] Asia-Pacific Metromonitor 2014, Engines of Global Growth, The

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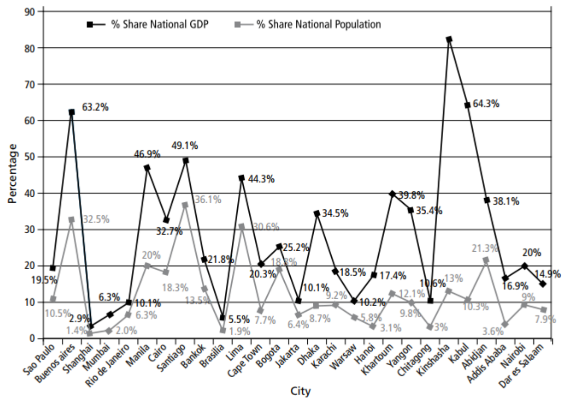

Figure 1 National population and GDP share in key cities of developing countries, 2008[2]

As demonstrated in the figure below, there is a direct correlation between the per capita energy consumption and the national GDP in most developing countries. However, a number of developed countries such as Japan, Italy or Germany have decoupled their energy consumption and strike a balance between economic growth and energy efficiency. It has been noted that when the annual income rises above US$20,000 in GDP per person, average emissions decline.[3]

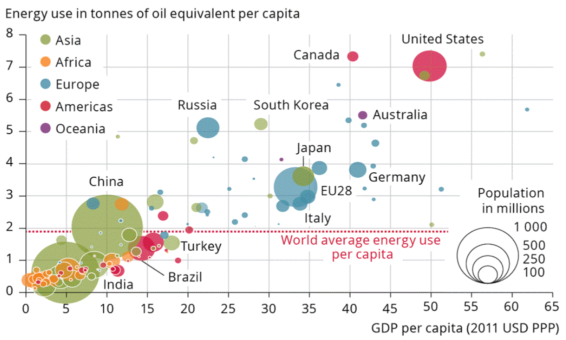

Figure 2 Co-relation of energy consumption and GDP per capita (2011 USD PPP) Source: European Environment Agency, European Union July 2016

Consequently, cities are at the forefront of GHG emissions and, hence, are major contributors to climate change. Globally, cities account for 80% of energy use and 40-50% of GHG emissions**.** The Asia – Pacific region alone is home to 6 out of 10 highest CO2 emitting nations and accounts for 43% of total global emissions.

Asian cities account for 30% to 38% of regional CO2 emissions. It is interesting to note that while per capita emissions in developing countries' mega-cities are higher than the national average, selected developed countries' mega-cities have a significantly lower level compared to the national average. In fact, cities with lower CO2 emissions such as Tokyo or Seoul have conducted a number of clean energy supportive policies.

Table 1 CO2 emission in selected cities and respective countries

Data Source: Asian green city index report, 2011

City	Co2 emission (tons/person)	
	City	Country
Shanghai	7.8	7.55
Bangkok	6.7	4.11
Tokyo	4.5	9.76
Seoul	3.9	11.75
Asian Average	**4.6**	

Importantly, cities are also major victims of climate change. Asia is urbanizing fast, which puts high stress on scarcely available natural resources and basic services, and renders cities highly vulnerable to extreme weather events, exacerbated by climate change.

More than half of the world population is projected to reside in cities by 2030. This growth will occur in cities and towns of the developing world, mostly in Africa and Asia. It is worth noticing that most of the fastest growing cities are secondary and tertiary cities with an annual growth rate of more than 6%. Nine of the 10 most populous cities in the world and 40 out of 47 fastest growing cities are located in Asia.[4] It is said that when the population of a city doubles, its built area triples. Asian cities are however rather characterised by dense urban forms. For instance, about 92% of cities in East Asia (excluding China) have witnessed an increase in urban density for a duration of 10 years (2000 to 2010)[5]

Consequently, the increasing frequency of extreme weather events related to climate change and increased pressure on a reduced amount of land and natural resources severely hit Asian cities' dwellers.

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[2] Source: Based on data of PriceWater House Coopers, National Statistics & QuanZhang, The trends, promises and challenges of urbanization in the world, Habitat International, May 2016

[3] Asian Green city index report, 2011

[4] P-6, The world cities in 2016, United Nations Data booklet2016

[5] Chandan Deuskar, Despite expectations, cities in East Asia are becoming denser, World bank blog, Feb 2015, http://blogs.worldbank.org/sustainablecities/despite-expectations-cities-east-asia-are-becoming-denser

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In 2015 alone, **natural disasters** caused a total loss of 16,046 lives and USD 45.1 billion in the Asia – Pacific region (EMDAT for disasters, 2015). Out of 10 world most vulnerable cities, 6 are located in Asia. Similarly, out of 100 most **polluted cities** in terms of air quality, 70 are located in Asia. According to the World Health Organization (WHO), urban air pollution is estimated to kill around 1.2 million people annually where as much as 80% of urban air pollution in the region is attributable to the transport sector[6].

Figure 3 Traffic gridlock in Lahore, Pakistan[7]

In urban areas, waste heat produced by human activities, including heat generated by vehicle combustion, industrial processes and buildings, cause local air temperatures to rise. This produces a phenomenon called **urban heat islands** (UHI) (Allen et al., 2010). The characteristics of UHI in Bangkok city[8] show a maximum temperature difference of 6-7 °C during the dry season and the mean annual temperature difference of 0.8 °C as compared to the surrounding areas. In general, cities are argued to have a temperature difference between 4°C and 5°C compared to neighbouring rural environments, with impacts that can extend for subsequent 82 kilometres in radius.

It is therefore an urgent priority for Asian cities to shift towards clean energy and help mitigate climate change at the earliest. However, the role of energy efficiency in building urban climate resilience has largely been underestimated.

Cities tend to focus on immediate measures and engineering solutions to prevent natural hazards, secure full water supply coverage or manage waste and wastewater in priority. A critical reason for this is the fact that, in most Asian countries, energy supply does not come under the local mandates, but is managed at the national or at the regional level. Urban local bodies therefore don't see incentives in investing time and resources into the sector. It hence requires national political will to widespread clean energy investments at the local level. Japan for example promoted clean energy by providing policy and regulatory support, building a renewable-based hydrogen economy, expanding smart-grid and district heating systems to shift towards low carbon economy as well as advantaging pro-renewable factions in other ministries, including the Ministry of Economy Trade and Industry[9].

Yet, there is a high potential to reverse the trend of achieving economic growth at the expense of environmental damages by putting energy efficiency at the core of the process. Clean energy is an service delivery sector that works well on a business model compared to other sectors. It is therefore wise to target energy savings to improve other sectors through the energy efficiency target. Not only this allows increasing energy efficiency but also, equally importantly, a large number of benefits spill over the city through such interventions. Energy efficiency greatly contributes to urban resilience by reducing GHG emissions, curbing heat island effect, air pollution and poverty through reducing the energy bills, and thereby triggers economic growth, improved health and wellbeing of citizens and ultimately mitigates climate change.

A demonstration of the above will be conducted through the transportation sector.

ACHIEVING URBAN CLIMATE RESILIENCE BY TARGETING ENERGY EFFICIENCY: CASE STUDY OF THE URBAN TRANSPORT

Sustainable development goals (SDG) state that transport and energy are crucial factors of sustainability. By 2030, SDG target 7.3 consists in doubling the global rate of improvement in energy efficiency and SDG target 11.2 – in providing access to safe, affordable, accessible and sustainable transport system for all, improving road safety,

[6] ADB, Transport, key priority, accessed aug 2017, https://www.adb.org/sectors/transport/key-priorities/urban-transport

[7] Imran Chaudhry, Traffic gridlocks on road continue, commuters fret, Daily Times Feb 2017

[8] Sigit D. Arifwidodo, Takahiro Tanaka, The Characteristics of Urban Heat Island in Bangkok, Thailand, Procedia - Social and Behavioral Sciences, Elsevier, July 2015

[9] Andrew DeWit, Japan's bid to become a world leader in renewable energy, The Asia Pacific Journal, October 2015

notably by expanding public transport, with special attention to the needs of the vulnerable. Apart from these, the target 3.6 on road safety, target 7.2 on renewable energy, target 9.1 on sustainable infrastructure, target 11.6 on air quality and target 13.2 on climate change all require substantial actions to be taken to achieve sustainable urban transport.

The transportation sector is one of the most energy consuming and CO2 emitting economic sectors. It contributes to 16% of total energy demand in Asia, which is projected to grow up to 19% by 2035[10]. Globally, about 23 % of CO2 emissions come from the transportation sector[11].

In Thailand, total transport energy-related GHG emissions represent about a third of national emissions. These go as high as 49% in Bangkok, where per capita GHG emissions are of 10.6 tons, which is more than 2.5 times the global average[12]. This shows a significant scope for reducing GHG emissions by focusing on the transportation sector.

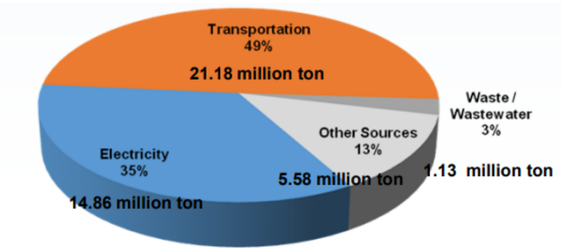

Figure 4 GHG emissions in Bangkok by Sector (million ton per annum)[13]

However, the energy demand and the volume of emissions vary and depend upon most popular transportation modes, supportive infrastructure, per capita income and national policy framework. For example, in India motorization policy is leading to higher energy demand in the transport sector. In Japan, on the other hand, there is a decline in the energy demand due to a shift towards improved technology in the form of fuel-efficient vehicles (mainly hybrids) and declining population of the country. Japan invested more than 2% of its GDP into new transport construction and improvement of the existing road network between 2000 and 2010[14]. As a result, emissions from the sector were considerably reduced: from 267 million tons in 2001 they decreased to 246 million tons by 2007, which over-achieved the projected reduction target for 2010[15].

The purchase power of urban dwellers is increasing as a result of the economic growth and more people can afford a motorized transport mean. When adequate public transportation is lacking, the number of privately owned vehicles increases. Consequently, **motor vehicle fleets double every 5 to 7 years, which is a much faster growth than the urban population growth.** This leads to a car-oriented infrastructure[16] and, hence, Asian cities lock themselves into a sprawl pattern. In Asia, **18% of urban land area is covered by transport facilities.** Land is an important resource for cities to perform social, environmental and economic activities, and about 1/5 of this resource is hence wasted from other potential uses. In addition, increased motorized traffic leads to increased congestion, accidents, air and sound pollution. People in Asia spend 43 minutes on an average for each trip, which eventually has a significant impact on health and productivity. According to the Global Status Report on Road Safety, Thailand ranked 3rd in the world for road accidents and total traffic accident cost equalled to 2.8% of GDP in Thailand[17]

Figures 5 and 6 below show to what extent **energy consumption and sustainable urban transportation are correlated.** Non-motorized transport means are most energy efficient and they also require least pavement space allowing cities to use the space for, for example, green areas and recreation facilities. Public transportation modes – trams, buses, metro and rail - are most energy and space efficient than motorized transport modes in terms of energy consumed per person: 1.6 to 1.75 MJ/ passenger /km travelled. The motorcycle is the second most fuel-efficient mode of private transport (after the bicycle) with lesser CO2 emissions, but much higher emissions of other pollutants such as hydrocarbon (416%), oxides of nitrogen (3,220%)

[10] Energy Outlook for Asia and the Pacific, APEC,ADB< October 2013
[11] IEA Statistics, OECD/IEA 2014, https://data.worldbank.org/indicator/EN.CO2.TRAN.ZS?page=6
[12] http://siteresources.worldbank.org/INTCARBONFINANCE/Resources/Chanin_Manopiniwes_Nat_Pinnoi_Bangkok_Urban_Transformation.pdf
[13] Nuanphan Phawawes, Low-carbon society development in Bangkok, 2014 http://www.iges.or.jp/isap/2014/PDF/pl11/pl11_08_phawawes.pdf

[14] OECD, 2014
[15] Japan for sustainability, JFS Newsletter No.95, July 2010
[16] World Bank 2010
[17] http://siteresources.worldbank.org/INTTHAILAND/Resources/presentation-traffic-accident-costs.pdf

and carbon monoxide (8,065%). Private transport and logistic vehicles rank lowest in terms of energy efficiency and also emit the maximum amount of CO2.

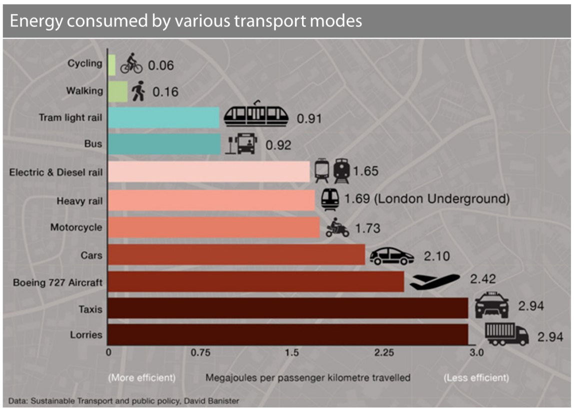

Figure 5 Energy consumed by various modes of transport[18]

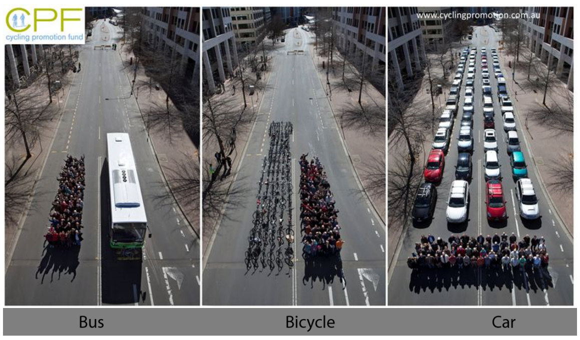

Figure 6 Comparison of road space consumed by different mode of transport for 40 people, Source: Cycling promotion find (CPF)

Based on these conclusions, a large number of cities are shifting towards a Transit Oriented Development (TOD). **TOD promotes compact, high density, walkable, mixed-use and safe cities developed along transit corridors** to reduce the requirement of vehicular travel, saving time, cost, space and develop a vibrant public realm along these corridors. The benefits of TOD include:

- Higher densities along transit nodes and corridors such as metro and bus routes to maximize the use of public transport facilities by making more people reside a walking distance away from them;
- Mixed building use: residential space and work space in close proximity, to promote short distance trips of less than 500 meters, which can be taken by walking or by a bicycle;
- Policy regulations to control the number of vehicles and peak hour traffic through taxes and higher charges for private vehicle parking;
- Active and safe streets for pedestrians by improving road design;
- Overall reduction of travel need, time and cost.

Figure 7 Principles of Transit Oriented Development (TOD), Source: Institute for Transportation and Development Policy (ITDP)

The TOD has been implemented in many cities across the globe and proved very effective to solve urban transportation issues. For example in Seoul, two major public transport systems are the railway with 35% passenger traffic share, mostly used for long distance travel, and buses, which had a 30% passenger traffic share. To increase the use of public transport, a bus reform was implemented: the quality of buses was improved both in terms of comfort and fuel efficiency. Bus-only lanes for faster travel and dedicated bicycle and pedestrian lanes for safety were key ingredients of the reform. A number of highly positive results could be observed after the implementation of the reform (2004 to 2005):

- 9.9% increase in bus passenger share;
- 32% to 85% increase in bus speed along various routes;
- 5.9 % reduction in traffic volume;
- 49 million tons equal to 19% of total energy from transport were avoided;
- Emissions from transportation sector haven't increased in past 5 years, even with the increase of the population.

[18] Data Source: David Banister, Sustainable transport and public policy, https://blogs.crikey.com.au/theurbanist/2013/02/21/do-public-transport-fares-cost-too-much/

Figure 8 TOD in Source: Seoul\https://citynetmembers.files.wordpress.com/2014/01/median-bus-lane3.jpg

In 2011, Seoul initiated car free days to reduce GHG emissions and to promote the use of public transport. This move has resulted in an annual 10% reduction in CO2 emissions and generated annual savings of $50 million USD in terms of fuel cost[19].

In addition to planning and regulation measures, technical measures to achieve energy efficiency may significantly transform the transportation sector. This relates to improving the vehicle design so that it creates less pollution and requires less fuel to cover larger distances. Improved technologies such as hybrid and electric vehicles have lately been recording significant progress. Electric vehicles charged with electricity from renewable sources can reduce future emissions and air pollutants from road transport.

Policy measures, such as pollution control certification that ensures a mandatory and regular check-up of a vehicle, are helpful to control highly polluting vehicles to ply on the road. Improvement in vehicle design and technology to further reduce pollution and fuel consumption have proven to be helpful, such as in case of a hybrid and electric vehicle technology. The use of information technology in public transportation also has a considerable impact in shifting people to the public transport modes. This is being done by e-ticketing, time estimation for next bus/metro arrival, travel time estimation per trip, automated fare collection, etc. Information on shortest routes, peak traffic hours and live GPS traffic mapping enabling vehicles to identify the best routes has also proved quite helpful in terms of increasing the urban public transportation usage.

The transportation sector, unlike other service delivery sectors, has proved to be economically viable in Asian cities. The cost recovery from public transport in Asia is 123% compared to 59% in Europe and 42% in North America. A significant amount of urban climate mitigation finance went utilized by transport and energy-efficiency projects because these sectors have suitable financing models that allow for the recovery of upfront capital costs and are well aligned with urban priorities.[20] Associated reduced pollution from the transportation sector helps reduce health risks and frees time for work, education and other productive activities.

Reducing transport related sound and air pollution through reducing traffic congestion and ensuring an energy efficient transportation system leads to improved urban environment quality.

Reducing CO2 emissions from transport has a positive impact on controlling the urban heat island effect. For instance, in the city of Guangzhou, China, setting up a 22.9 km long Bus Rapid Transit System (BRTS) has led to reducing bus related energy consumption by 4.3%, per person per trip. CO2 emissions decreased by 31.5% and, overall, 86,000 tons of CO2 emissions per year were avoided over the first decade of the project.

The overall quality of life considerably improves when urban planning renders cities more transit oriented by changing the urban growth pattern from a sprawl to higher densities, targeting a reduction in fuel consumption by improved vehicle design, technology and higher vehicle standards. Cities need to focus on strengthening and promoting an integrated public transport network such as a combination of a Bus Rapid Transit Systems (BRTS), Mass Rapid Transit systems (MRTS) and Light Rail systems with non-motorized transport

[19] http://www.c40.org/case_studies/seoul-car-free-days-have-reduced-co2-emissions-by-10-annually

[20] Andy Gouldson et al., "Accelerating low-carbon development in the world's cities", Seizing the Global Opportunity, The New Climate Economy: The Global Commission on the Economy and Climate, 2015

options such as walking and cycling to reduce per capita fuel consumption. Active transport systems, such as **walking, cycling and cycle rickshaws,** which are already popular in many Asian cities, have practically no energy requirement, no emissions and numerous health benefits. Promotion of electrified cycle rickshaws contributes not only to cutting CO2 emissions and lower travel time, but also to mitigating the human physical effort compared to a traditional rickshaw. Shared public transport facilities reduce the travel time and minimize per trip cost by sharing the resource.

CONCLUSION

Energy efficiency is a core player in urban climate resilience and national governments in Asian cities need to incentivize urban local bodies to focus on energy efficiency. When Seoul Metropolitan Government launched the Building Retrofit Program (BRP) to spur retrofitting in government, commercial and residential buildings, it aimed to reduce 2 million TOE from 2012 to 2014. This was achieved in only 6 months. The program also contributed to cutting 25,841 tons of CO2 emissions for the period of 2012 to 2015 from 4,200 projects, and aims at a 40% CO2 reduction from 2005 level by 2030[21]. The Seoul BRP model is not only a climate resilient growth model, but also a **sustainable business model with return on investment with a considerable reduction in annual building energy cost**.

With climate change risks increasing day-by-day, there is a greater need for policy regulations and support to urban local bodies in improving energy efficiency of urban public services and promoting emerging clean energy technologies in Asian cities.

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MAINSTREAMING ENERGY EFFICIENCY FOR MARKET TRANSFORMATION

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Keywords: Energy-efficiency, productity, market transformation, energy-intensity, agents-of-change

ABSTRACT

What have been the lessons learnt from efforts to mainstream energy efficiency (EE) in India through policies, institutions, financing and partnerships over the last five decades? How does EE emerge in the context of India's growth and economic transformation? There has been dynamic growth in the different sectors of Indian - industry, infrastructure, urbanisation, housing, transportation networks, trade and commerce. Further, the country has witnessed geometric growth in the services sector, spurred by the digital revolution.

Could India have achieved more with less energy? Is energy intensity falling? If so what are the factors that are enabling it? What policies, incentives and levers have helped achieve this trend. Are the number deceptive, and has energy scarcity been a factor that has kept India in the slow lane compared to other global competitors?

The paper examines both policies and institutions and their contribution to understanding India's energy economy. Are we able to mainstream energy efficiency well in time to avert the severe impact of energy scarcity and the adverse effects of energy profligacy?

The paper identifies 5-8 key factors and organisations that have played a role in this movement and aimed to analyse and quantify their impact, and specific contributions, respectively.

Does India’s long-standing commitment to Global Climate Agreements, along with some of the high energy consumers portend a different global energy scenario?

INTRODUCTION

The first attempts at channelising energy as a resource and bundling its various activities within the framework of a Law was the enactment of the Indian Electricity Act (IE Act), 1910. The IE Act propelled a basic structure for electricity generation and supply in India. It streamlined and bundled several activities of generation, transmission and distribution of electricity.

Post independence, electricity was dealt with as a critical sector. The initial legislation sought to circumvent the colonial redundancies and take a renewed approach to implementing robust policies, legislation and programmes. Regulatory bodies and authorities to govern and streamline the functions of the Government were created, along with multiple government companies focusing on various forms of generations. The primary concern was the supply of electricity, and also oil and coal, to support growth; conservation of energy was not a matter of priority during the first 15-20 years after Independence.

POST-INDEPENDENCE SURGE

The Electricity (Supply) Act of 1948 created a platform to enable co-ordinated development of electricity. The Central Electricity Authority (CEA) was established in 1950, to develop sound, adequate and uniform nation-wide power policies and co-ordinate development. The Planning Commission was set up in March 1950 and tasked with the responsibility of assessing of all resources in the country, augmenting deficient resources, formulating plans for the most efficient and balanced utilisation of resources and determining priorities. The first Five Year Plan (1951-56) allocated 27% of the budget outlay towards irrigation and power and multi-purpose river valley projects. The second and third Five Year Plans (1956-61 and 1961-66) gave impetus to interconnect regional grids and allowing the networks of different states to be connected. The third Plan, for the first time, referred to increased efficiencies in large thermal boilers by using high temperatures and pressures. It also acknowledged that the overall efficiency of thermal stations had been very low, around 20% until 1960, but improvements were expected in the future due to the operation of larger units. One of the earliest movements to promote "productivity culture" in India was started by the Government of India when the National Productivity Council (NPC) was set up in 1958 under the Industry Ministry. Besides providing training and consultancy, the NPC researched in the area of productivity. NPC's creation coincided with the formation, in 1959, of the Tokyo based Asian Productivity Organisation (APO), an inter-governmental body of which the Government of India was a founding member. NPC became the rallying point for efficiency in fuel and energy over the next few years and was the focal point for some of the earliest international support and exchange from the UK, Japan and other developed countries.

Integrated Energy Planning was recognised as an essential element of development planning in India as early as the sixties, but with very little focus on Demand Side Management (DSM). The Energy Survey of India Committee (ESIC) was established in 1963 to study demand and supply of energy on a national, regional and sectoral basis and provide a framework for energy development planning until 1981. Further, the Fuel Policy Committee (FPC) was set up in 1970 to develop the country's national fuel policy for the next 15 years. FPC adopted techniques like the econometric forecasting and end-user analysis in arriving at sectoral energy demand estimates. The focus of the Committee was on the necessity of substitution of oil by coal and higher efficiency in electricity generation and transmission with particular attention to hydel power developments. The fourth Five Year Plan (1969-1974) for the first time decoupled power and irrigation and considered power as a separate area for development.

Installed capacity increased to 14,290 MW at the end of 1969, from about 1,710 MW in 1950. Although the power sector began with 40% ownership of installed capacity by the public sector, a national push towards increasing public sector dominance in the power sector resulted in State Electricity Bodies in the power sector resulted in State Electricity Bodies (SEBs) owning 80% of installed capacity by 1970.

For the first time, an energy cartel took shape in the formation of the Organization of Petroleum Exporting Countries (the OPEC). The 1973 Yom Kippur war between Israel and a coalition of Arab states, lead to an embargo on oil exports from the OPEC countries. The consequent increase in the price of petroleum products led to a worldwide rise in oil prices, introduced rationing, and triggered efforts towards energy conservation.

Fuel and energy issues became the focus of policy in the mid-1970s. The Working Group on Energy Policy was constituted under the fifth Five Year Plan in 1977 to outline the national energy policy over the next 5-, 10-, and 15-year periods. The Group submitted its report in 1979 covering the existing and future energy scenarios of the country and measures to optimise energy use in India. The primary thrust of these policy prescriptions was towards:

a) curbing oil consumption to the minimum levels,
b) increasing the efficiency of utilisation of energy,
c) minimise the overall energy demand by reducing the intensity of energy consumption
d) increased reliance on renewable energy sources, mostly hydropower.

In 1976, in the wake of the oil crisis recognising the importance of energy conservation, the Petroleum Conservation Action Group (PCAG) was established under the initiative of NPC, IOC and DGTD. Out of this Action Group evolved the Petroleum Conservation Research Association (PCRA) in 1978, under the aegis of the Ministry of Petroleum and Natural Gas. The technical expertise for this body was drawn from NPC, to make oil conservation a national movement. PCRA created awareness about the methods and benefits of conserving petroleum products; promoting research and development in industry, transport, agriculture and domestic consumers in fuel-efficient technologies; by providing training and technical assistance to increase energy efficiency; and also by promoting the substitution of petroleum products by alternative sources. PCRA developed a number of awareness and training programmes.

In the Sixth Plan (1980-85) emphasis shifted to reduce dependence on energy imports, since the country imported about 28% of petroleum products consumed in 1984-85.

The Advisory Board on Energy (ABE) was set up in 1983. It took up the technical, financial and institutional aspects of energy. ABE, for the first time, made detailed projections of energy demand in different regions till 2004 considering different macroeconomic scenarios. Unlike the earlier working groups, the ABE provided policy guidelines for energy sector planning, looked at investment choices available in energy and energy-related sectors, and evaluated various options in terms of costs and technologies. For the seventh Plan (1985-90), the Planning Commission took up long-term energy modelling to analyse the supply options available in coal, oil, natural gas and electricity concerning the economic resource costs involved.

From 1985, the former Department of Power (now the Ministry of Power) functioned as the nodal point for the government to facilitate the implementation of a coordinated strategy on energy conservation. The Department focused on Energy Conservation (EC) strategies and funding support for strengthening EC programmes, including outreach programmes.

In 1989, an Energy Management Centre (EMC) was also set up as an autonomous organisation, with the assistance of the World Bank and United Nations Development Programme (UNDP), to promote energy conservation. The centre co-ordinated energy auditing of consumers, energy management systems, education and training, and energy generation and conservation-based employment and poverty alleviation programmes. In 1986, PCRA started focusing on energy auditing and took up a landmark initiative for the empanelment of energy auditors.

THE 1990S

Despite all these diverse initiatives, there was no comprehensive legislation on the conservation of energy, and no legal mechanism to enforce energy conservation and efficiency activities. In 1994, the Ministry of Power constituted a working group of representatives from various ministries to formulate legislation on energy conservation. This Group proposed the Energy Conservation Bill in 1997.

The Ninth Plan (1997-2002) recognised the need to conserve natural resources and the need to encourage the use of renewable sources of energy like the sun and wind.[ii] The Plan also gave cognisance to the need for an appropriate technology base to tackle the issue of natural resource conservation.

THE ENERGY CONSERVATION ACT 2001 (ECA)

In February 2000, the Government introduced the Energy Conservation Bill in the 13th Lok Sabha. Both Houses of Parliament passed the EC Bill, which received the President's consent in September 2001. ECA was published in the Gazette of India in October 2001 (with an effective date of 1 March 2002) and is known as the Energy Conservation Act 2001.[iii]

In 2002, the Energy Management Centre was re-instituted as the Bureau of Energy Efficiency (BEE). The EC Act identifies BEE as the statutory body under the Ministry of Power, entrusted with regulatory powers for enforcement of various recommendation of the Act and for the first time proposed penalties for non-compliance with the passing of the Energy Conservation Act.

Following a period of rapid economic growth leading to an acceleration of power demand and an increase in electricity-based appliance stock, with extended lifetimes, especially for some household goods and industrial equipment. Each kW saved at the end-use side is equivalent to almost 1.8 kW saved on the generation side (once auxiliary consumption at the power plant and T&D losses are taken into account). Further, there was a realisations that the deployment of energy efficient lighting, more efficient refrigerators in households, and more efficient motors in industry could save as much as 10% of the power generation.

The industrial and domestic (residential) sectors are the two most significant consumers of utility-generated power in the country. Consumption in the residential sector has been proliferating, mainly as a result of increasing penetration of energy-consuming appliances such as refrigerators and air conditioners. For the power distributors, Demand Side Management (DSM) measures by utilities, including load shaping, was seen as possible means to reduce the steep rise in power demand.

Key directives of EC Act 2001

As a diagnostic step towards identification of conservation measures, the first decade of the EC Act was a formative period with the introduction of Minimum energy consumption standards for appliances and labelling of energy use, the identification of the energy-intensive industries and other establishments to be notified as Designated Consumers (DC)

The Energy Auditor and Manager Certification programme was initiated, and Energy Audit was recognized as a key diagnostic tool. The energy conservation building codes were introduced and adapted to suit local and regional conditions. However, the EC Act got is the regulatory and mandatory authority only after its 2010 amendments.

1st Amendment to the EC Act, 2010[iv]

The original EC Act 2001 was primarily prescriptive, provisional and voluntary, as there was no mechanism yet for enforcement.

The first decade of the EC Act was a formative period with the introduction of Minimum energy consumption standards for appliances and labelling of energy use, the identification of the energy intensive industries and other establishments to be notified as Designated Consumers (DC)

Energy audits were recognized as a diagnostic step towards identification of conservation measures. The Energy Auditor and Manager Certification programme was initiated. The energy conservation building codes were introduced and adapted to suit local and regional conditions. However, the EC Act got its regulatory and mandatory authority after the 2010 amendment.

- ✓ Expands the scope of energy conservation norms for buildings and tightens the applicability of energy efficiency norms for appliances and equipment.
- ✓ For the first time, a framework where the savings on energy use can be traded between those industries who are energy efficient and those whose energy consumption is more than the maximum set by the government.
- ✓ Before the amendments, the government had specified energy conservation building codes for commercial buildings with a connected load of more than 500 kW or contract demand of 600 kVA. The Amendments broaden the range of commercial buildings to which such building codes apply to those with a connected load of more than 100 kW, or contracted demand of more than 120 kVA.
- ✓ The central government can issue energy savings certificates to those industries whose energy consumption is less than the maximum allowed. Such certificates can be sold to other consumers whose consumption is more than the maximum allowable.
- ✓ The 2010 amendment increases the penalty specified for offences committed under the Act. Each offence shall attract a penalty of Rs 10 lakh (Rs 10,000 earlier), with an additional penalty of Rs 10,000 for each day that the offence remains (Rs 1000 earlier). The additional penalty, for those industries who consume energy in excess of norms, will be the value of the excess energy consumed.

Parallel to these efforts on the Conservation side, the government carried out significant reforms for standardisation and benchmarking of technical and commercial aspects in the Electricity sector.

ELECTRICITY ACT, 2003

The Electricity Act 2003 was enacted to harmonies provisions of existing laws and to reform legislation by "promotion of efficient and environmentally benign policies"; the Act mandates efficiency in various forms in the generation, transmission and distribution. Under the provisions the Electricity Act, the Central Government released the National Electricity Policy in 2005, for the development of the country's power system based on optimal utilisation of resources.

- ✓ The policy emphasises higher efficiency levels of generating plants, stringent measures against electricity theft, energy conservation measures and boosting renewable and non-conventional energy sources.
- ✓ DSM was accorded a high priority. Periodic energy audits were made compulsory for power intensive industries. Labelling of appliances and high-efficiency pumps in agriculture were emphasised. Load management and differential tariffs were suggested.

- ✓ Energy Service Companies (ESCOs) were to be encouraged to identify and implement energy efficiency projects. This gave impetus to BEE to actively promote energy performance contracting (EPC), first in the government buildings and subsequently in the private sector buildings and industries.

RELIANCE ON IMPORTED OIL

Along with the electricity demand, India's oil requirement has been growing rapidly. The fuel consumption rose from 3.3% to 16.79 MT, accounting for about 40% of total fuels in India.[v]. Power generation, industrial fuel, transport, fertilisers and petrochemicals form some of the major consumers of petroleum products. In tandem with the electricity sector the government has initiated various steps to promote conservation of petroleum products in the transport, industrial, agricultural and domestic sectors:

- ✓ Adoption of measures and practices which are conducive to increase fuel efficiency and training programmes in the transport sector
- ✓ Modernisation of boilers, furnaces and other oil-operated equipment with efficient ones and promotion of fuel-efficient practices and equipment in the industrial sector
- ✓ Standardisation of fuel-efficient irrigation pump sets and rectification of existing pump sets to make them more energy efficient in the agricultural sector
- ✓ Development and promotion of the use of fuel-efficient equipment and appliances like kerosene and LPG stoves in the household sector.

NATIONAL MISSION FOR ENHANCED ENERGY EFFICIENCY (NMEEE)

The Working Group for the Eleventh Plan (2007-12) suggested an outlay of about USD 1.4 billion (INR 94,000 cr) for energy conservation measures. One of the objectives of the Eleventh Plan is to reduce the energy intensity per unit of Greenhouse Gas (GHG) by 20% from the period 2007–08 to 2016–17. The Government of India launched the National Action Plan on Climate Change (NAPCC) in mid-2010 to address the objective of GHG emission reduction. The NAPCC relies on eight missions where the National Mission for Enhanced Energy Efficiency (NMEEE) is a critical one. NMEEE aims to boost the programmes under the EC Act through four major initiatives:

- ✓ Perform, Achieve and Trade (PAT) scheme, designed as a market-based mechanism to enhance efficiency in DCs (energy intensive industries and facilities as specified by BEE) by setting goals, reducing energy intensity and allowing those who exceed goals to receive energy permits that can be traded with other DCs.
- ✓ Market Transformation on Energy Efficiency (MTEE), which envisages an active shift to energy efficient appliances and machinery in designated sectors through innovative measures
- ✓ Financing mechanisms to help finance Demand Side Management (DSM) programmes
- ✓ Enhancing of EE in power plants

JAWAHARLAL NEHRU NATIONAL SOLAR MISSION

The National Solar Mission is an initiative of the Government of India and State Governments to promote solar power. The mission is one of the several initiatives that are part of the National Action Plan on Climate Change. The program was inaugurated by former Prime Minister Manmohan Singh on 11 January 2010 with a target of 20GW by 2022[vi] This was later increased to 100 GW by the Narendra Modi government in the 2015 Union budget of India.[vii] India increased its solar power generation capacity by nearly 5 times from 2,650 MW on 26 May 2014 to 12,288.83 MW on 31 March 2017. The country added 5,525.98 MW in 2016-17, the highest of any year.

Year-wise Targets (in MW/100)[viii]

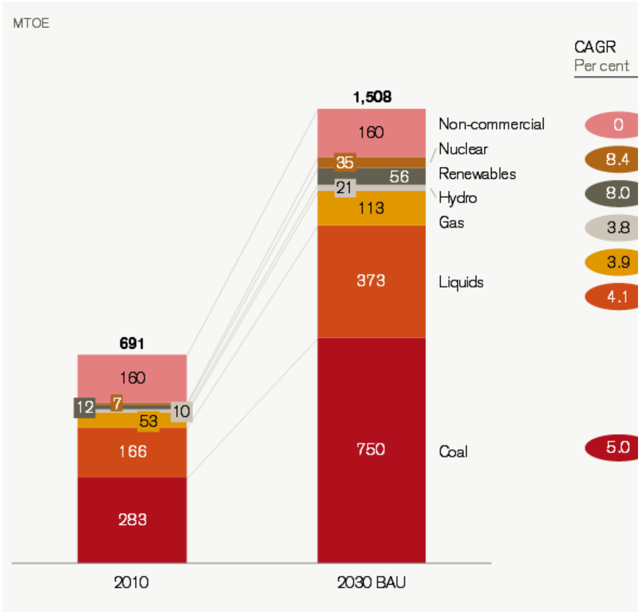
Category	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	Total
Rooftop Solar	200	4,800	5,000	6,000	7,000	8,000	9,000	40,000
Ground Mounted Solar projects	1,800	7,200	10,000	10,000	10,000	9,500	8,500	57,000
Total	2000	12,000	15,000	16,000	17,000	17,500	17,500	97,000

EMERGENCE OF ENERGY EFFICIENCY IN INDIA AS CORE POLICY OBJECTIVE, ROLE OF DIFFERENT ORGANISATIONS AND DEVELOPMENT PROSPECTS ACROSS SECTORS

India's energy demand is growing at 4 percent annually and is expected to double, from 700 million tonnes of oil equivalent (MTOE) in 2010 to 1,500 MTOE by 2030.[ix] India's dependence on energy imports increased from 20 percent to 33 per cent over the last ten years and could cross 50 percent by 2030 on account of higher demand and challenges in domestic production (Exhibit 2).

In global climate negotiations this growing dependence on fossil fuels has become a matter of rising concern in recent years.

Exhibit 1: India's primary energy demand by fuel type



SOURCE: IEA Energy Balances

Since the early 1990s, various bilateral bodies have actively worked with the Ministry of Power and its nodal organisations for energy conservation in India. The organisations such as USAID, GIZ, SIDA, DFID, JICA, ADEME, DANIDA, ADB, World Bank and UNDP, have put in significant efforts in bringing in their expertise and technical support to intensify national-level energy conservation efforts.

The dilemma posed by the strong two-way relationship between economic development and energy consumption had to be addressed. On the one hand, the growth of an economy, with its global competitiveness, hinges on the availability of cost-effective and environmentally benign energy sources, and on the other hand, the level of economic development is reliant on the energy demand.

Energy intensity is an indicator to show how efficiently energy is used in the economy. The energy intensity of India is over twice that for the matured economies, which are represented by the OECD (Organization of Economic Co-operation and Development) member countries. India's energy intensity is also much higher than the emerging economies—the Asian countries, which include the ASEAN member countries as well as China. However, since 1999, India's energy intensity has been decreasing and is expected to continue to decrease.

The indicator of energy–GDP (gross domestic product) elasticity, that is, the ratio of the growth rate of energy to the growth rate GDP, captures both the structure of the economy as well as the efficiency. The energy–GDP elasticity during 1953–2001 has been above unity. However, the elasticity of primary commercial energy consumption for 1991–2000 was less than unity (Planning Commission 2002). This could be attributed to several factors, some of them being demographic shifts from rural to urban areas, structural economic changes towards lesser energy industry, the impressive growth of services, improvement in efficiency of energy use, and inter-fuel substitution.

At present, the service sector is witnessing a progressive, healthy growth rate of 9.2% annually. The sector contributed around 66.1 percent of its Gross Value Added growth in 2015-16, thereby becoming an important net foreign exchange earner and the most attractive sector for FDI (Foreign Direct Investment) inflows. As per the first advance estimates of the Central Statistics Office (CSO), the services sector is expected to grow at 8.8 percent in 2016-17.

The contribution of the IT sector to India's GDP rose to approximately 9.5 percent in FY15 from 1.2 percent in FY98.[x] According to a report by leading research firm Market Research Store, the Indian telecommunication services market is expected to grow by 10.3 percent year-on-year to reach US$ 103.9 billion by 2020. The Indian digital classifieds industry is expected to grow three-fold to reach US$ 1.2 billion by 2020, driven by growth in horizontal segments like online services, real estate and high-end automobiles.

Out of overall services sector, the sub-sector comprising financial services, real estate and professional services contributed US$ 305.8 billion or 20.5 percent to the GDP. The sub-sector of community, social and personal services contributed US$ 188.2 billion or 12.6 percent to the GDP.[xi]

Sectoral demand for energy arises mainly from lighting and cooking in the household sector; irrigation and other operations in the agricultural sector; transport of passengers and freight and fuel input requirements in the industrial sector.

Table 1 shows sector-wise activity level and energy consumption pattern in India. India's commercial energy consumption has increased from 130.7 million tonnes of oil equivalent (mtoe) in 1991/92 to 176.08 mtoe in 1997/98. Per capita, commercial energy consumption increased from 152.7 kilo grams of oil equivalent (kgoe) to 184.7 kgoe over the same period. The average annual growth rate of the agricultural GDP is 2.6 percent, the same figures for the industrial, transport and the service sectors are 6.8 percent, 7.6 percent and 6.4 percent respectively. The industry has consistently remained the largest consumer of commercial energy, followed by the transport sector despite declining share of industrial sector from 50.4 percent in 1991-92 to 47.8 percent in 1997-98.

The energy sector in India has been receiving high priority in the planning process. The total outlay on energy in the Tenth Five-year Plan has been projected to be 4.03 trillion rupees at 2001/02 prices, which is 26.7% of the total outlay. An increase of 84.2% is projected over the Ninth Five-year Plan, relative the total plan outlay in energy sector. The Government of India in the mid-term review of the Tenth Plan recognised the fact that under-performance of the energy sector can be a significant constraint in delivering a growth rate of 8% GDP during the plan period. It has,

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therefore, called for an acceleration of the reforms process and adoption of an integrated energy policy.

In the recent years, to address the concerns of energy security, the Government of India has given a high priority to energy independence.

Further, the country has witnessed geometric growth in the services sector, spurred by the digital revolution. The Indian services sector which includes financial, banking, insurance, non-financial/business, outsourcing, research and development, courier and technical test analysis among others. These avenues have attracted the highest amount of FDI equity inflows in the period April 2000-December 2016, amounting to about US$ 58.345 billion. Of the total foreign investment inflows, this accounts for about 18 percent according data released by the Department of Industrial Policy and Promotion (DIPP).

Indicator analysis

Energy use can be viewed as a function of total GDP, structure of the economy and technology. Aggregate energy intensity is taken as an energy performance indicator in energy demand analysis. Literature on indicator analysis adopts either of the two approaches: energy consumption approach or energy intensity approach. We follow the intensity approach and decompose total energy-GDP ratio into structural effect (S.E) and intensity effect (I.E). Structural effect shows that part of change in energy use which is attributable to change in activity composition of an economy. Intensity effect tells us that keeping GDP effect and structural effect unchanged, what has been the change in energy use solely due to conservation measures.

Figure 1 and accompanying table show the respective values for the structural effect (Dstr), intensity effect (Dint) and the total effect (Dtot) comprising of these two effects.

In last decade, India experienced a structural change that has worsened the overall energy intensity index as it is greater than one except in two intervening years of 1992-'94. Beyond 1993-94 the structural effect shows a rising trend in energy intensity. Intensity effect showing the conservation effort had a fluctuating trend, though this effect alone could outweigh the structural effect and overall energy intensity index shows falling trend after 1995-96, as seen in Table below.

Table 1: GDP at constant prices (Rs Th crores) and energy consumption (mtoe) in India								
Years	Agriculture GDP	Energy consumed in agriculture	Industry GDP	Energy consumed in industry	Transport and trade GDP	Energy consumed in transport	Services GDP	Energy consumed in services
1989-90	63.3	4.3	50.6	60.5	35.9	27.8	51.7	15.8
1990-91	65.7	4.9	53.9	62.9	37.7	28.0	55.0	16.5
1991-92	64.1	5.6	52.8	65.9	38.6	29.3	58.4	17.1
1992-93	68.0	6.1	55.1	68.5	41.0	30.6	61.1	17.8
1993-94	70.5	6.8	59.3	71.0	44.0	31.6	65.3	18.7
1994-95	74.1	7.7	66.0	73.9	48.7	33.4	68.9	20.0
1995-96	71.9	8.44	74.5	87.0	55.2	45.3	74.5	21.8
1996-97	77.6	8.34	79.4	92.3	60.0	42.1	79.9	18.8
1997-98	76.4	8.71	84.0	77.5	63.1	47.6	88.4	27.6

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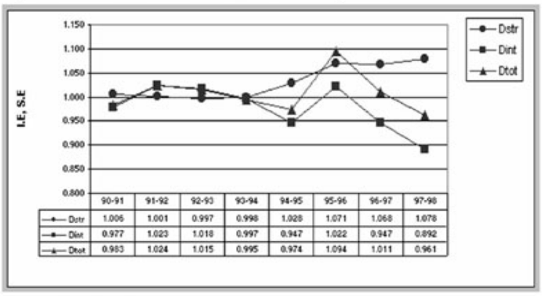
The structural effect is dominated by a sharp increase in the Industrial and transport sector the figure below shows that intensity is higher in the industry, followed by the transport sector. But industry records a downward trend in energy intensity. The average annual decline in energy intensity during 1989-90 to 1997-98 is 2.14 percent as compared to 0.33 percent in the transport sector and 1.08 percent in the service sector. On the other hand, agriculture sector records an increase in the energy intensity over the same period (6.5 per cent). But, there seems to be significant energy efficiency improvements to curb the rising structural effect, and as a result of which the aggregate energy intensity index of the economy has improved after 1995-96. This improvement could be attributed to demographic changes, including relatively faster growth in urban areas, high per capita GDP, penetration of more end-use devices, technological improvements in conversion equipment and inter-fuel substitution with more efficient alternatives in the energy intensive industries.

Figure 1. Results of Refined Divisia Index Decomposition.



Since sectoral output growth is the main contributing factor to rising energy intensity, one might think that policies should be designed to curb this growth. However, this would mean imposition of real cost on the economy. Hence, policy alternatives should see how to offset this increasing output effect by a negative intensity and structural effects.

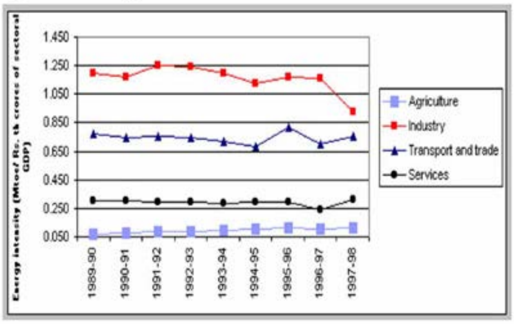
Declining structural effect can be achieved by a greater shift towards non-energy intensive industries, expansion of service sector etc. The negative trend in intensity effects can be intensified by inter-fuel substitution, introducing efficient technology to improve energy productivity. Other country studies reveal one thing in common that in most of the OECD countries energy intensity declined and improved energy efficiency played a substantial role in it. Intensity effect is smaller for India than for other countries. Energy demand can be restricted directly through economic instruments like prices, taxes or rationing etc. But they have their adverse welfare impact also unless supplemented by indirect policies in the form of introduction of more efficient technologies.

Conservation in industry sector has been successful in putting a break to rising overall intensity trend. Energy efficiency improvement through R&D, labels and standards, technology transfer may be a better policy tool to strengthen conservation effect to offset rising energy intensity due to structural change and activity growth.

Economic growth and structural change are the big drivers of positive growth in energy intensity in India. The structural component is driven mainly by incomes and by forces not directly related to energy or energy policies.

Since it is difficult to restrict rising energy demand resulting from increased economic output or activity, conservation measures need to be stressed at the early stage of development. Sectoral policies on housing, commercial buildings, industry and transport must integrate energy efficiency at local, regional and national levels.

Figure 2. Sectoral energy intensities.



CONCLUSION

While all eyes have been on China and its incredible economic growth in recent years, India has been quietly catching up. Just recently, Apple CEO Tim Cook described the country’s potential as “incredibly exciting”, and it’s a sentiment shared by many. But if India is to live up to this potential, its growth is intertwined with its energy sector.

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[i] See, ‘Energy Efficiency in India – History and Overview' December 2011, Alliance for Energy Efficient Economy, at pg. 1

[ii] It states, *"It is important that conservation of natural resources receives adequate priority, especially from the environmental angle. The danger of further deterioration in the quality of air and water is not unreal. Therefore, it is essential that these resources are used with utmost care so that growth is sustainable."*

[iii] Challenge of Availability: Continuity of supply quality & reliability of service, Background Paper, Indian Energy Congress, 2010, New Delhi. Legal Frame Work for Energy Conservation, MSDA, http://www.msda.nic.in/downloads.html Last Visited 19 June’17

[iv] See - http://www.prsindia.org/billtrack/the-energy-conservation-amendment-bill-2010-1040/

[v] Bloomberg Link - https://www.bloomberg.com/news/articles/2017-05-12/india-oil-demand-rises-3-3-in-april-after-falling-for-3-months
Last Accessed on 19 June’17

[vi]Refer http://www.mnre.gov.in/solar-mission/jnnsm/introduction-2/

[vii] See, Press Information Bureau, Government of India Cabinet, Revision of cumulative targets under National Solar Mission from 20,000 MW by 2021-22 to 1,00,000 MW - India surging ahead in the field of Green Energy - 100 GW Solar Scale-Up Plan. Refer to http://pib.nic.in/newsite/PrintRelease.aspx?relid=122566.

[viii] See, Resolution of Government of India Dtd. 01.07.2015 athttps://web.archive.org/web/20170226140523/http://mnre.gov.in/file-manager/grid-solar/100000MW-Grid-Connected-Solar-Power-Projects-by-2021-22.pdf

[ix] See, Exhibit 1, Energy Security index for India

[x] See, https://www.ibef.org/industry/services.aspx, last visited 19 June’17

[xi] *Id.*

ENTERPRISE ENERGY MANAGEMENT
THE SCHNEIDER ELECTRIC INDIA STORY

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Keywords: Enterprise, portfolio, energy management

ABSTRACT

This paper discusses Schneider Electric India's successful enterprise energy management journey over the last 5 years.

The defining challenge for energy efficiency is that of visibility; as energy is invisible and energy efficiency is the absence of energy use. Schneider Electric (SE) has been focusing on making energy use and performance visible, meaningful and actionable. This approach has been corroborated in SE's own internal programme – Schneider Energy Action (SEA). More than 300 Schneider Electric sites are covered by this programme globally, representing over 80% of its global energy consumption. Launched in 2012, SEA aims to promote energy efficiency at Schneider Electric sites using its own energy management solutions. In India, 17 energy-intensive facilities, that accounted for approximately 70% of SE's nationwide energy spend in 2011, were a part of this programme.

This paper presents how, from 2012 to 2016, Schneider Electric India has reduced energy consumption at its most energy-intensive facilities by almost 40%, resulting in over 12,900 tonnes of avoided CO_2 emissions, as compared to the 2011 baseline. In the first phase of the SEA programme (2012-2014), Schneider Electric has avoided energy costs of over INR 50 million, with an investment of less than INR 20 million. In the ongoing phase (2015-2017), more than INR 27 million in energy costs has already been avoided by the end of 2016.

This paper discusses the critical elements for driving a successful enterprise energy management programme and concludes with challenges and lessons learned from the experience.

INTRODUCTION TO ENTERPRISE ENERGY MANAGEMENT

Energy, as one experiences it, is largely invisible. Energy efficiency is effectively determined based on the absence of energy use as compared to the baseline. This is the defining challenge of energy efficiency – how does one effectively articulate the value of the absence of something that is invisible? How does one make energy efficiency, energy use and performance; visible, meaningful and actionable?

Schneider Electric has been focusing on this challenge and on effectively turning a mirror on a facility's energy performance. As a point in case, even in a building with best-in-class energy performance (65% reduction as compared to business as usual); by simply making the right kind of energy data visible and meaningful, Schneider Electric has demonstrated that optimization opportunities (low- or no-cost measures) resulting in about 5-6% energy savings, are available. Making energy use visible, meaningful and actionable in turn facilitates an effective way to make energy efficiency a top-of-mind issue for leadership or management, and fits well into efforts for energy management system certifications such as ISO 50001, which provides a systematic framework for engaging with organizational leadership on energy performance.

Through robust smart monitoring of facilities and assets, a baseline can be established to determine how energy is consumed. Efficiency improvements can also be simulated, tested, and measured. With accurate measurement comes the ability to facilitate change and to engineer real (and financially quantifiable) improvement. The resulting modifications to business processes then result in dramatically reduced operating costs.

SCHNEIDER ENERGY ACTION: SCHNEIDER ELECTRIC'S ENERGY MANAGEMENT STORY

Schneider Electric (SE) started with its resource sustainability approach in 2002 by creating a dedicated department for sustainability.

Being the global specialist in energy management and automation, Schneider Electric realized that to have a significant impact on the environment and to drive sustainable change, it is imperative to measure performance. Therefore, the Planet & Society Barometer, a composite indicator that is updated every quarter with a performance dashboard, was launched in 2005. Every 3-5 years, Schneider Electric defines a new Planet & Society Barometer. The Barometer's score is part of the key indicators included in the company performance scorecards. The Barometer's results are the Group non-financial results; they are presented in an integrated manner, together with the Group's financial information: by the CEO at the annual and half-year results declarations, and by the CFO at the first and third quarters' results declarations, to institutional and SRI investors. This integrated communication demonstrates SE's commitment to making sustainability a part of the company's long-term strategy.

One of the key initiatives under the Planet & Society Barometer is the Schneider Energy Action (SEA) programme which was launched in 2012. Schneider Electric believes in embedding energy efficiency in its DNA. This approach has been corroborated in its own internal programme - Schneider Energy Action. SEA gives Schneider Electric an opportunity to "walk the talk" by evaluating and improving the energy performance of its own operations by deploying its own energy monitoring and management solutions.

The main objectives of SEA are:

- Reducing the CO_2 footprint of Schneider Electric facilities, as part of its ambitions for continued reductions in greenhouse gases and in line with its climate change commitments.
- Reducing all forms of energy consumption (electricity, heat, gas, oil, etc.), and thereby lowering operating costs.
- Deploying Schneider Electric's energy efficiency solutions at its own sites.
- Demonstrating Schneider Electric's expertise to its customers.
- Raising employees' awareness about new energy efficiency solutions and how these can contribute to their optimal use or even their future improvements.

Globally, more than 300 of SE's sites - representing over 80% of the organization's global energy consumption – are covered by this programme. In India, 17 energy-intensive facilities (that account for approximately 70% of Schneider Electric India's nationwide energy spend), were equipped with its online energy monitoring tools in 2012-13.

In the first phase of the programme (2012-14), sites greater than 5000 m^2 area (accounting for almost ~70% of SE's total energy spend) were equipped with SE's best in class energy monitoring and management solutions, making energy data visible in real time. In the second phase (2015-17), the site selection criterion was changed to sites having >1.5 GWh of annual energy consumption in 2014. The SE solutions used were:

- EcoStruxure Resource Advisor (RA) – a cloud-based solution for managing energy invoices, analysing cost and consumption, and managing energy projects that can be accessed online by the facilities and energy managers using their login and password. As a Software-as-a-Service (SaaS) offering, it also offers help in strategically sourcing clean and cheap energy as per market opportunities.
- EcoStruxure Power Monitoring Expert (PME) – a site-based operations-level tool that provides real-time information for tracking of power conditions, analysis of power quality and reliability, and quick response to alarms, to avoid critical situations.
- Smart Metering Solutions – a range of metering and basic energy monitoring products from simple meters to high end power quality analysers. These solutions allow monitoring, managing and controlling of energy consumption efficiently.

Implementation of energy monitoring solutions has resulted in meaningful and actionable energy use visibility, across the organization, globally. "From the shop floor to the top floor", everyone concerned with energy use now has access to energy performance information with a range of online tools.

This programme has thus helped SE uniquely to make the demand for and consumption of energy more efficient, which is the basis of its innovation in energy management and automation.

As mentioned above, SEA has been spread over two phases till date, i.e., from 2012-14 and 2015-17.

Phase I (2012-14)

In the first phase of the programme, the organisation had set itself the goal of achieving a 10% reduction in its energy consumption over a three-year period. From 2012 to 2014, energy consumption at the most energy-intensive facilities in India was reduced by approximately 30%, resulting in 8,600 tonnes of avoided CO_2 emissions, as compared to the 2011 baseline. In the first phase of the SEA programme (2012-2014), SE had avoided energy costs of over INR 50 million, with an investment of less than INR 20 million.

Ongoing Phase II (2015-17)

Encouraged by the overwhelming success of first phase of the SEA programme, it was extended for another three years, which clearly shows the ongoing commitment of Schneider Electric towards energy efficiency and sustainability. In the ongoing phase, which started from 2015, the goal to reduce energy consumption was renewed with an identical objective of a 10% reduction over a three-year period. The 2015-2017 programme includes the following energy performance objectives globally:

- Reduction of energy consumption by 10% over three years compared to 2014.
- Deployment of certification for energy management systems in accordance with standard ISO 50001 for 150 industrial sites (i.e. a major part of the Group's industrial scope) by 2017.
- Identification of opportunities to reduce energy consumption at all sites as a result of the Energy Action audits.
- Promotion of renewable energy (mainly solar) adoption on its own sites, integrating Schneider Electric solutions, and purchasing renewable energy when it is available locally.

As compared to the 2014 baseline, by the end of 2016, the energy consumption at the 10 most energy-intensive facilities in India has been reduced by 7%, resulting in 4,300 tonnes of avoided CO_2 emissions and more than INR 27 million of avoided energy costs.

Combining both the phases, from 2012 to 2016, Schneider Electric reduced energy consumption at its most energy-intensive facilities in India by approximately 37%, resulting in over 12,900 tonnes of avoided CO_2 emissions and more than INR 77 million of avoided energy costs as compared to the 2011 baseline. Also, 13 Schneider Electric India facilities have attained the ISO 50001 Certification.

Case Study – Schneider Electric Salt Lake Works Unit

Salt Lake Works (SLW), with an employee strength of 380, representing ~2% of the total SEI workforce, is a unit of Schneider Electric Infrastructure Limited, located at Kolkata. SLW Kolkata is mainly a manufacturing unit for Schneider Electric India's medium voltage power distribution products & solutions, comprising switchgear & vacuum interrupter units, with Air Insulated Switchgear (AIS), Circuit Breaker and Vacuum Interrupter (VI) as the major manufactured products.

Highlights of the energy efficiency related performance: SLW Kolkata, an ISO 50001 certified unit and one of the facilities covered under the SEA programme; has reduced its specific energy consumption (SEC) by 44% over the last 3 years. The unit has also invested more than INR 2.9 million in energy efficient products and services in the last two financial years, with a payback of less than two years. The efforts that have resulted in this significant reduction in SEC over the last 3 years are described in the sections below.

Energy performance monitoring: As described previously, all energy-intensive Schneider Electric (SE) facilities in India are equipped with SE's own energy metering and monitoring solutions. In addition to EcoStruxure Resource Advisor, EcoStruxure Power Monitoring Expert and smart metering solutions described previously, the SLW Kolkata plant also uses another SE solution called StruxureWare Energy Operation – a cloud-based energy monitoring solution for viewing metered data, energy consumption and performance reporting, that can be accessed by the energy manager using a unique login ID and password.

The information and data from the above tools and software is recorded and analysed after the implementation of various energy efficiency measures (EEM) and initiatives taken to improve energy performance. The annual energy savings achieved and investment made due to implementation of various EEMs are:

- FY 2014-15 – In FY 2014-15, annual energy savings of 62,500 kWh worth INR 580,000 were achieved with an annual investment of INR 76,000. EEMs implemented during this year were automatic operation of water pump house and water treatment plant, and automated operation of chilled water temperature controller and chilled water circulating pump for furnace.
- FY 2015-16 – Annual energy savings of 130,500 kWh worth INR 1,200,000 were achieved in FY 2015-16 with an investment of INR 930,000. Major EEMs implemented were installation of sky-tube (for daylighting) and LEDs to reduce lighting energy consumption, and rainwater harvesting and using of AC condensate water in cooling tower to reduce water use.
- FY 2016-17 – In FY 2016-17, annual energy savings of 76,600 kWh worth INR 730,000 were achieved with an investment of INR 500,000 for improving energy performance through measures like installation of solar water heater, replacing metal halide lamps with LEDs, and installation of VFDs for condenser and chilled water pumps.

With the above implemented EEMs, the SLW unit at Kolkata didn't just install high efficiency equipment, but it also improved the effectiveness of its operational energy use.

Initiatives for energy efficiency enhancement: In 2013, the unit took the initiative to get certified under the ISO 50001 standard. Consistent with SEA goals, a quantitative target of reducing the energy consumption by 10% in three years was set for the unit. Also, to verify the continuous improvement process, a few more steps were taken under the SEA programme and ISO 50001 framework:

- A quarterly energy performance reporting call along with all the other SE facilities to track progress.
- An energy audit to be conducted every three years to identify the gaps and opportunities to improve energy performance.
- An internal audit to verify the effectiveness of the Energy Management System (EnMS) every six months.
- An external audit every year to verify the above.

The plant's operational efficiency was improved after introduction of these initiatives; and the unit could reduce its SEC significantly – by 34% – in 2013 (calendar year) itself, as compared to 2012.

Major energy efficiency projects: In keeping with the above initiatives, some of the major energy efficiency projects that were implemented at the unit are:

- Automatic operation of water pump house and water treatment plant (WTP) – Water pump house and WTP operation was manually controlled, which resulted in either overflow or shortage of water. There were a total of 11 manually operated pumps. Over-running of these pumps also resulted in wastage of energy. To resolve this issue, 11 level sensors & controllers for filling the overhead tanks were installed in the pump house and the water treatment plant. Electrically operated valves with level sensors were also installed for filling the underground tank. The project resulted in a completely unmanned operation with zero overflow and shortage of water, and an annual energy savings of 2,500 kWh worth INR 20,000.
- Automatic operation of chilled water pump for the furnace – The chilled water pump was manually controlled for the furnace cycle, due to which it was running for an extra 5 hours every day. After the chilled water pump was automated with a temperature sensor, the pump would stop automatically after the temperature of the furnaces was less than 60˚ C. The project resulted in an annual energy savings of 60,000 kWh, worth INR 480,000.
- Installation of Sky-tube – Sky-tube is a tailored solution for the area where it is to be installed. The dome of the tube collects and concentrates the ambient daylight. A highly reflective tube delivers good illumination despite the long tube length or angles. Under this project, 50 metal halide lamps were replaced with 37 sky-tubes, which resulted in annual energy savings of 51,600 kWh and zero maintenance cost. The whole project provided an annual financial gain of INR 630,000.
- Installation of solar water heater – A solar heater with 500 litres capacity was installed to replace the electric geyser being used in the canteen. This measure resulted in reducing energy consumption by 4,172 kWh in a year, which was worth cost savings of INR 31,000.
- Replacing metal halide lamps with LEDs – Replacement of high energy consuming metal halide lamps with LEDs resulted in an annual energy savings of 31,200 kWh, worth INR 240,000.

Initiatives for process improvements: At every Schneider Electric manufacturing facility, a yearly assessment is carried out under its Schneider Production System (SPS) initiative, involving all employees from the unit to give ideas and suggestions for driving continuous improvement in all the areas with a major focus on energy and production. The objective of this assessment is to take advantage of each employee's problem-solving potential.

This assessment is also carried out at SLW Kolkata, where, after recording all the ideas, a designated team consisting of plant managers provides a first round of feedback to the suggested ideas within a week. The team is empowered to immediately implement the "quick hit" ideas. After addressing the first round of feedback, the team refines the ideas that can be taken forward and a final round of feedback on the implementation aspect is given within two weeks, after which the selected ideas are taken forward for implementation in the plant.

In 2015, as a part of the Schneider Production System (SPS) audit at SLW unit, some of the major improvements that were made to the plant processes are as follows:

- Chemical etching to electro-etching in the Vacuum Interrupter (VI) plant surface treatment process – Hazardous chemicals like trichloro ethylene were removed from the surface treatment plant which resulted in an improved quality of the surface treatment process.

- Enhanced design for testing of VI – A Bakelite separator was added in the VI testing design to reduce the internal gap and avoid flashover or arcing. The design change resulted in the testing of 5 VI in a single cycle as compared to the earlier design of 5 VI in 2 cycles. The testing time for one VI was reduced from 217 seconds to 109 seconds.
- Design time reduction in VI high voltage arcing process – In VI high voltage arcing process, nitrogen needs to be charged at high pressure. After that, high voltage is delivered to the vacuum interrupter. This nitrogen charging time was 72 seconds in each cycle due to very low nitrogen flow in the charging line. The nitrogen charging pipe line diameter was therefore increased from 10 mm to 25mm and nitrogen charging pressure regulator was replaced with a high flow regulator. After this measure, nitrogen charging time was reduced considerably from 72 seconds to 10 seconds.

All the above measures taken after the SPS assessment in 2015 helped the SLW unit at Kolkata to reduce its specific energy consumption by 35% and increase its production by 54% as compared to 2014 (calendar year).

Reduction in carbon footprint: Due to the various initiatives and EEMs implemented at the SLW unit, the plant has significantly reduced its carbon footprint.

The SEC for FY 2013-14 was 16.11 kWh/unit of production. As compared to this base year:

- In FY 2014-15, the plant reduced its SEC by 27% which was equivalent to avoided CO_2 emissions of 849 tCO_2.
- In FY 2015-16, the SEC was reduced by 52% which was equivalent to avoided CO_2 emissions of 2,208 tCO_2.
- In FY 2016-17, the SEC of the plant was reduced by 43% which was equivalent to avoided CO_2 emissions of 1,849 tCO_2.

Overall, in the last 3 years, SLW Kolkata has avoided 4,906 tCO_2 emissions.

Select Listing of Projects Implemented at Other Schneider Electric Facilities in India

Some of the major energy efficiency projects implemented at Schneider Electric India facilities under SEA are mentioned below:

Installation of VFDs, room temperature sensors and controllers at APC facility, Bangalore: In 2015, to reduce the HVAC energy consumption of the plant, VFDs were installed for all the chiller pumps and AHUs, along with room temperature sensors and controllers. The project had an investment of INR 891,500, and resulted in annual energy savings of 92,372 kWh, which is equivalent to INR 646,604. The financial payback for the project was 1.3 years.

Installation of lighting transformer at TBI, Vadodara: Lighting transformer installation at TBI Vadodara was carried out in 2015. The project had an investment of INR 550,000. With this project, the plant could reduce their lighting energy consumption by operating the lighting fixtures at lower voltage levels. The project resulted in an annual energy savings of 70,000 kWh, worth INR 595,000.

Arresting of air leakages in the compressed air distribution system at Chennai facility: During an energy audit carried out in the facility in 2016, it was found that the facility's compressed air distribution system had several leakages. Using an ultrasonic leak detector, an immediate project was carried out to arrest all the air leakages in the facility. The project had an investment of INR 150,000 and resulted in annual energy savings of 159,704 kWh, worth INR 1,357,484.

Replacement of FTLs with LEDs at Chennai facility: In 2016, 1300 FTLs (mainly T5 and T8) were replaced with 18W LEDs. The project had an investment of INR 2,387,000 and resulted in annual energy savings of 112,207 kWh, worth INR 953,760. The project has a payback of 2.5 years.

Critical Success Factors

The critical elements that are responsible for the success of SEA are:

- Executive ownership,
- Clear roles and responsibilities for all possible and related stakeholders,
- Strong programme and project management,
- Importance of reporting and accountability.

Executive ownership:

Executive ownership is one of the most important elements for driving any enterprise level programme successfully. In case of SEA, Schneider Electric (SE) has a presence in more than 100 countries, with a continuous rhythm of internal development and acquisitions. SE applies a common environmental policy to all its entities and rolls out the same programmes for certification, reporting and performance objective throughout all its locations. Since 2005, Schneider Electric has fixed annual objectives for reduction and publishes (internally) the annual energy consumption of each of its production and logistics sites, (now) as part of the Schneider Energy Action (SEA) programme. These policies and actions are initiated by the top management, which triggers and drives the continuous development of SEA. Also, the results of the Planet and Society Barometer are monitored in the Sustainability Executive Committee, which decides the corrective actions potentially needed to achieve the objectives. Twice a year, this committee gathers four members of the Group's Executive Committee in charge of Strategy, Global Supply Chain, Human Resources and Marketing.

Therefore, it's very important that the programme or initiative is driven from the top management and executive level.

Clear roles and responsibilities for all possible and related stakeholders:

Different stakeholders to contribute and play their part – SEA is a global contract between two of Schneider Electric's entities, Global Supply Chain which is the customer (facilities) side in this contract and Energy and Sustainability Services which is the supplier for energy management services. Both entities collaborate to ensure that objectives of the SEA programme are effectively achieved, resulting in a positive outcome. Also, there are various stakeholders involved at every level of the programme and for every region. To ensure that the programme is driven successfully, each stakeholder group is required to play their part. In India, SEA is mainly driven by three teams or stakeholder groups – Environment, Health and Safety (EHS), Energy Efficiency (EE) and Energy and Sustainability Services (ESS). EHS is responsible for all the activities related to the facilities, from collection of energy data to planning of energy conservation measures (ECMs) in the plant. EE is responsible for initial energy analysis and developing energy models based on the energy data provided by the EHS team. Finally, the energy analysis done and the models developed are validated by the ESS team, along with suggestions for undertaking any action plans for improving the energy performance. In this way, each stakeholder group must play their part for driving the programme successfully across the globe or any region or country.

Strong programme and project management:

As described above, with the involvement of different teams or stakeholder groups in a programme, a robust framework for project and programme management is critical to ensure that the programme is driven effectively across the organization. In case of SEA, a global programme management and deployment team was appointed, which was responsible for programme management and deployment, and for managing the relationship between the internal service provider and the internal client on a global level. Its responsibilities included:

- Setting Key Performance Indicators (KPIs), energy performance indicator (EnPI) tool development, and KPI training.
- Global Programme Reporting (Energy Performance Reporting, Programme Reporting, ISO 50001 certifications).
- Global communication.
- Global budgeting and contract development.
- Facilitating the sharing of best practices globally.
- Providing guidance on development and standards.
- Managing the execution and finances for the SEA global contract.

Importance of reporting and accountability:

For programmes that span an enterprise as large as SE, an unambiguous communication of the importance of reporting and accountability, is critical to ensure that the energy management programme is driven successfully at all levels of the organization. Reporting the correct or actual performance numbers along with the responsibility or accountability for the same, is of paramount importance to drive continuous improvement in energy performance of the facilities across the organization, which in turn is one of the most important factors for the success of the programme.

CHALLENGES FACED AND LESSONS LEARNED

Driving an enterprise energy management programme is not without its fair share of challenges.

In the case of SEA, with the presence of different stakeholder groups, with each group responsible or accountable for its role, the first and foremost challenge for all the teams, especially the facility teams, was to understand the Measurement and Verification (M&V) principles and the fundamental concepts of how energy models are developed to determine the energy performance for a plant or a facility. It is very important to ensure that all the stakeholder groups are clear about the methodology followed for determining energy performance in keeping with the M&V method.

Further, developing correct and accurate energy models is also a challenge if baselines are to be adjusted in case of plant expansions and if there's a variation in the product mix that is manufactured; making it a complex task requiring a fair amount of judgment to ascertain the best fit correlation for the energy model, for determining the energy performance.

Finally, to drive the energy management programme successfully and to show the commitment of the organization towards energy efficiency and sustainability, the goals and objectives of different stakeholder groups or teams are linked with the energy performance of the plants. Paradoxically, this can sometimes result in a focus on reporting good results rather than acknowledging opportunities for improvement and developing action plans for the same.

There were also some lessons learned that helped overcome the challenges described above. These are described below.

Continuous Engagement on M&V Principles and Models

As the M&V concepts and approach form the very basis on which energy performance of the facilities is determined and reported, frequent and continuous engagement with all the stakeholder groups is necessary to ensure a sound understanding of the M&V principles, approach, and its underlying processes. In the past, workshops have been organized in manufacturing plants to facilitate this strong engagement and provide education on the M&V approach and working principles of energy models used for determining the energy performance of the plants and to show how the models can be made even more accurate.

A Focus on Continuous Improvement

The stakeholders involved need to be recognized and rewarded for focusing on continuous improvement, and not just on reporting good results. One step that has been taken to ensure this, is verifying the energy data that is provided as input to the energy models, against the data that has been recorded in the centrally installed energy management system (EMS). Here, a gradual shift towards an automated M&V approach, where the energy models are developed automatically with the use of software, can help.

If the focus on continuous improvement is lost, it is seen that even a high performing facility gradually goes through a phase of deteriorating energy performance. Therefore, it is important to treat data and results as inputs and to continuously look for opportunities to improve the energy performance of the plant. Under SEA, adoption of ISO 50001 certification across almost all the facilities in India, serves as a great platform to strive for continuous improvement of energy performance. Also, as the baseline for energy reporting changes every three years, it ensures that continuous improvement is driven across the organization.

CONCLUSION

This paper has described Schneider Electric's successful enterprise energy management journey in India over the last five years, including a discussion on the way the programme has been set up, examples, and results. The paper also describes the various improvement measures carried out at one of Schneider Electric India's most energy intensive facilities, as a case study; along with examples of some of the major energy efficiency projects implemented at other SE facilities in India. The paper concludes with a discussion on critical success factors, challenges and lessons learned.

THE M&V 2.0 OPPORTUNITY AND CHALLENGES

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Keywords: M&V, analytics, M&V 2.0, data, energy

ABSTRACT

This paper presents the role of advanced and improved data collection tools and data analytics in the changing paradigm of measurement and verification (M&V), along with the associated challenges.

The paper starts with a discussion on conventional M&V approaches – usually carried out based on an agreed-upon protocol or method; by quantifying energy savings by comparing measured energy use before and after implementation of energy efficiency measures; including adjustments or normalization. The paper also discusses the limitations of the current M&V approaches.

The paper further addresses data collection and analysis enhancements related to new technology and computing capabilities, often referred to as M&V 2.0, an approach that has the potential to reduce the cost of M&V and produce more timely results with higher confidence and transparency. The paper discusses how these approaches are enabled through advances in software, cloud computing and large-scale data processing. M&V advancements are broadly enabled by:

1. Improved Data Collection Tools
2. Advanced Data Analytics

The paper then describes how Schneider Electric has been currently using the conventional M&V approach in validating energy savings at its own facilities; and the gradual shift towards M&V 2.0 through auto- validation of energy savings using:

1. Smart Energy Metering and Sub-Metering
2. Energy Management System

The paper concludes with a discussion on the practical challenges faced in adopting M&V 2.0, such as building in appropriate baselines and adjustments, analysis of complex projects and basic challenges of maintaining continuity of connectivity and communications.

CONVENTIONAL M&V APPROACH

Measurement and verification (M&V) of energy efficiency measures (EEMs) is critical for ascertaining the effectiveness of a project. As efficiency cannot be measured directly, an M&V approach provides a method of determining savings for a project or a measure, using observations and measurements taken at the site, together with engineering calculations (Kumar and Deshmukh, 2015). It is a process of quantifying energy savings by comparing measured energy use or demand before and after implementation of the energy efficiency measure, including adjustments or normalization. The approach uses the calculation of savings based on the number of measures installed and the historic or calculated savings from those measures.

M&V methods or approaches can differ depending on the project characteristics, including the type of measure, method of delivery, and project penetration. For example, on-site measurement or metering are used more often for larger scale and commercial projects, whereas billing analysis is generally used for projects related to small/medium businesses.

The objective of M&V is to reliably determine energy savings. For the savings report to be reliable, there needs be a reasonable or acceptable level of uncertainty. The uncertainty of a savings report can be managed by controlling random errors and data bias. Random errors are affected by the quality of the measurement equipment, the measurement techniques, and the design of the sampling procedure. Data bias is affected by the quality of measurement data, assumptions and analysis. Energy savings computations involve a comparison of measured energy data, and a calculation of "adjustments" to convert both measurements to the same set of operating conditions (IPMVP, 2014). Both the measurements and the adjustments introduce error, and errors occur in three forms – modelling, sampling and measurement.

Limitations of Conventional M&V Approach

The errors, uncertainties and factors described above result in the following limitations that are characteristic of a conventional M&V approach:

- Inaccurate energy models,
- Lack of transparency and confidence in the modelling results,
- Inability to handle large data in a timely manner,
- Inability to incorporate adjustments in real-time.

These limitations are discussed below.

Inaccurate energy models:

Errors can occur from insufficient data either in terms of quantity (i.e., too few data points) or time (e.g., using summer months in the model and trying to extrapolate to winter months). The data used in modelling should be representative of the range of operations of the facility with the availability of sufficient number of data points. Also, the range of time covered by the model needs to include various possible seasons, types of use, etc. This would call for a frequent or continuous monitoring and measurement of the relevant variables and use of those data points for the energy modelling.

Lack of transparency and confidence in the modelling results:

Although the measurements can be made using on-site metering equipment or instruments, the overall process of energy modelling and determination of results remains largely manual. Additionally, with the records of historical data being maintained manually, the level of transparency and confidence level in the results remain relatively low, unless the modelling is verified at every level and every stage.

Inability to handle large data in a timely manner:

To increase or improve the accuracy of the energy models, one needs more data points and relevant variables. Due to this, for processing a large volume of data points and variables, the conventional M&V approach can be relatively slow in determination of results.

Inability to incorporate adjustments in real-time:

Because these estimates are determined manually, the baseline adjustments due to change or modification in the fixed factors or values (for example, electrical load of a facility) are possible or can be made only over a longer time period (i.e., a month, a quarter, a year, etc.), which can result in a time lag for accurate estimation and modelling reports until after the adjustments are made.

INTRODUCING M&V 2.0

M&V 2.0 is an approach to provide new tools and technology with a potential to reduce the cost of conventional M&V and produce more timely results with higher levels of confidence, transparency, and accuracy. It provides more granular data that allows program or facility managers to make real-time or near-real-time adjustments to better drive the performance of energy efficiency projects.

M&V 2.0 includes various new approaches that are employed to enhance the measurement of energy efficiency measures. Although it doesn't replace the entire conventional M&V process, rather, it introduces new software and energy data communication technologies and measurement approaches to enhance the way M&V is carried out. Advances in software, cloud computing, and large-scale data processing are enabling these approaches, that provide for the continuous measurement of energy savings.

Major Enablers for M&V 2.0

Some of the major enablers for M&V 2.0 are as follows (DNV GL, 2015):

- Advanced data analytics,
- Using software as a service,
- Improved data collection tools.

These enablers are discussed below.

Advanced data analytics:

With a growing range of cloud-based software and platforms that process large volumes of data efficiently, advanced data analytics present opportunities for M&V 2.0 programs by analysing the higher volumes of data collected and using statistical models on large historical data to forecast the future energy consumption. Through advanced data analytic tools, billions of data points of disparate data can be processed within seconds or minutes. With these tools, it is also possible to prepare large M&V datasets. Most data variances fall into discrete categories and consistent patterns. In M&V programs, high-speed analytics and machine learning can identify these patterns and provide good prospects for data cleaning, detection of patterns and variances, and developing forecasted energy use.

Using software as a service (SaaS):

Using SaaS, along with advanced metering infrastructure (AMI) and analytics, M&V can be automated and energy savings, as the difference between the adjusted baseline and metered consumption, can be reported in near-real-time.

Energy savings for a whole facility can be estimated by creating an adjusted baseline from metered consumption in the pre-retrofit period to model the facility energy use in the future, had the energy efficiency measure not been implemented.

- Automated M&V and SaaS can be used as a combination for conducting energy audits, tracking and benchmarking of projects, doing virtual energy assessments, and project planning and optimization.
- Virtual and remote audits and assessments are a subset of automated M&V functions beyond tracking savings. These tools identify specific projects and assess investments in energy efficiency measures or track the operational and maintenance changes to improve energy efficiency.

A traditional audit requires a site visit to assess energy savings potential. Remote assessments model consumption, facility characteristics and operations, without a site visit. Remote assessment often precedes an on-site audit and savings estimates are developed and reported using industry-accepted simulation models.

Improved data collection tools:

With advancements in instrumentation to collect enhanced data, some of the tools that can play an important role in implementing the concept of M&V 2.0 are smart meters and advanced metering infrastructure (AMI), smart sensors, controls and home energy management system (HEMS), and non-intrusive load monitoring (NILM) tools.

Smart Meters and Advanced Metering Infrastructure (AMI): Smart meters range from basic hourly interval meters to real-time meters with built-in two-way communication, capable of recording and transmitting instantaneous data. AMI data facilitates dynamic load profiling and time-differentiated impact estimation for energy efficiency projects, demand reduction and short-term forecasting. Smart meters and AMI can cater to the need for more data points and relevant variables to improve the accuracy of energy models discussed earlier. For example, in a building, statistical analysis of more granular data from smart meters may enhance the ability to separate heating, cooling, and base loads with increased precision; as compared to analysis of monthly consumption data. With increased granularity, new variables can be included in consumption models, such as day types (weekends, holidays), peak hours, and consecutive hot or cold days. These expanded model specifications enhance the ability to analyse and predict energy performance of a building. Similarly, combining daily meter and temperature data reveals the relationship between degree-days and HVAC loads when they occur, rather than averaged over 30 days. Finer interval data also can reveal insight into differences in building performance in mild versus extreme conditions. While finer resolution does not improve the ability to answer questions like estimating the persistence of energy savings, but it does provide or indicate the energy performance at a particular instance or over a time period in an accurate manner. Overall, with large volumes of energy consumption data possible in an hourly or 15-minute range, smart meters and AMI can increase the visibility of energy efficiency measures by their ability to estimate overall changes in kWh use by time of day.

Smart sensors and controls and home energy management system (HEMS): Using machine-learning techniques, smart controls can replace manual controls with a customized, agile, and automated system. The smart controls generate savings if it reduces the facility energy consumption compared to the consumption before the controls were installed. Sensors can transmit data to the facility team or third party providers over wireless networks. Taking the example of a building, multiple temperature and occupancy sensors can be programmed to adapt to building schedules automatically, monitor indoor and outdoor conditions, and set back thermostats. The smart sensors can function with already programmed algorithms about when occupants return to the building or an office space and when they move out, accordingly the indoor temperature is set to their comfort zone. These devices also support load reduction programs such as dispatchable demand response programs. A common design for demand response programs employs direct load control using the smart sensors and controls. The overall advantage of smart sensors and controls for M&V 2.0 would be the enhanced interconnectivity of all devices in a facility or building, which will allow real-time or near- real-time adjustments to happen and the energy efficiency interventions to be implemented and verified successfully.

Similarly, home energy management system (HEMS), can be briefly defined as any hardware and/or software system that can monitor and provide feedback about a home's energy use, and enable advanced or remote control of major and minor energy loads as well. HEMS presents a unique opportunity for M&V 2.0 by collecting and reporting real-time feedback on site level energy use to facilitate the incorporation of automated M&V into products and technologies. For example, in a project, a user can be provided with potential energy savings information in near-real-time by the HEMS using deemed savings or statistical models and measured run times from smart sensors and controls. But the potential goes beyond the whole house energy management system and smart sensors and controls. Communications and control technologies are getting added to a wide range of powered devices (e.g., appliances, LED lamps, etc.). As more devices are made smart, each device gains the potential to self-report its own energy use and operations. A potential scenario is that the HEMS integrated with smart sensors and controls can serve as a communication hub for various smart devices in a home or building, and transmit the information for the use of energy modelling and analytics.

Non-intrusive load monitoring (NILM): Intrusive methods of direct load measurement is basically placing data loggers, meters, and sensors on facility and building systems to capture energy consumption and demand on a high frequency basis. End uses can also be measured at the electric panel if it is isolated on a single circuit. The conventional M&V approach, which uses direct measurement, is time consuming and expensive. Alternatively, NILM is a process for analysing changes in the voltage and current going into a facility or a building or the run-times of in-house systems, and deducing what appliances or equipment are in use and then measuring their respective energy consumption. NILMs are meters that record high frequency signals at the facility level, compute granular level load profiles, and identify time-stamped transitions in energy consumption. These load profiles and load transitions are stored in the NILM and is transmitted to a central system using a form of IP-based communications periodically. An emerging technology in the NILM category uses harmonic signatures to identify end uses. Although promising, it is a complex exercise, because individual loads must be turned on and off during the labelling process. NILM facilitates M&V 2.0 by capturing multiple loads from a single device, for assessment of programs with multiple energy efficiency interventions or measures, thus lowering the overall cost of measurement and verification.

SCHNEIDER ELECTRIC'S GRADUAL SHIFT TOWARDS M&V 2.0

Schneider Electric currently uses the conventional M&V approach globally for evaluating the energy performance of its own manufacturing facilities and large commercial offices. The organization, under a global program – Schneider Energy Action (SEA), has set a target of reducing the energy consumption of its most energy intensive facilities by 10% in a three-year period. The current or ongoing three-year phase of SEA is 2015-17 with a 2014 baseline. The conventional M&V approach used across Schneider Electric can be summarised in the sections described ahead.

Collecting Energy Data

The facilities, manufacturing and commercial, are equipped with Schneider Electric's own energy management products and solutions to capture the energy data. The data is recorded using energy meters and provided monthly for energy modelling. Extensive sub-metering helps in capturing overall as well as major energy consuming sections of the facility. Other than the energy consumption, relevant variable data like production volume, cooling degree days, staff working hours, facility operation hours, etc. are also captured and recorded monthly.

Developing Energy Models

This second part of the M&V approach involves providing the captured data from the facilities as input to the spreadsheet tools for developing and running of the energy models to evaluate energy performance of the facility. If required, the baseline needs to be adjusted as well, to reflect the static factor changes or modifications (for example, electrical load expansion) correctly in the model. Schneider Electric uses a set of acceptable range of values (like p-value, f-test value and co-efficient of regression, R^2), which indicate the accuracy of the energy model. The regression model is modified accordingly with different variables if the set accuracy indicators don't fall within the acceptable range of values. Once the value of these indicators is within the range and the best possible model accuracy fit has been achieved, the energy performance is recorded for the facility.

Reporting Energy Performance

The energy performance calculated for every facility is then compared to its target energy performance for the year, and if the performance is not on track, then a deeper and end-use specific analysis is done for the facility to identify the problem and resolve it accordingly, so that the energy performance of the facility can be improved.

The process or exercise described above is done at the end of every quarter and is reported globally, and it is audited by a third party annually. At Schneider Electric India, 10 energy intensive facilities are covered under SEA. Starting from the collection of energy data to developing models and reporting the energy performance, the overall quarterly process for all the 10 facilities takes 20 days on an average entailing contributions from three teams with different responsibilities in the program.

The initial work is carried out by the facility team, which is responsible for the collection of energy and variable data and recording other details like energy efficiency projects implemented and any major changes in the facility that can have an impact on the facility's energy consumption and performance. These details are then provided to the other two teams (Energy & Sustainability Services and Energy Efficiency) who are a part of the program and who carry out the analysis to develop energy models and report the energy performance with recommendations for improvement.

Although the ongoing SEA program with the conventional M&V approach has been successful, with further advancement in technology, Schneider Electric has been looking forward to incorporate M&V 2.0 in their approach to evaluate energy performance of their facilities.

The same has been initiated with an ongoing project where all energy intensive facilities under the SEA program have been integrated on a central energy management system (EMS) platform. The input energy and variable data used for modelling will thus be verified automatically and the possibility of data tampering or fiddling will be reduced to very low levels.

The next step after integration of facilities on a central EMS platform would be automated M&V, where regression analysis modelling equations would be developed automatically and energy savings would be reported in a near-real-time basis on the software. As discussed earlier in this paper, analysing or developing energy models in real- or near-real-time, along with an overall move towards an automated M&V process will result in a considerable increase in the available data for energy use and relevant variables, which in turn will make the energy models a lot more accurate; and will eventually make for a lot more effective energy management program.

Beyond the discussion above, as it relates to its enterprise energy management journey, the larger objective of Schneider Electric, while going forward with the M&V 2.0 approach is to ensure that all its products, energy meters, sensors and controls, breakers, etc. are integrated on a central platform to facilitate the process of advanced analytics.

COSTS AND BENEFITS OF M&V 2.0

The financial costs and benefits of M&V 2.0 are best illustrated with an example of a facility. For a medium-size manufacturing unit having an average demand of 500 kVA, one needs to collect, record and analyse monthly data for 5 different variables (kWh – HVAC and non-HVAC, production volume, employee working hours, facility operation hours, and cooling degree days). Based on the authors' experience with their in-house energy management program described above, the time required for collecting these data and developing IPMVP-based energy models for such a facility would be 2 working days per month, on average (assuming 50 energy meters are already installed in the unit). Considering a daily rate of INR 5,000; it would cost INR 120,000 annually for carrying out the process of conventional M&V. If one considers the same case with an automated M&V infrastructure (EMS) in place, not only will this recurring expenditure be minimised (resulting in an estimated 75% reduction in the time and effort needed monthly); but the results will be more accurate and reliable, by being less prone to human error. The additional investment for installing an EMS and facilitating automated M&V for such a manufacturing unit would be approximately INR 200,000 (this estimate includes the additional cost of gateways for 50 energy meters and a complete software installation with requisite analytical capabilities to perform M&V). This results in a simple payback of a little less than 27 months and a return on investment (RoI) of 35% over 3 years, based only on the reduction in time and effort for carrying out conventional M&V.

CHALLENGES IN ADOPTING M&V 2.0

One must bear in mind that there are limitations and challenges in adopting the M&V 2.0 approach too, as all issues can't be solved by greater volumes or frequency of energy data, or higher speeds of data processing. Those limitations and challenges, are the explained in the sections below.

Developing and Adjusting Energy Baselines:

Building or estimating appropriate energy baselines and adjustments for energy modelling is a challenging task that often requires judgment. In the conventional M&V approach, the developing or adjustment of energy baseline happens not just manually but it also involves the understanding and judgment of the person or the team who are assigned that role or responsibility. But, in M&V 2.0, the baseline creation and modification happen automatically with programmed algorithms, which may turn out to be wrong. This may also end up being a tedious exercise, if the input or data provided for baseline creation and modification is not compatible with the requirements of or within the boundaries of the software or the algorithm.

For SEA, Schneider Electric is planning to incorporate the concepts of automated M&V on a central EMS platform called Resource Advisor. Here, one may face similar challenges with developing and adjustment of energy baseline that would be done through pre-set algorithms and programming; which could go wrong in two scenarios, if the algorithm or programming is not flexible enough to incorporate the possibility of baseline adjustments or the inputs, or if the data points required for the algorithms are not enough to provide a correctly adjusted or modified baseline.

Analysis of Complex Projects or Processes:

Analysis of projects in a facility manufacturing a wide variety of products with processes catering to those products, becomes a very complex task due to the difficulty in normalizing the product mix with respect to one equivalent production unit. Taking the example of SEA in India, at most of the Schneider Electric's energy intensive sites, there is a wide variety of product mix and processes, which could be a challenge with regards to M&V 2.0. This is due to the fact that to maintain a high or acceptable degree of modelling accuracy, either separate energy models would be required for different products and processes on the central EMS, or very complex programming has to be done on the EMS platform, for incorporating the effects of all the products and processes on the overall energy consumption. This whole exercise can result in increased cost due to the requirement of additional software capabilities and energy meters and other measuring instruments.

Slow Adoption of Energy Management Systems (EMS) in India

A robust and granular EMS – with adequate sub-metering and the requisite analytical capabilities – is at the heart of an effective M&V 2.0 approach. In India, this is still not commonplace. In large part, this is due to the challenge around effectively articulating the return on investment (RoI) for an EMS installation. However, the adoption of EMS appears to be growing rapidly over the last few years, driven by the implementation of the Perform Achieve and Trade (PAT) scheme and increasing interest in green ratings and recognitions as well as growing adoption of ISO 50001. For M&V 2.0 to scale up, widespread adoption of EMS is the key. For this to happen, the energy efficiency community needs to better articulate and quantify the benefits of EMS for the users; including but not limited to improved energy efficiency, asset management and power quality monitoring. Going forward, it is likely that the growing interest in and adoption of outcome-based delivery models such as energy-as-a-service and energy performance contracts will also drive faster adoption of EMS in India.

Data Connectivity and Communication:

Lastly, with advanced analytics and software being the platform for modelling and M&V 2.0, the basic issue or challenge of maintaining data connectivity and communication assumes paramount importance. Missing data can lead to inaccurate models and wrong or less accurate energy savings estimation. For example, during various exercises carried out as a part of SEA, this issue has been encountered and observed several times when an energy meter or some other device has stopped communicating in middle of the month and it was noticed only at the month-end. This kind of situation can be challenging for the approach of M&V 2.0, where the whole process is dependent on the continuous communication and real- or near-real-time data recording and reporting.

CONCLUSION

The trends in new and advanced tools and technology for data collection and analysis hold great potential for effective energy management and optimization using M&V 2.0 approaches. Although emerging technologies with regards to software, hardware, and data availability are still evolving; the new tools and methods will enhance data collection, data availability and data processing efforts. Overall, the role of advanced and improved data collection tools and data analytics in the changing paradigm of measurement and verification (M&V) would be very critical. This paper has described the opportunity that M&V 2.0 presents, with a description of a conventional M&V process and the gradual shift towards the M&V 2.0 approach in the context of an ongoing enterprise energy management program, along with a discussion about some of its inherent challenges.

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MOVING TO MONITORING BASED COMMISSIONING

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Keywords: MBCx, commissioning, continuous commissioning, monitoring, optimization

ABSTRACT

This paper discusses going beyond the conventional process of building commissioning with monitoring based commissioning (MBCx).

The paper starts with a discussion on the current scenario of maintaining building performance with a need for continuous operational monitoring to achieve the desired results. Though the whole focus of cost management in buildings is centred around the construction phase, 75% of a building's lifetime costs are incurred after the construction phase – during operations. Although technology continues to evolve and many facilities already have building energy management and automation systems, building owners and facility staff still struggle to leverage the existing infrastructure and to make the most of the available technology.

The paper discusses how a Monitoring Based Commissioning (MBCx) approach provides an opportunity to maximize the use of available technology by bringing together meaningful analytics and intelligent control to create a truly optimized facility. MBCx, using continuous monitoring and web-accessible data for implementation of energy saving measures; has the potential to significantly reduce energy use in large buildings. Unlike Retro-Commissioning (RCx) and Re-Commissioning, MBCx is an ongoing process which incorporates monitoring and analysis of building energy use and systems, as provided by the installed metering and sub-metering and controls infrastructure, to maintain desired levels of performance. Due to the continuous nature of monitoring, MBCx can identify issues that usually emerge only after the retro-commissioning investigation stage.

The paper concludes with a discussion on the savings MBCx can provide through persistence and optimization as compared to RCx; because of early identification of issues using technology and analytics.

INTRODUCTION: GROWING NEED TO FOCUS ON BUILDINGS

Buildings consume one-third of world's energy and more than half of the world's electricity (IEA 2014). Globally, electricity consumption in buildings is expected to grow by 80% (OECD/IEA 2012) in the next 25 years. In India, 33% of the total electricity consumption goes to buildings and it has been increasing by 8-10% per annum over the past 7-8 years (CEA 2017). Hence the need for building energy management and efficiency has never been more pressing. With 82% of energy efficiency potential yet to be tapped in buildings and data centres (OECD/IEA 2012) and 30-50% of this potential achievable through active control of building space (US DOE 2010), there are many opportunities for buildings to be more energy efficient. Although the whole focus of cost management in buildings is centred around the construction phase, a substantial part of the cost is incurred after the construction phase – during maintenance and operations. 75% (US DOE 2010) of a building's lifetime costs go towards maintenance and operations. An operationally efficient approach focused on predictive maintenance and analytics, can save up to 20% per year on maintenance and energy costs and provide very attractive returns on investments (ROI).

Many facilities already have building energy management systems (BEMS). But most facility users are not able to make the most of that technology. Over a period of time, on account of building system and equipment changes and evolving maintenance needs; building operators struggle to leverage the existing systems, since they have to manage the system and infrastructure while juggling the operational challenges.

CONVENTIONAL METHODS TO MAINTAIN BUILDING PERFORMANCE

Buildings rarely perform as intended, with the result that energy use is often higher initially, or over time, than anticipated by the design and engineering estimates of savings. In recent years, building commissioning has emerged as a highly cost-effective quality control and quality assurance strategy for remedying this problem in non-residential buildings. Complementing traditional hardware-based energy savings strategies, commissioning is a process of verifying performance and design intent and correcting deficiencies (Mills et al., 2009).

Described in the following sections are three types of conventional commissioning processes that are carried out to maintain building performance (Haasl et al., 2006).

Commissioning (Cx)

This is a method of risk reduction for new construction and major renovation projects to ensure that the building systems meet their design intent, operate and interact optimally and fulfil the requirement of the process or the operation along with meeting the owner's expectations. This systematic process typically includes building HVAC, controls, lighting, hot water, security, fire, life and safety systems. Total building commissioning often includes additional essential building systems such as the building's exterior wall, plumbing, acoustical and roofing systems. Commissioning these additional systems can contribute to the building's energy and resource efficiency and occupant productivity. Successful Cx results in optimal energy performance, enhanced indoor environmental quality, reduced change orders during construction, extended system life and reduced operation and maintenance costs, often paying for itself before construction is completed. To be most effective, building commissioning begins in the planning phase and continues through design, construction, start-up, acceptance, training and the warranty period, and continues throughout a building's life cycle.

Retro-Commissioning (RCx)

The commissioning process can be applied to existing buildings that have never been commissioned, to restore them to optimal performance. RCx is a systematic, documented process that identifies low cost operational and maintenance improvements in existing buildings and brings the buildings up to the design intentions of its current use. RCx typically focuses on energy using equipment such as mechanical equipment, lighting and related controls and usually optimizes existing system performance, rather than relying on major equipment replacement; typically resulting in improved indoor air quality and thermal comfort, controls, energy and resource efficiency. RCx usually includes an audit of the entire building including a study of past utility bills and interviews with facility personnel. Then diagnostic monitoring and functional tests of building systems are executed and analysed. Building systems are re-tested and re-monitored to finely tune the improvements. This process helps find and repair operational problems. The identification of more complex problems is presented as a part of the final report along with the recommissioning plan and schedule.

Re-Commissioning

This is another type of commissioning that occurs when a building that has already been commissioned undergoes another commissioning process. The need for recommissioning is usually driven by a change in building use or ownership, the onset of operational problems, or some other need. Ideally, a plan for recommissioning is established as part of a new building's original commissioning process or an existing building's retro-commissioning process. Any building that has undergone changes, or whose systems have not been examined for many months or years, are obvious candidates for recommissioning.

MOVING TOWARDS MONITORING BASED COMMISSIONING

Monitoring-based commissioning (MBCx) emphasizes continuous performance monitoring and trending for diagnosis of energy waste, for savings accounting, and to enable persistence of savings.

Until recently, building RCx practice has relied heavily on test protocols and modelling for diagnosing problems and energy savings accounting. Persistence of energy savings from RCx over the long-term is and has been a major concern (Brown et al., 2006).

Here, monitoring-based commissioning (MBCx) has emerged as a paradigm shift for owners and operators of large buildings and the commissioning industry that serves them. A monitoring based approach can often deepen the scope of commissioning projects, provide savings accounting with more credibility, enable persistence of savings, and provide a platform for ongoing efforts to manage building energy use (Meiman et al., 2012).

Monitoring-based commissioning (MBCx) can also be considered as a monitoring-enhanced building operation that provides ongoing performance diagnostics and fault detection by utilising components like permanent energy information systems (EIS) and diagnostic tools at the whole-building and sub-system level. This facilitates retro-commissioning based on the information from these tools with savings focussed on measurement and monitoring as opposed to estimation or assumptions; and ongoing commissioning to ensure efficient building operations and accounting of measurement-based savings. Manual remote monitoring services or advanced analytics engines process building data to continuously diagnose facility performance and identify equipment and system faults, improvements in sequence of operations, and system and energy use trends (Mills et al., 2009).

Also, to effectively use the existing systems, fine tuning is critical; and MBCx is all about fine-tuning systems and equipment and enabling facilities and staff to respond effectively to expected and unexpected changes. MBCx tools leverage manual remote monitoring services or advanced analytics engines to continuously diagnose facility performance and identify equipment and system faults, sequence of operations improvements, and trends in system and energy use. These consistently help staff maintain a building's performance at desired levels over time (Wheless B., 2015).

Furthermore, monitoring is used to help ensure the persistence of savings by alerting building staff and management to degradation in performance and to detect faults in operation. MBCx based techniques and tools can significantly reduce the time, effort and level of knowledge required to acquire and analyse data to reveal energy-consuming operational faults, such as failed sensors and controllers, poorly implemented schedules, improper operations, systems running during unoccupied hours, and valves leakages. These tools provide information which is valuable for identifying opportunities for saving energy through improved operations and detecting faults and performance degradation as they occur, enabling their timely correction, thus helping ensure persistent savings.

Operational improvements can be made by changing the control parameters, replacing or repairing the failed components, and doing further diagnostics or troubleshooting to identify underlying root causes for equipment and systems with degraded performance.

Tools and technologies like a building management system (BMS), which is mainly used for on-site management and control of HVAC, lighting, fire, and safety and security systems, integrated along with an energy management system (EMS), that has the capability to provide analytics for energy use, demand, and power quality; can be used to continuously monitor and control equipment and systems during operations.

Different phases or stages of MBCx to ensure continuous improvement in the facility performance are explained in the sections below.

Continuous Monitoring

This is about having an ongoing data collection process with various meters and sensors installed to gather building energy use information on a real- or near-real-time basis. Continuous monitoring is a process that is also useful for setting up a baseline for building performance. Periodic equipment and operational audit, long-term energy monitoring and upfront and ongoing utility data collection are some of the methods for continuous monitoring and creating a baseline. Also, with a permanently installed energy management system (EMS), as an outcome of the continuous monitoring process, a status report can be generated on a regular basis.

Evaluation

After continuous monitoring and data collection, it is necessary to analyse the information gathered or collected. Therefore, energy analysis, as part of evaluation, is the second stage for MBCx. Modelling and analytics, energy benchmarking, remote analysis and energy data review are ways to perform regular evaluation of the data using comprehensive software to develop highly detailed and insightful recommendations regarding energy efficiency measures (EEMs). Besides using the ways described above, the evaluation phase also requires extensive knowledge and a deep understanding of the whole facility and its operations along with a close co-ordination between facility managers, engineers and operators.

Implementation

This is the final stage for MBCx, where the approved or planned EEMs are executed or implemented. The outcome of this phase is or should be a priority report for EEMs along with a schedule for implementation, which will require a well-co-ordinated team of facility managers, engineers and operators. Also, after the implementation, a continuous fine-tuning occurs to ensure optimal operation. The implementation phase also provides inputs for the preceding phase of evaluation to drive persistent energy savings.

MBCx provides an opportunity to maximize the effective use of installed technology, document each systems capabilities, and create a truly optimized facility. Through web-based data collection, implementation of energy saving measures, and continuous monitoring, MBCx has the potential to significantly reduce energy use in large buildings (Brown et al., 2006). The additional energy savings from MBCx mainly come from:

- Persistence of savings from RCx due to early identification of deficiencies through metering and trending. Several studies have shown that RCx savings can degrade without an explicit effort to monitor and maintain them.
- Continuous identification of new measures. Due to the continuous nature of monitoring utilising permanently installed infrastructure along with a combination of an energy and building management system, MBCx can identify new problems that emerge after the initial retro-commissioning investigation stage, such as equipment cycling and excessive simultaneous heating and cooling (Mills et al., 2009).

STATE OF COMMISSIONING IN INDIA

The practice of commissioning is extremely rare in India, driven mainly by the requirements of green building rating systems. Responses to queries sent to some leading green building and commissioning practitioners in India suggest that there is no information available on the adoption of commissioning in India. Even in cases where commissioning is carried out as part of a projects pursuit of a green rating, it is carried out with rigour only in mission-critical installations and applications such as banking, data centres, etc., where there is an appreciation of the value of uptime, reliability and reduced disruption in operations. As such, since conventional commissioning itself is nascent in India, it is safe to say that MBCx is not being practiced in India. There is an opportunity here to leapfrog to MBCx in India. The infrastructure required for MBCx (energy meters, EMS, BMS, lux meters, sensors, etc.) is available in the market today. If MBCx is approached as a part of the standard operating procedures adopted by the facility or maintenance staff, with limited and timely engineering guidance, one can achieve desired levels of performance maintenance and assurance in operations.

COST AND TIME IMPLICATIONS OF MBCX

In countries where the practice of commissioning is commonplace, building systems commissioning usually costs between 0.5% to 1.5% of the hard construction costs of a project. There is no data available on this count for India. For effective MBCx, for a commercial office of 2,000 sq. m. with annual energy consumption of 500,000 kWh, one would need to have a metering and monitoring infrastructure in place for at least the significant energy end uses (e.g., HVAC, lighting, UPS, raw power). In this case, the facility would need 12-15 energy meters, a BMS with an EMS (either separately or combined), a lux meter and 4-6 temperature sensors (at least one sensor per thermal zone or 300-500 sq. m. of office space) to carry out MBCx. The total cost for this installation would be in the range of INR 1-1.5 million. However, for a facility or building of this size, often, a lot of this would be a part of the project anyway, in some manner. The time required for carrying out continuous monitoring in this case would be 1-2 person-days per month. The case study in the following section discusses the benefits of MBCx in a setting similar to the case discussed above.

CASE STUDY: SCHNEIDER ELECTRIC INDIA CORPORATE OFFICE

Schneider Electric India's (SEI) corporate office at Gurgaon (Haryana), which is also an ISO 50001 (a global standard for Energy Management System) certified space, is a case where a semi-automated approach of MBCx has been implemented. Three different scenarios are discussed here to illustrate this:

- Scenario A – business as usual – no monitoring,
- Scenario B – current situation – combination of continuous and periodic monitoring and periodic corrective actions,
- Scenario C – ideal situation – continuous monitoring and better controls with near-real-time corrective actions.

Scenario A – Business as Usual – No Monitoring

The purpose of the global ISO 50001 standard is aligned with the overall approach of MBCx, which is to strive for continuous improvement in energy performance by enabling an organization to establish the systems and processes necessary to be efficient in the use and consumption of energy; thus creating a culture of energy management within the organization. Implementation of the standard is intended to lead to reductions in greenhouse gas emissions and other related environmental impacts and energy costs through systematic management of energy. In the absence of this approach or standard, the critical inefficiencies that might arise, would be:

- No energy policy being defined, implemented and maintained – resulting in the absence of a framework for action and for the setting of energy objectives and energy targets. Also, a lack of engagement with the top management and other levels for the energy management efforts of the organization.
- Lack of energy data – without a focus on continually improving the energy performance, the energy consumption of the office could be inefficient and high, due to low or no visibility of the energy use. Without the necessary data, it would also be difficult to create an energy baseline for the office.
- Absence of energy analysis or evaluation – not having the relevant energy data would also make it impossible for analysing the energy use and identifying trends and patterns to find performance gaps. It would also result in a lack of energy action plans or recommendations for energy conservation measures (EEMs).
- Energy savings not persisting – savings not lasting for a longer time could be a result of the lack of continuous monitoring and review of energy use after the retrofits or implementation of EEMs.
- Lack of energy use related awareness among the employees.

Scenario B – The Current Situation

The Schneider Electric India head office at Gurgaon has been a certified ISO 50001 space since 2013. It has established its Energy Management System (EnMS) based on the ISO 50001 standard. The management system implemented ensures identification and monitoring of various opportunities in areas of significant energy consumption and strives to reduce its consumption by deploying energy efficient solutions. It covers deployment of technology for monitoring and control of electrical energy consumption. The top management at Schneider Electric's Gurgaon office is committed to the development and implementation of the EnMS and continuously improving its effectiveness by setting energy objectives consistent with its energy policy.

The Policy is communicated within the organization at regular intervals and reviewed by the top management every six months. A permanent energy metering and monitoring infrastructure is installed to carry out an energy review at defined intervals for analysing energy use and consumption based on measurement and other data, for identifying significant areas of energy use, and for identifying, prioritizing and recording opportunities to improve energy performance. An energy baseline has also been created along with identifying and defining relevant energy performance indicators and setting up of energy objectives, targets and action plans.

The above defined EnMS, energy policy and other operational activities has helped the office in striving for continuous improvement in its energy performance, identifying gaps, conducting energy audits as well as internal EnMS audits to find non-conformities and opportunities for improvement. Conducting a management review with the top management at defined intervals also helps the organization take corrective actions faster and in the implementation of the identified EEMs. The following sections present a few examples of how the approach of MBCx, i.e. continuous monitoring of specific parameters representing the significant energy use has resulted in savings in energy consumption and cost at SEI Gurgaon.

Uninterrupted Power Supply (UPS) system optimization: The Gurgaon office has a dedicated energy meter for all the major end uses including UPS, and the same is monitored and analysed every month. Because of continuous monitoring of UPS consumption and its loading patterns, the UPS system was optimized for increasing its efficiency and one of the two 120 kVA UPSs, along with the associated battery bank, was moved from the Gurgaon office to another Schneider Electric India office in Bangalore. The continuous monitoring was possible because of dedicated energy metering. This re-configuration resulted in multiple cost savings for the Gurgaon as well as the Bangalore office. At Gurgaon, an increase in UPS efficiency from 87% to 92% due to an improved utilization (from 15% to 30%) of the UPS system, resulted in annual energy savings of approximately 11,500 kWh, which is worth energy cost savings of approximately INR 156,000 per annum. The efficiency curve for 120 kVA UPS is shown below.

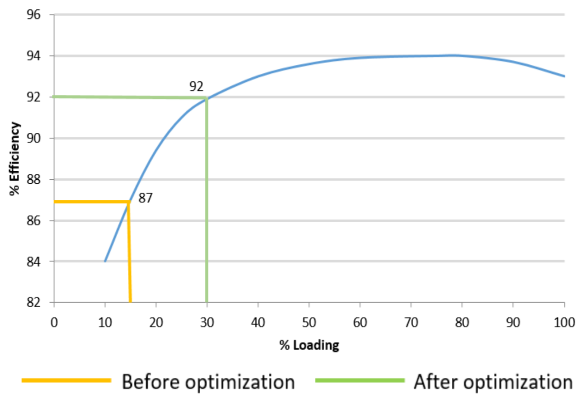

Figure 1: UPS Loading-Efficiency Curve Chart

Also, due to a smaller battery bank, O&M cost (recurring battery maintenance and periodic replacement cost) of batteries was reduced by approximately INR 150,000 per annum taking the overall savings in annual operating expenses for the Gurgaon office from this activity to about INR 306,000. The 120 kVA UPS which was freed up from the Gurgaon Office and was moved to Bangalore, thus avoided a capital expenditure of approximately INR 1.3 million (the cost of a new 120 kVA UPS) for the Bangalore office.

Optimizing the cooling set-point in the server room: The server room has a permanently installed temperature sensor and indicator which is monitored, and the temperature is recorded daily. The same is analysed with respect to the energy consumption of the precision air-conditioners (PACs) installed in the server room. The PACs also have a dedicated energy meter. With the continuous monitoring of the sever room energy consumption and temperature, the cooling set-point temperature for the PACs was found to be lower than required and it was increased from 20°C to 24°C after ensuring that it won't affect the server performance in any manner. This intervention resulted in an annual energy savings of approximately 4,500 kWh, worth almost INR 61,000.

Reducing high lighting energy consumption due to over-illumination: By monitoring illumination levels monthly using a lux meter, it was found that the illumination levels were higher than required at many workstations and in some circulation spaces as well. Therefore, many of the lighting fixtures were turned off or removed permanently to bring down the illumination levels to the desired range, thus resulting in an annual energy savings of approximately 40,000 kWh, worth INR 540,000.

As described above, the Schneider Electric Gurgaon office has reduced its energy consumption considerably with continuous monitoring of various parameters. Also, the measures discussed above make a strong case for the adoption of MBCx by showing that rather than relying on conducting periodic energy audits (that usually happen only once every 2-3 years and need to be carried out by trained energy auditors); the facility management staff could monitor these parameters and take corrective actions on an ongoing basis (at least monthly). A critical aspect of MBCx is to have the infrastructure in place to help in continuous measurement and monitoring of the significant energy end uses. This infrastructure is not just restricted to energy meters, but as demonstrated with this case study, it should also include other meters and sensors as needed (e.g., lux meters, temperature sensors, etc.).

Thus, despite being a rented space with little control over many significant parameters that drive energy use, practicing MBCx has helped reduce SEI's Gurgaon office energy consumption by almost 17% by the end of 2016, as compared to the 2012 baseline.

Scenario C – The Ideal Situation

The energy performance can still be improved by around 7% using better (near-real-time) operational control and corrective actions with alarms and indicators in place for arresting performance drift and to catch any significant deviation from the set operating parameters.

Table 1: Scenario Comparisons

	A	**B**	**C**
Method & Approach	No ongoing monitoring or performance tracking	Continuous energy use and temperature monitoring, monthly lux-level monitoring	Better controls and corrective actions with alarms and indicators
Estimated Annual Energy use	600,000 kWh (Modeled)	538,000 kWh (as of 2016)	500,000 kWh (Estimated)
Impact	11% increase in energy use in the absence of monitoring		Further 7% reduction in energy use as compared to the current situation

CONCLUSION

MBCx can be very useful for effective energy management. It can help in identifying a wide range of deficiencies and faults in systems and operations. Energy savings are expected to be more persistent from MBCx, rather than from conventionally commissioned buildings or facilities or equipment, due to continuous monitoring. Also, as is evident from the case study presented, the approach of MBCx and a focus on continuous improvement through ongoing monitoring; can result in a significant reduction in energy use and cost.

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INCREASING THE FLOW OF INVESTMENT INTO ENERGY EFFICIENCY

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Keywords: Finance investment standardisation

ABSTRACT

This paper examines the current state of the energy efficiency financing market with reference to the US and EU markets as well as globally, and discusses the barriers to the growth of private capital investment into energy efficiency. These include: lack of standardisation in development and documentation, small project size and the need to develop large pipelines, the need for both development as well as project finance, and the need to build capacity in the demand side, the supply side and the finance industry. It then looks at various examples from around the world that have successfully brought the elements together to increase the flow of capital into energy efficiency. It reviews significant developments including the Investor Confidence Project, the EEFIG Underwriting Toolkit, project performance databases and platforms and their role in the ecosystem of energy efficiency financing. It also looks forward to emerging business models such as metered efficiency and Pay for Performance.

INTRODUCTION

It is now increasingly recognised that in order to achieve global and regional energy and climate goals we have to significantly scale-up the rate of investment into energy efficiency.

The IEA in its 2016 Energy Efficiency Market Report estimated that total global investment into energy efficiency in 2015 was USD 221 billion. Of this half was in buildings, the sector also showed the highest growth rate at 9%. Some USD 39 billion of the total investment was in industry, with a growth rate of 6%, and USD 64 billion in transport with a growth rate of 3%. Total investment grew by 6% but was only 14% of total investment into the energy system, the remaining USD 1.4 trillion flowing into energy supply.

The US, China. Germany and France accounted for 73% of global investment into buildings. Interestingly, even though Zero Energy buildings and policies to promote them are relatively new, this segment of the market attracted USD 15 billion of investment, USD 14 billion being in the EU.

Despite these encouraging trends there is still much to be done. The IEA and IRENA estimate that to hit their 2^0C scenario investment into energy efficiency will need to increase by a factor of five by 2050, to approximately USD 1 trillion per annum. This is a significant challenge for the energy efficiency industry, the finance sector and policy makers.

TYPES OF ENERGY EFFICIENCY INVESTMENT

It is important to note the various types of investment that lead to improved energy efficiency. There are three basic types of investment which can improve energy efficiency whichever sector is being considered:

- retrofit
- embedded
- new build.

Retrofit investments are those stand-alone projects where the primary purpose is improved energy efficiency. Examples include switching lighting to LEDs or adding heat recovery to an industrial process to reduce the use of input fossil fuel used for heating water.

Embedded projects are projects are part of wider investment being implemented for reasons other than energy efficiency, such as the refurbishment of a building to bring it up to modern standards, or modifying a process line to increase production.

New build projects are new buildings, industrial facilities. Again the primary purpose of these investments is not energy efficiency but supporting an organisations overall objective or mission.

It should be noted that often investments of the second and third types do not achieve the optimum level of energy efficiency, which means that the opportunity is missed and higher than necessary energy consumption is "locked in", often for decades. This occurs for a number of reasons including; lack of know-how, engineering conservatism, and the perception, (not necessarily correct), that higher levels of energy efficiency imply higher capital cost.

In order to reach the target of multiplying investment into energy efficiency by a factor of five we need to work on maximizing all three types of investment.

SOURCES OF INVESTMENT

To date most investment in energy efficiency is financed by savings, equity or straight forward commercial lending. Of the USD 221 billion invested only USD 24 billion was invested through Energy Performance Contracts (EPCs) and an additional USD 8 billion was through green bonds. As most energy efficiency is hidden in normal, everyday investment and finance, it is not often recognised as such. A householder applying for a loan or a mortgage may make improvements to their house such as a new, more efficient boiler or added insulation, but the lender only recognises this as “home improvements”. Lenders, or investors in refurbishment and new build projects rarely record the energy efficiency element or improvement, although in some cases in Europe this is beginning to change with pressure on banks to tag green assets in order to assess the climate risk of their portfolios.

The need to grow investment in energy efficiency by a factor five which was noted above, also implies a similar or greater increase in the use of external financing. The level of finance required is too high for public budgets and the availability of finance may help address some of the barriers to investment in energy efficiency.

Over the last five years there has been growing interest in energy efficiency from the financial sector including global institutional investors and lenders. This interest has been driven by five main factors:

- realisation that energy efficiency financing represents a large potential market.
- recognition that improving energy efficiency can reduce credit risks by helping clients improve cash flows and be less exposed to energy price volatility.
- the risk of financing stranded assets, particularly in the building sector as energy efficiency regulations (Minimum Energy Performance Standards) are tightened to the extent that low efficiency buildings will not be able to be sold or rented.
- the very positive environmental benefit. Institutional investors are increasingly driven by sustainability factors and impact investing, particularly to address climate change.
- increasing attention from financial regulators who have identified climate change as a systemic risk to the financial sector and have started, at least in some jurisdictions, to require more reporting of climate related risks.

With this growing interest we have now arrived at a point where there is more capital looking to be deployed into energy efficiency than there are well-developed, bankable projects available – despite the large potential that exists in all sectors.

BARRIERS TO INVESTMENT AND FINANCING

Energy efficiency, despite being economic, is actually hard to invest in for a number of reasons including, amongst others:

- savings are less interesting, and more difficult to capture, than revenues.
- savings are a counter-factual and sometimes hard to measure despite the growth of Measurement and Verification protocols such as those of the International Performance Measurement and Verification Protocol (IPMVP).
- project size is typically very small compared to the “cheque size” of institutional investors.
- there is no standardisation in the way that energy efficiency projects are developed and documented.
- there is a lack of capacity within the financial sector to originate, develop, evaluate and risk assess energy efficiency projects.

These will be reviewed briefly in turn.

Savings versus revenues

Despite being mathematically identical there is no question that for individuals and organisations savings are less attractive than revenues. Increasing revenue is usually a corporate strategic objective with saving costs being the poor relation of revenue generation, something that is reinforced by incentive structures and culture.

From a financing perspective it is harder to identify and secure savings as a cash flow than it is revenue from energy generation as an example. Energy generation is recorded by a meter and revenue payment flow in based on metered output.

Energy savings are a counter-factual

Energy savings are always a counter-factual, they are relative to what would have happened without an investment or intervention. In addition the actual level of savings made will vary with several exogenous factors such as weather, production levels and use patterns in a building – as well as the changing price of energy. This means measurement is difficult. Although the principles of Measurement and Verification (M&V) have been in use for some two decades they are not yet universally understood or used to support energy efficiency investments.

Project size

Typically energy efficiency investments are small compared to the level of transaction size required by institutional investors. A large efficiency project in a European hospital may be USD 10 to USD 15 million but many projects are much smaller, even down to the hundreds or thousands of USD in many cases. This makes energy efficiency difficult for many investors and points the way to the need for aggregators of projects.

Lack of standardisation

Despite numerous technical standards there is no standardisation in the development process and documentation of energy efficiency projects, which results in a number of problems for financial institutions including:

- higher performance risk
- higher due diligence cost
- difficult to build capacity
- difficult to aggregate.

In the words of Michael Eckhart of Citi Bank; "energy efficiency projects do not yet meet the requirements of capital markets….No two projects or contracts are alike."

Lack of capacity in the financial sector

Despite the growing interest and commitment of investors and lenders to energy efficiency there is still a lack of capacity to originate, develop, evaluate and risk assess energy efficiency projects. Building capacity takes time and requires tools which are now starting to emerge, some of which will be discussed below.

BUILDING INVESTOR CONFIDENCE AND CAPACITY

A number of important initiatives are now helping to build investor confidence in energy efficiency.

The Investor Confidence Project

One of the important international initiatives aimed at addressing some of the barriers to energy efficiency financing, notably the lack of standardisation, is the Investor Confidence Project (ICP). ICP started in the USA and was then introduced to Europe with the help of European Commission funding. It is now gaining traction on both sides of the Atlantic with additional activity in Canada and interest from India, China and Australasia. It has the support of some 400 Allies covering project developers, investors and lenders, NGOs, and insurance companies.

The ICP has developed a system called Investor Ready Energy Efficiency™ which is based on following a transparent process set out in Protocols covering different types of projects, initially in tertiary buildings and apartment blocks, and now being developed for industrial projects, street lighting and district energy. Projects that are developed following the Protocols by an ICP accredited project developer, and then checked by an independent QA professional receive the Investor Ready Energy Efficiency™ certificate.

It should be noted that the Protocols use best practice, local standards in each geography. ICP is not defining technical standards but rather standardising a process and documentation set. This is an essential foundation to grow the energy efficiency financing market, reduce performance risk, reduce due diligence costs and enable aggregation. A similar process of standardising project development and economic assessment happened in the early years of the wind industry, driven by project finance banks, but in the energy efficiency market an external stimulus was needed.

The EEFIG Derisking Project

In 2013 the European Commission and UNEP FI formed the Energy Efficiency Financial Institutions Group (EEFIG) to bring together representatives from the financial sector and the energy efficiency industry to make recommendations for growing investment into efficiency. In 2015 EEFIG published a report setting out the barriers and in 2016-17 the EC supported the EEFIG Derisking Project.

This project had two main elements;

- building a database of energy efficiency projects with the aim of demonstrating their performance (technical and financial).
- developing a Toolkit to build capacity within financial institutions, particularly in regard to the valuation and risk appraisal of energy efficiency investments.

In November 2016 the database, called Derisking Energy Efficiency Platform (DEEP), was launched with over 7,500 projects covering buildings and industry. It is the largest European database of energy efficiency projects and continues to grow as additional projects are added. DEEP can be found at: https://deep.eefig.eu

In June 2017, at European Sustainable Energy Week, the EEFIG Underwriting Toolkit was launched. It includes sections on:

- Financial Institutions and Energy Efficiency. This covers the reasons why financial institutions should be active in energy efficiency financing and makes recommendations for senior decision makers.
- Financing Energy Efficiency. This section covers the various mechanisms for financing efficiency of all types.
- The Project Life Cycle. This section sets out the project life cycle from the perspectives of both project developers and financial institutions in order to start to build a common language and process.
- Value and Risk Appraisal. This covers the multiple sources of value created by energy efficiency projects and how to value them. It also describes the various types of risk inherent in efficiency projects and hwo to mitigate them.
- Resources. An on-line directory of resources which is seen as a “living document” that can be added to as the energy efficiency financing market grows.

The Underwriting Toolkit can be found at: https://valueandrisk.eefig.eu

ICP and EEFIG as important models

The ICP and the EEFIG Derisking Project both have important roles to play in developing the energy efficiency financing market. The use of ICP’s Investor Ready Energy Efficiency™ directly addresses the barriers that come from a lack of standardisation. The EEFIG Derisking project addresses the lack of capacity within the financial sector, particularly in regard to understanding the value proposition and risks of energy efficiency projects. In other markets outside the USA and the EU similar initiatives would be useful. As demonstrated in Europe where it covers all 28 EU countries and Switzerland, ICP can be successfully adopted to differing national technical standards and languages, and yet retain commonality of approach. Given the international nature of financial markets a global approach based on ICP would be benefical and ICP is currently beginning co-operations to take the system to different countries and regions.

The EEFIG DEEP database, and similar projects elsewhere such as the US Department of Energy’s Buildings Performance Database, show the importance of open source databases of project performance. National and regional versions would be helpful in the development of energy efficiency financing in all markets.

NEW BUSINESS MODELS

The two barriers identified above, namely savings being less attractive than revenue and savings being a hard to measure counter-factual, remain barriers for most existing energy efficiency contracting and procurement models. Existing conventional business models such as Energy Performance Contracts (EPCs) have a number of issues including complexity and cost. Two new business models, both based on using smart meters and advanced IT to actually meter efficiency, are emerging in the US and address some of the barriers to energy efficiency.

Firstly, the Metered Energy Efficiency Transaction Structure (MEETS) uses a dynamic base line to meter units of energy efficiency, effectively for the first time measuring negawatt hours in near- real time. MEETS has been piloted in a Zero Energy Building in Seattle, the Bullitt Center, and interest is growing in this new model. In MEETS the units of energy efficiency are charged for just like units of energy. Thus the structure raises the possibility of energy users selling their energy efficiency and hence creating a revenue stream rather than savings.

The second development, which like MEETS, is effectively a Pay for Performance model, has been brought about by changes in Californian regulations and pioneered by OpenEEMeter. OpenEEMeter is using smart meter data to determine the actual level of savings across portfolios of energy efficiency measures installed in the residential sector. It allows utilities and regulators to see the real performance of the measures and their impact on overall demand, as well as measure the relative performance of different technologies and contractors. This allows, for the first time, energy efficiency to be accessed by utilities and used as a reliable distributed energy resource which will help make it more investable.

Implementing models based on Pay for Performance may in some jurisdictions require changes in the regulation of electricity markets. In any event such changes will be needed as electricity markets everywhere have an increasing share of renewables and storage, thus creating a value in flexibility. Metered efficiency models such as MEETS and OpenEEMeter should be incorporated into market regulatory reforms to reward demand flexibility.

CONCLUSION

Increasing the level of investment into, and financing of energy efficiency is a vital task for the coming years in order to achieve our energy and climate goals. Interest from the financial sector in efficiency has grown dramatically but there remain a number of barriers to scaling up investment and finance to the required levels. Chief amongst these are a lack of standardisation and lack of capacity within the financial sector to understand and evaluate energy efficiency projects. A number of developments are addressing these including the Investor Confidence Project and the EEFIG Derisking Project. These should be regarded as necessary market infrastructure and foundations for the energy efficiency finance market. In addition to these building blocks new business models are beginning to emerge based on Pay for Performance and metered energy efficiency. These new models, combined with the market infrastructure initiatives, are grounds for optimism that we can achieve the challenging targets for energy efficiency investment.

ACKNOWLEDGEMENT

The author would like to acknowledge the support of the European Commission Horizon 2020 programme for the Investor Confidence Project and DG Energy for support of the EEFIG Derisking Project.

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ENERGY EFFICIENT TECHNOLOGIES AND BEST PRACTICES FOR ENERGY CONSERVATION IN CEMENT INDUSTRY

Rajendra Giri, Mangalam Cement Ltd, India

Keywords: Reduction in specific energy consumption, increase in productivity, cost reduction in production, reduction in green house gas(co2), clean and healthy environment

ABSTRACT:

In order to achieve this objective it was necessitated to undertake following energy saving measures in our plant:

1. Up gradation of kiln -1 from old vintage 4 stages cyclone pyro-system to most energy efficient 6-stage pyro-system with latest energy efficient FLS :SF :Cross-Bar Clinker Cooler, Vertical Atox Coal Mill and Vertical Atox Raw Mill in place of in-efficient old Ball Mills.
2. Installation of VVVF (MV) Drive for 1250 KW HT Motor for VRPM Main Drive in Cement Mill-1.
3. Installation of DD cones in all the 4 cyclones to reduce pressure drop, along with replacement of double flap valves by rotary air locks, to reduce false air ingress in cyclones.
   start and stop of VRPM, HT Motor was frequent due to filling of cement mill surge hopper

JUSTIFICATION IN SELECTING THE ABOVE PROJECTS:

Up-gradation of Unit-I Clinkerisation section:

The old 4 stage in efficient cyclone preheater kiln, Ball Mill for Coal Mill and Ball Mill for Raw Mill were having more specific electrical power consumption up to Clinkerisation i.e. 70.18 kwh/ton of clinker and up to cement 95 kwh/ton and thermal specific energy of 860 kcal per kg of clinker.

Hence, unit-1 was upgraded with energy efficient 6 stage preheater, precalciner & efficient FLS Make : FS: Cross-Bar Cooler along with Atox VRM (Vertical Raw Mill) & Atox VCM (Vertical Coal Mill) for clinker production capacity up gradation from 1750 TPD to 3000 TPD and also reduction in SEC(Specific Electrical Energy Consumption) and Specific Thermal Energy Consumption.

1. **Installation of VVVF Drive (MV Drive) for 1250 kW HT Motor for VRPM (Vertical Roller Pressed Mill) Unit-I Cement Mill:** Installation of medium voltage variable frequency drive for 1250 KW HT Motor of VRPM Main Drive of unit-1 cement mill. The start and stop of VRPM, HT Motor was frequent due to filling of cement mill surge hopper because VRPM main drive was running at full speed. This was causing mismatch of running hours of cement Ball Mill and VRPM. In order to get continuous running of VRPM along with Ball Mill running, the speed of HT Motor was reduced with the installation of VVVF (MV) Drive. Cement Mill-2- installation of DD (De Dusting) cones in all the four Sepol Cyclones to reduce pressure drop. The conventional cyclones separation efficiency was not up to the expectation level. We have designed, fabricated and installed 4 Nos De-Dusting (DD) cones into existing cyclones of dynamic separator for better efficiency. (Sketch of DD Cyclone is attached.)

OTHER ENERGY EFFICIENCY MEASURES TAKEN BY MCL

The consistent and continual improvement of plant energy conservation measures got impetus by the following in house projects, planning, designing, fabricating, erection and commissioning:

- Replacement of chain type bucket elevator with belt type bucket elevator in kiln feed system.
- Replacement of old in-efficient air separator with high efficiency dynamic separator in Raw Ball Mill.

Unit-2, Kiln:

- Increase in TA- Duct Dia from 1.74 m to 2.5 m.
- Increase in height of calciner by 7.8 m and total length by 15.6m
- Increase in down comer duct area from 5.72 sq.m. to 9.99 sq.m for reduction in pressure drop.

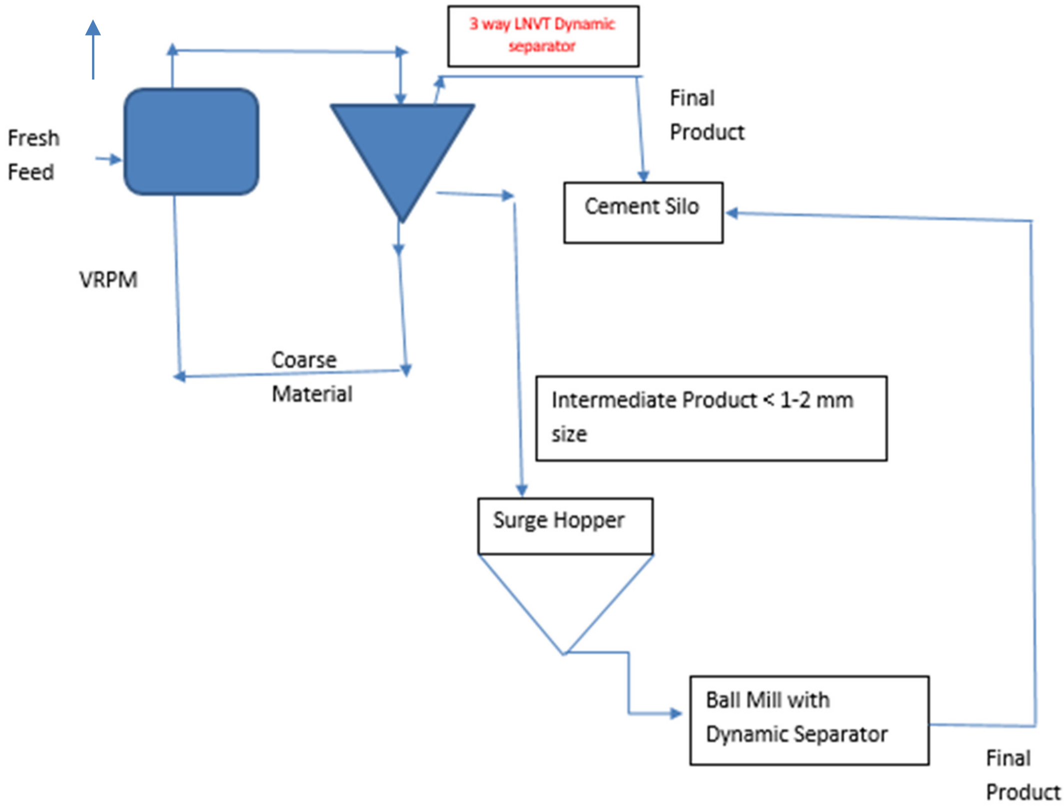

Figure 1: Up-gradation of Unit-I Clinkerisation

<u>THE TREND OF LAST 5 YEARS SPECIFIC ENERGY CONSUMPTION (SEC) DEPICTS THE CONSISTENT AND CONTINUAL IMPROVEMENT AS FOLLOWS:</u>

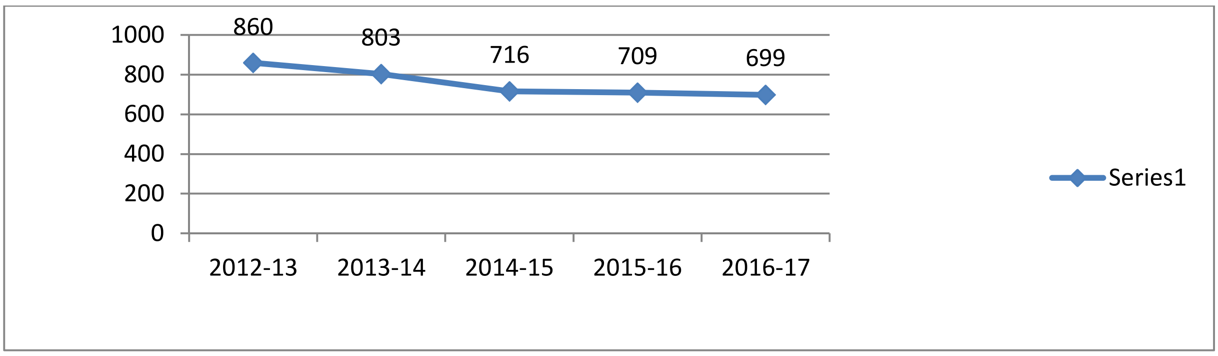

Figure 2: *Thermal specific heat consumption of clinker of Unit 1 Kiln (Kcal /Kg of Clinker)*

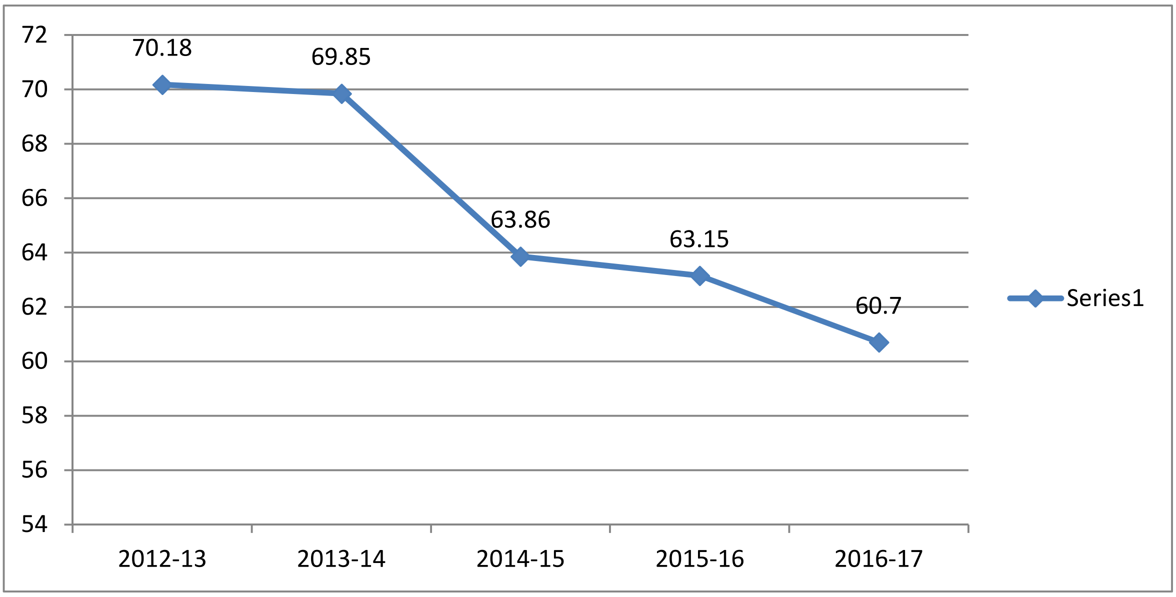

Figure 3: *Electrical specific Energy consumption up to Clinkerisation of Unit-1 Kiln (KWH /Ton of Clinker)*

INTRODUCTION OF COMPANY:

Mangalam Cement Ltd is a cement unit, belongs to renowned industrial house of B.K.Birla group of companies, located at Morak, Distt. Kota, Rajasthan, India. The company is presently producing cement in 43 grades,53 grades and Portland Pozzolona Cement (PPC) using the dry process technology and marketing under the brand name of "Birla Uttam".

The company started commercial production of cement in 1980 with an installed capacity of 4 lakh tons cement per annum. The company then took up two further expansion scheme envisaging increase in the installed capacity from 4 lakh tons to 20 lakh tons of cement per annum in between 1994 to 2005.The company have recently expanded its clinker capacity from 1750 TPD to 3000TPD of clinker by up grading its Kiln –I in the year 2013. The company have also installed a cement grinding unit of capacity of 1.25 million tons of cement in 2014 at Morak.

The present capacity of the company is 3.25Million Tons per annum

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UP GRADATION OF KILN-1:

Figure 4: 6 STAGE PREHEATER

The Kiln-I was earlier 4 stage pre-heater with ball mills for coal and raw meal grinding circuit where in specific power consumption of electrical energy as well as specific thermal energy were more. In order to reduce the specific energy, it was decided to up-grade the 4 –stage cyclone pre-heater system to 6 stage cyclone pre-heater system along with Vertical Coal Mill and Vertical Raw Mill and Energy Efficient Cross-Bar Cooler in place of old Ball Mills and in-efficient clinker cooler.

The investment and cost benefit analysis is as follows:

Sr no.	Description of items	Electrical Energy Saving per Annum in Lac Unit (kwh)	Thermal Energy Saving per Annum in Million Kcal	Total Investment (Rs.) in Lacs	Total Saving per Annum in Rs. In Lac.	Pay Back
1.	Up-gradation of 4 stage cyclone pre-heater to 6 stage cyclone pre-heater of kiln.	53.14	121069	15000	3645	4 Years (With actual production). 3 Years (With Full Capacity)
2.	Installation of energy efficient vertical coal mill.		-			
3.	Installation of Energy Efficient Vertical Raw Mill		-			
4.	Total					

Saving Calculation:

Clinker production : Before up-gradation: 1750 TPD

: After up-gradation: 3000 TPD

Annual Clinker Production Before Up-Gradation in FY: 2012-13: 569484 Ton

Annual Clinker Production After Up-Gradation in FY: 2014-15: 840755 Ton

Annual Increase in Clinker production: (840755-569484) =271271 Ton

Saving in Rupees due to increase in clinker production@Rs721 per Ton=721x271271

=Rs1955.9 Lac =Rs.1956 Lac

Thermal Specific Energy Consumption Before Up Gradation: 860 Kcal/Kg of clinker.

Thermal Specific Energy Consumption After Modification: 716 Kcal/Kg of Clinker

Reduction in thermal specific heat consumption = 144 kcal /kg of clinker

Saving in Thermal Energy in Million Kcal=144x840755/1000=121069

Equivalent Saving in Rupees due to thermal saving =Rs1318 Lac

Reduction in electrical energy consumption = (70.18-63.86) Kwhx840755= 53.14 Lac Unit

Saving due to electrical energy=Rs6.98x53.14=Rs370.89 Lac. =Rs.371 Lac

Total Saving in Rupees Per Annum= Rs.1956+Rs.1318+Rs.371=Rs.3645 Lac.

Installation of VVVF (MV) Drive in 1250 kW HT Motor of Vertical Roller Pressed Mill (VRPM) in Cement Mill -1:

Figure 5: VVVF (MV) DRIVE

Sr. No.	Description of project	Total Electrical Energy Saving in KWH	Yearly Saving in Rs. In Lac	Investment in Rs.in Lac	Pay Back
1.	Installation of VVVF(MV) Drive in VRPM 1250 KW HT Motor	6.29 Lac	44.0	90	2 .0 Years

After installation of VVFD the speed of the VRPM got reduced to 80 % which resulted in, not only reduction of power consumption of HT Motor from 961 kw to 797 kw ,but the reduced speed helped in maintaining sustainable running of cement grinding Ball Mill and enhanced out put of the Ball Mill from 110tph to 140tph.

Power consumption before mv drive= 961 kW.

Power consumption after mv drive = 797 kW.

Saving after modification =164 kW.

Saving in Electrical Energy per Annum: 164 kwx3835hrs=628781

Saving in Electrical Energy per Annum: Rs6.98x628781=Rs.43.90 Lac =Say, Rs44.0Lac (As per actual cement production in FY: 2014-15).

Additional Benefit after Optimization of Process:

The mill output increased from 110 TPH to 140 TPH.

The reduction in total power of cement grinding from 39 kWh to 32 kWh per ton.

Installation of DD Cones in Unit-2 Cement Mill:

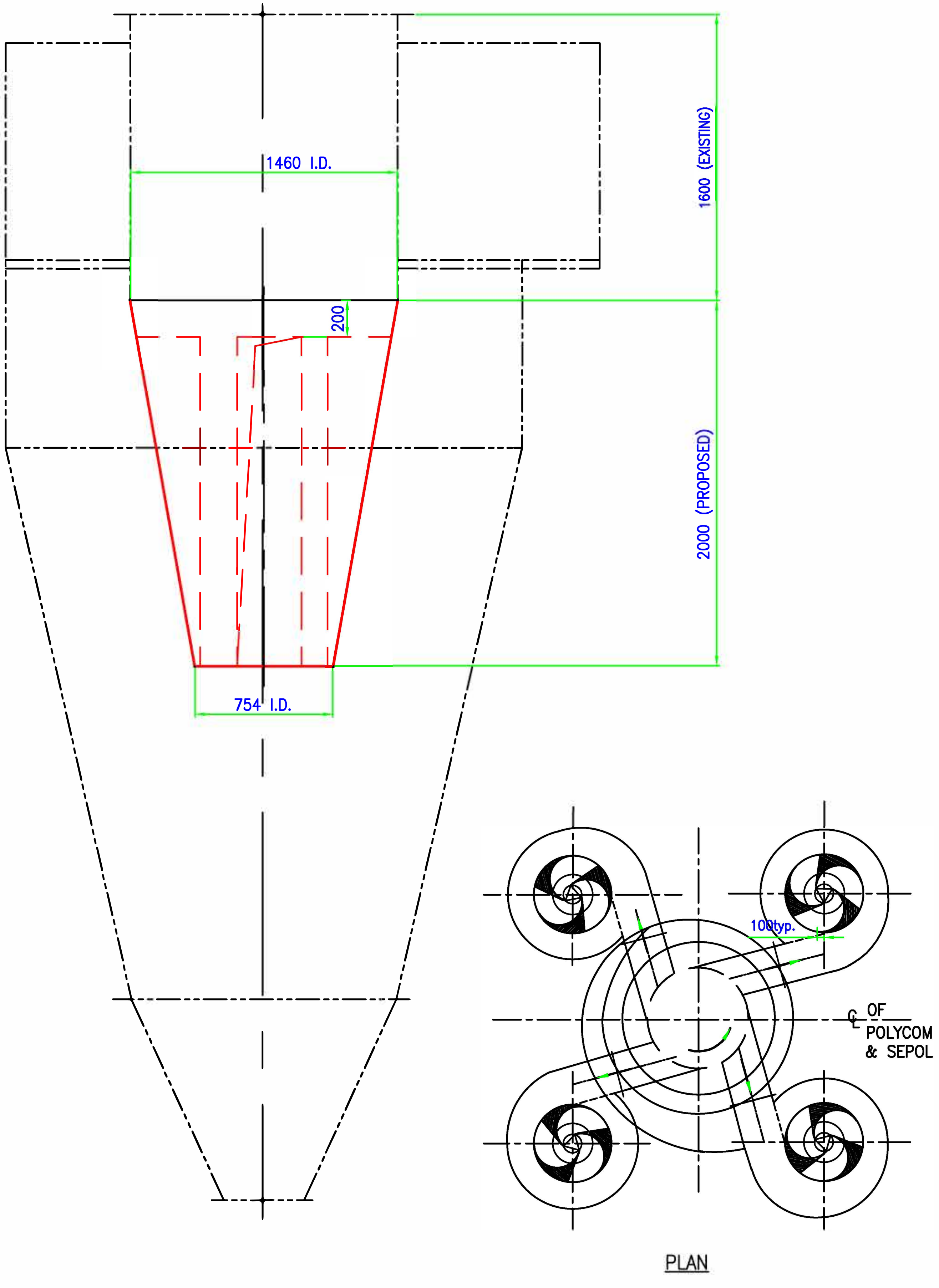
Sr. No.	Description of project	Electrical Energy consumption in kw before installation	Electrical Energy consumption in kw after installation	Electrical Energy Saving per Annum(kwh /Annum)	Saving in Rs. In Lac per Annum	Investment in Rs.in Lac	Pay Back
1.	Installation DD cones in all four Sepol Cyclones to reduce pressure drop along with replacement of double flap valve with rotary air lock to arrest leakages.	540	458	132194	9.23	7.21	9 Months

All the four cyclones of Cement Mill-2 dynamic separator were modified by inserting dedusting cones to achieve better separator efficiency. Also double flap valves below cyclones were replaced by rotary air locks to all the four minimize ingress of false air.

Additional Benefit:

Along with power saving it has also improved separation efficiency in the cyclones up to 98%, from 90-92% which has resulted in remarkable reduction in the wear of Sepol fan impeller.

HIGH EFFICIENCY SWIRL TUBE CYCLONE
(CEMENT MILL)



ENERGY EFFICIENT TECHNOLOGIES AND BEST OPERATING PRACTICES FOR IMPROVING RESOURCE EFFICIENCY IN SMALL SCALE FOUNDRY

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Keywords: Foundry, cupola, Best operating practices, Energy efficient technologies, CO2 emission

ABSTRACT

MSME are the prime movers of employment and economic growth in India. Foundries are very vital for the infrastructure development and progression of other industries. A majority of the foundries fall under MSME category. Due to global competition especially from China, the Indian foundries are facing diminishing profits. High energy intensity in foundries further reduces profit margin, forcing a few foundries out of business. Reducing energy intensity by best operating practices and energy efficient technologies will not only improve energy efficiency, enhance labour and machine productivity but also make the foundries competitive.

TERI, with support from SDC is implementing an energy efficiency program in two select foundry clusters - Howrah and Rajkot. In Howrah, the focus has been on skilling of foundry operators and implementing best operating practices in 60 foundries. This has led to energy intensity reduction by 4% equivalent to energy saving of 356 toe per year. Similarly, in Rajkot, the focus has been on promoting and implementing energy efficient technologies in 75 foundries. This has led to energy intensity reduction by 8% equivalent to energy saving of 653 toe per year. The project is under progress and TERI is providing continuous technical support to the foundry units in these two clusters. By the end of the 2017, the program will cover a total of 200 foundries. The paper attempts to showcase actual case studies from these two clusters.

INTRODUCTION

The Micro, Small and Medium Enterprises (MSME) play a vital role in the Indian economy In the manufacturing sector, MSMEs account for about 40% of the total output and about 7.5% of the total GDP of the country. The share of MSMEs in India s total exports is about 40% (MSME Annual Report 2015-16, 2016). There are more than 4500 foundries in India and about 80% of them fall under small-scale category (E Nand Gopal, 2014). The production of Indian foundry industry is estimated to be 10.77 million tonnes of casting per year (Foundry Informatics Centre, 2017) accounting for about 10.3% of total castings production of the world (50th Census of World Castings, 2016). Ferrous foundry corresponds to nearly 90% of total casting production (Foundry Informatics Centre, 2017).

Foundries are one the most energy intensive sub- sectors among MSMEs. The energy cost accounts to 15 – 20% of total production cost in small-scale ferrous foundries (TERI, 2016). The specific energy consumption (SEC), i.e. energy consumed to manufacture one tonne of good casting varies significantly from unit to unit. Also, due to global competition especially from China, the Indian foundries are facing diminishing profits. High specific energy consumptions among Indian MSME foundries further reduces profit margin, forcing a number of foundries out of business. MSME foundries in India are geographically clustered with a great deal of commonality in level of technology, operating practices and trade practices.

TERI is implementing an energy efficiency enhancement program in two foundry clusters: Howrah and Rajkot with support from the Swiss Agency for Development and Cooperation (SDC) focusing on uptake of energy efficient technologies and practices. Initiated during, December 2014 the program will continue till December 2017. This paper will focus on results achieved so far in Rajkot cluster (75 foundries) and Howrah cluster (60 foundries) along with salient features of the program.

Overview of clusters

The *Rajkot* foundry cluster has about 700 grey iron foundries in the cluster. The annual production of castings in the cluster is estimated to be 0.5 million tonnes per annum, which is about 4.7% of total

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production of the country (TERI, 2016). Majority of units use induction furnace for melting and are known for producing high quality and precision castings. *Howrah* foundry cluster is the one of the oldest foundry clusters in India. The cluster once housed over 500 foundries but at present about 320 of them is operational. The annual production of castings in the cluster is estimated to be 0.75 million tonnes per annum, which is about 7.0% of total production of the country (TERI, 2016). Howrah is famous for producing high quantities of low value castings and majority of units use cupola furnace for melting. More details are shown in table 1.

Table 1: Details of Rajkot and Howrah foundry cluster (TERI 2015)

PARTICULAR	RAJKOT CLUSTER	HOWRAH CLUSTER
Number of units	700	320
Annual production (million tonne)	0.50	0.75
Annual turnover (Rs. crore)	4,000	1,350
Major products	Pumps & valves Automotive Agricultural implements	Sanitary Railways Earth movers & mining
Type of melting furnace (based on numbers)	Cupola – 40% Induction furnace – 60%	Cupola – 85% Induction furnace – 15%
Major energy consumption	Coke – 41% Electricity – 56% Others – 03%	Coke – 85% Electricity – 12% Others – 3%
Total annual energy consumption (toe)	45,660	73,760

Production process and energy consumption

The major steps in foundry production process are mould sand and charge preparation, melting, pouring, knockout and finishing. A foundry unit uses two main forms of energy: coke and electricity. In foundries which employ induction furnaces for melting, electricity accounts for about 85 – 90% of total energy consumption, whereas in cupola-based units, coke accounts for the major share (90 – 98%) of the total energy consumption. Apart from melting, a typical MSME foundry in selected cluster has major energy consumption in mould and core preparation, sand preparation, compressed air system, cooling water system (only for induction furnace) and lighting system.

MATERIAL AND METHODS

The methodology followed to implement energy efficiency interventions in Rajkot and Howrah foundry clusters is discussed below. (Figure 1)

Selection and short-listing of units: The local industry associations in the clusters were closely involved in the process of selection of foundries. Within the cluster, a random sampling design is followed for selecting the units. Sample foundries were short-listed for initial pilot and number of units required for detailed interventions. The selection criteria included a mix of technology, product profiles, production, capacity utilization, etc. The sample size with finite population is estimated using the following formula (Kothari, 2001):

$$n = \frac{\{Z^2.N.\sigma_p{}^2\}}{\{(N-1).e^2 + Z^2.\sigma_p{}^2\}}$$

where:
n = size of the sample required for a given precision and confidence level;
N = finite population size;
Z = standardised variant at a given confidence level (1.96 for 95% and 2.57 for 99% confidence level)
e = acceptable error or the precision required (about 2–5% of mean value)
$_p$ = standard deviation of the population (estimated through pilot study or past experience)

With SEC as the variable criterion, the required sample size is estimated after conducting a pilot study with an error of 2% and confidence level of 95%, as given in table 2.

Table 2: Details of sample size estimation

POPULATION SIZE	ESTIMATION OF SEC (TOE/TONNE) THROUGH PILOT			REQUIRED SAMPLE SIZE
	Mean	e (2%)	$_p$	
Rajkot – 700	0.129	0.0026	0.01373	95
Howrah – 320	0.141	0.0028	0.0151	81

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Energy audits and diagnostic studies: TERI conducted detailed energy audits in short-listed foundries to identify energy saving measures which included (1) best operating practices (BOP) involving low or no investments, (2) retrofits of equipment to enhance energy efficiency involving medium level investments, and (3) replacement of inefficient systems with energy efficient systems which involve high investments. The detailed study was conducted using sophisticated portable instruments (table 3).

Table 3: Portable instruments used

INSTRUMENT	PARAMETER	APPLICATION
Power analyser	• Electrical parameters • Harmonics analysis	• Induction furnace • Air compressor • Pumps & Motors
Ultrasonic flow meter	• Water velocity • Volume	• Pumping system
Hygrometer	• Ambient conditions	• Temperature • Humidity
Thermal imager	• Surface temperature	• Furnace • Core shooter
Anemometer	• Air velocity	• Air compressor • Blower
Lux meter	• Lux level	• Work space

Sharing of results with foundries: A comprehensive report for each unit was prepared, where the study was carried-out, has provided information and data such as specific features of identified solutions, energy savings, cost benefits and investment needs.

Technical backup support for implementation: Lack of technical capacities was one of the major barriers for energy efficiency and TERI extended technical backup support to these foundries in adopting energy saving measures in order to realise savings. TERI supported in finalization of technical specifications, identification of vendors and project implementation. It further demonstrated various BOP measures identified in the units and extended training to workers and supervisors in the adoption process. The cost for implementation of the energy saving measures was borne by individual foundry units.

Documentation of benefits: TERI made efforts in documenting the actual energy saving measures implemented by the foundries that helped in evaluating energy savings and monetary savings. It is envisaged that the documentation of benefits would motivate more foundry units to adopt energy saving measures on their own.

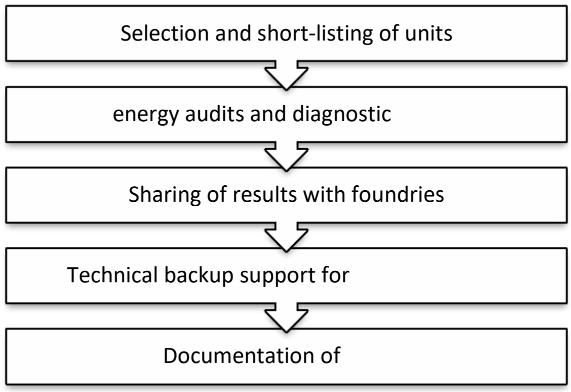

Figure 1: Methodology adopted

Based on statistical sampling the study has been planned in 95 foundries in Rajkot and 80 foundries in Howrah. As of March 2017, the methodology was adopted and implemented in 75 foundries in Rajkot cluster and 60 foundries in Howrah cluster.

RESULTS AND DISCUSSIONS

A good mix of foundries were selected for the study such as cast iron, ductile iron and steel castings. The baseline of the foundries was first established to understand their present level of energy intensity. The variation in SEC was high (figure 2).

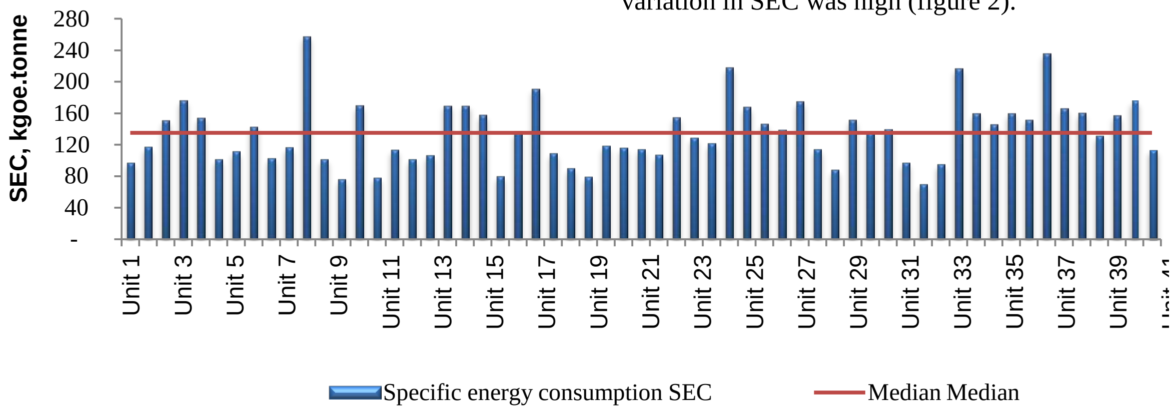

Figure 2: Variation in specific energy consumption (a sample of select units)

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In the two foundry clusters a total of 1677 energy saving measures has been identified in the 135 units, of which 27% were replacements/revamps, 25% were retrofits and remaining 48% were related to operating practices (figure 3).

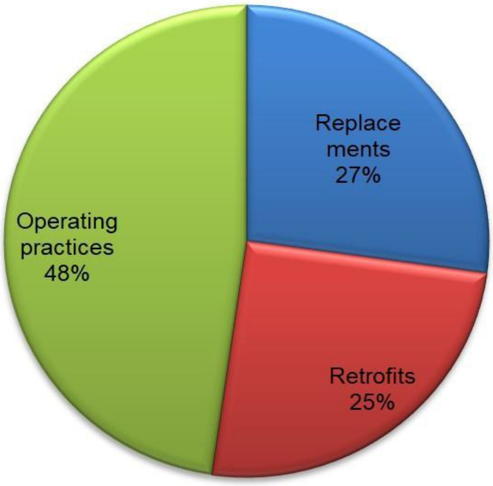

Figure 3: Types of energy saving measures

A significant number of energy saving potentials is being identified in both the target clusters. The energy saving measures which are being adopted by the foundries are categorised as replacements, retrofits and best operating practices (BOP). A few key energy saving measures are listed in table 4.

Table 4: Key energy saving measures

REPLACEMENTS
• Melting furnace: Cupola or Induction furnace • Pumps and cooling tower • Air compressors • Sand mixer or mullers • Heat treatment furnace
RETROFITS
• Lid mechanism for induction furnace • Inverter or sequence controller for air compressor • Insulation improvement in cupola furnace • Waste heat recovery in heat treatment furnace • Cogged V-belt for coupling with drive
OPERATING PRACTICES
• Melting process optimization • Optimization of compressed air utilization • Analysis of rejection levels • Monitoring of slag quality in cupola • Optimization of cupola blower pressure

This following section presents selected implemented case-studies on energy efficiency improvement in the two clusters.

Case study – 1: Replacement

Adoption of energy efficient induction furnace

An induction route foundry unit manufacturing about 850 tonne per year of castings had an annual electricity bill of around Rs 126 lakhs. A performance study of the foundry was conducted by TERI. The foundry was equipped with a SCR type induction furnace of 450 kW power rating with a 500 kg crucible. The specific energy consumption (SEC) of induction furnace was found to be 743 kWh per tonne, which is much higher than achievable SEC for induction furnace of similar capacity (Prosanto Pal, 2017).

On TERI s recommendation, the unit went for replacement of the induction furnace with an energy efficient (EE) induction furnace of IGBT type. The investment in a new furnace led to a saving of about Rs 16.7 lakh per year for the foundry and the payback was just over 2.1 years (table 5).

Table 5: Adoption of energy efficient induction furnace

PARAMETER	BASE CASE	POST IMPLEMENTATION
Type of furnace	SCR	IGBT
SEC, kWh/t	743	569
Annual melting, t	1,315	1,315
Energy cost, Rs lakh/year	71.23	54.55
Monetary saving, Rs lakh	-	16.68
Investment, Rs lakh	-	35.75
Payback, years	-	2.1

Case study – 2: Replacement

Adoption of energy efficient sand mixer

A foundry producing 600 tonne of castings per year had an energy bill of about Rs. 56 lakh. The plant has installed a sand mixer of 250 kg capacity with a mixer motor of 11 kW and blender motor of 3.7 kW to meet its sand demand. The cycle time of the sand mixer varies according to operator in range of nine to twelve minutes. The mixer was run based on operator judgement rather than monitoring the required parameters. Average power consumption during operation was 10.7 kW.

On TERI s recommendation, the foundry replaced the convemtional sand mixer with energy efficient automatic type sand mixer. The new sand mixer is equipped with 15 kW mixer motor and 7.5 kW blender motor. It was also fitted with a 0.75 kW

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motor for skip charging of the sand, thus avoiding delay caused by manual process. The mixer has a timer circuit which is set for 2.5 minutes. The average power consumption during operation has been measured to be 12.3 kW. The investment in a new automatic type energy efficient sand mixer led to a saving of about Rs 1.26 lakh per year for the foundry and the simple payback was about 3.4 years (table 6).

Table 6: Adoption of energy efficient sand mixer

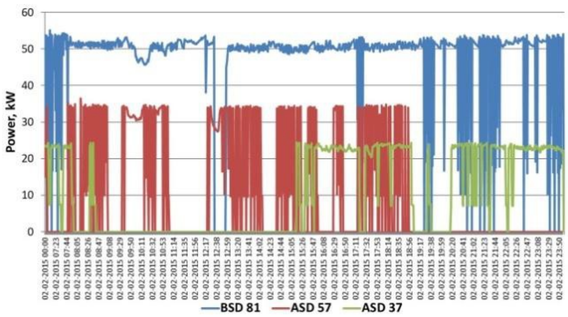
PARAMETER	BASE CASE	POST IMPLEMENTATION
Capacity, kg	250	250
Average power consumption, kW	10.7	12.3
Batch duration, min	10.0	2.5
Energy cost, Rs lakh/year	1.77	0.51
Monetary saving, Rs lakh	-	1.26
Investment, Rs lakh	-	4.30
Payback, years	-	3.4

Case study – 3: Retrofit

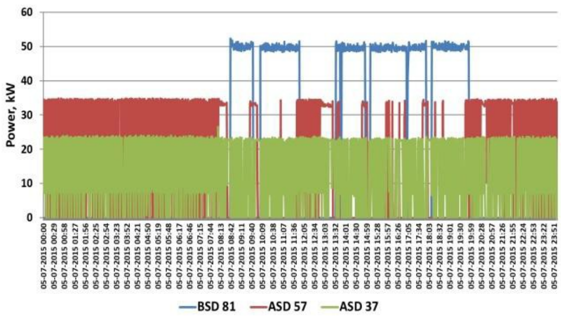
Sequence controller for compressed air system

An induction furnace based foundry was equipped with three air compressors, which run simultaneously. The three air compressors, BSD81, ASD57 and ASD37 were of Keaser make. The daily power consumption of the compressed air system was measured 1,029 kWh. All the three compressors were running ON-OFF at ad-hoc basis. The overall demand of foundry was highly variable and the specific power consumption of the compressed air system was high.

On TERI s recommendation, the unit retrofitted the three compressors with a sequence controller. A closed loop feedback system was formed using a power transducer installed at the air receiver. Post implementation the daily energy consumption came down from 1,029 kWh to 775 kWh (figure 4). The investment in sequence controller led to a saving of about Rs 4.1 lakh per year for the foundry and the payback was about 0.5 years.



Base case: 1029 kWh/day



Post implementation: 775 kWh/day

Figure 4: Sequence controller for air compressor

Case study – 4: Retrofit

Adoption of lid mechanism for induction furnace

A foundry producing 1860 tonne of castings per year had an energy bill of about Rs. 167 lakh. The plant has installed a 450 kW rated induction furnace. The SEC of the induction furnace was estimated to be 659 kWh per tonne of melting. There was no lid cover on furnace crucible, thus leading to radiation and convection losses.

On TERI s recommendation, the foundry installed a hydraulically operated lid mechanism for induction furnace to avoid opening losses. This led to a saving of Rs 1.1 lakh per year for the foundry with a simple payback of 1.9 years (table 7).

Table 7: Adoption of lid mechanism for induction furnace

PARAMETER	BASE CASE	POST IMPLEMENTATION
Furnace rating, kW	450	450
Radiation loss, kWh	30.8	23.9
SEC, kWh/t	659	652
Monetary saving, Rs lakh	-	1.06
Investment, Rs lakh	-	2.0
Payback, years	-	1.9

Best operating practices

Based on actual experience the implementation of various best operating practices (BOPs) yield energy savings in the range of 3 – 5%. The BOPs are typically charectarised with low or negligible investments. Under the program, TERI has been covering both cupola and induction furnace-based foundries for BOP studies. A few examples of BOP implementations are depicted in table 8. The table describes some of the inefficient operating practices related to the melting furnace and other areas in foundry that were being followed by units, along with the relevant BOPs recommended to improve energy efficiency.

Table 8: Current operating practices related to melting, and BOPs recommended

PARTICULAR	CURRENT PRACTICE	BEST PRACTICE
Dharani hawa (initial ignition air) and ash blowing in cupola	Blower is used during bed preparation for *dharani hawa* and ash blowing in cupola. The blower is kept „ON for almost 30 minutes. This reduces the bed preparation time, but leads to burning of around 25–30 kg bed coke.	Bed coke should be prepared using natural draft air only. The blower should be used only for ash blowing, and only for around 45 seconds, after full ignition of bed coke.
Monitoring slag quality	The slag is thick and blackish in color, indicating high oxidation. The test result indicates iron oxide content in order of 12 – 16%, which is very high. 	The slag should be easy flowing and bottle-green in color, with iron oxide less than 8%. High oxidation could be due to one or more of these factors: thin rusty scrap, hard blowing, uneven charge distribution, high percentage of steel, or bridging. 
Control of blast air	The blast air from wind box is fed to cupola by eight tuyeres (top and bottom four each). There is no control arrangement in tuyeres such as butterfly valve and peep-hole, leading to improper air distribution.	It is desirable to have 55% of blast air in bottom tuyeres and 45% in top. This may be achieved by retrofitting tuyeres with butterfly valve.
Sizing limestone	Limestone (which plays a vital role in de-slagging the molten metal) is used in varying size. Most of the limestone is very large in size. 	The limestone should be of 15–20 mm size. 

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Bed coke charging	Bed is prepared by igniting bed coke in two installments. Once first installment is ignited, the remaining portion of bed coke is charged, poking is done for consolidation and bed height is measured.	The bed coke should be charged in four equal installments. Addition of installment should be done once previous installment is ignited and flame starts becoming visible (bluish color) from charging door.

CONCLUSION

The program is being executed in Rajkot and Howrah foundry clusters. The overall achievement of the program as of March 2017 in 135 foundry units is summarised in table 9. Based on the results achieved by implementation in the foundries so far, the total energy savings observed is 1,009 tonnes of oil equivalent (toe).

Table 9: Summary of program achievements

PARAMETER	RAJKOT	HOWRAH
Number of units covered	75	60
Number of energy saving measures	685	982
Total energy saving, toe/year	653	356
Monetary saving, Rs lakh/year	514	175
Investment, Rs lakh	487	73
Payback, months	11	5

The project support provided by TERI is being well accepted by foundry units in both Howrah and Rajkot clusters. The energy and monetary savings achieved by foundries with technical backup support from TERI are quite significant. Under the existing program TERI aims to improve energy efficiency of at least 200 foundries in the two clusters by end of 2017.

Based on the TERIs experience, it is envisaged that the successful adoption of these energy saving measures by various foundries would further motivate other foundries in these clusters to adopt energy efficient technologies and best operation practices, thereby enhancing resource efficiency of the units and their sustainability in day to day operations.

ACKNOWLEDGEMENT

This study was conducted as part of project “Scaling- up Energy Efficiency in Small Enterprises” being undertaken by TERI with the support of the Swiss Agency for Development and Cooperation (SDC).

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ENERGY EFFICIENT DOWNDRAFT KILN FOR SMALL-SCALE REFRACTORY INDUSTRIES

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Keywords: Refractory, Downdraft (DD) kiln, coal, CO2 emission

ABSTRACT

The small-scale refractory industries in India are geographically clustered. These units have a great deal of commonality in the level of technology, operating practices and even the trade practices followed by the entrepreneurs. Refractory manufacturing is an energy intensive sector. The technologies employed are obsolete and inefficient. There is a lack of research and development for new technologies in these industries. TERI conducted a preliminary study of a few operating kilns in two adjacent refractory clusters in Chirkunda and Asansol areas through structured discussion with stakeholders as well as local industrial associations. There are about 350 units in the two clusters and majority (>95%) use traditional downdraft (DD) kilns. DD kilns are generally characterized by low energy efficiency and poor control over product quality. Apart from poor kiln designs, the units lack skilled firemen/operators that would help them in improving firing practices.

With this background, TERI is reviewing feasibility of energy efficient DD kiln in Chirkunda refractory cluster. The paper presents performance observed in walk through study related to energy balance of existing kiln, feasibility of waste heat recovery from flue gases and estimated cost benefit and GHG reduction potential on adoption of “Best Operating Practices” (BOP).

INTRODUCTION

MSMEs in India are geographically clustered with a great deal of commonality in level of technology, operating practices and trade practices. Indian MSME sectors suffer from low energy and resource efficiency and poor waste management.

Among MSME sectors, refractory manufacturing is an energy intensive sub-sector. Energy cost accounts to 30–35% of total production cost in small-scale refractory industry (TERI, 2016a). The specific energy consumption levels of refractory units are quite high due to requirement of substantially high temperatures in the kilns. The performance of refractory industries is linked closely with steel industry very closely, as it accounts for over 2/3rd of total consumption (IRMA Databank, 2015). Indian steel industry consumes on average about 12 kg of refractory per tonne of steel produced against 7 kg in the developed countries (Steel Insights, September 2014). Other major consumers of refractories include cement, glass, ceramics industries. A number of challenges are faced by the refractory industry, issues related to raw material, energy and recycling are a few to name. The improvement in quality of refractory is bridging this gap. As refractories are highly energy-intensive industries, improvement in energy efficiency can largely contribute to the decreasing revenues of this industrial sub-sector.

TERI conducted a walk-through study of a few representative refractory units in two adjacent refractory clusters namely Chirkunda (Jharkhand) and Asansol (West Bengal) through collection of data and structured discussion with stakeholders as well as local industrial associations. There are a total of 350 units in the two clusters and majority (>95%) use traditional downdraught kilns. Downdraught kilns are generally characterized by low energy efficiency and poor control over product quality. Some of the key issues identified during the study include poor design of kilns and lack of skilled firemen/operators which requires focus for improving the performance of refractory units.

Overview of clusters

Chirkunda refractory cluster is the one of the important industrial clusters in Jharkhand state and is a notified area in Dhanbad district. There are about 129 refractory industries in the cluster of which about 120 units use down draft (DD) kilns and tunnel kilns in 9 units (as shared during discussion with local entrepreneurs). The type of refractory products produced in the cluster include refractory blocks and bricks, graphite stopper head, insulation bricks, ladle, refractory mortar, ramming mass, roof bricks, silminite bricks, suspended roof bricks, monolithic,

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burner quarl, bottom pouring, silica brick, etc. The average production capacities of kilns also vary widely – 100 tonne per month (tpm) for DD kilns whereas 600 tpd for tunnel kilns. The cluster is estimated to produce about 103,000 tonne per year (tpy) of different refractory products (TERI, 2016).

Asansol refractory cluster is the one of the important industrial clusters in West Bengal state. There are about 206 refractory industries in the cluster of which about 200 units use down draft (DD) kilns, 5 units have tunnel kilns and only one has chamber kiln. The average production capacity of DD kilns is about 100 tpm. The estimated production of different refractories in the cluster is about 120,600 tonne per year (tpy), which is around 42% of the installed capacity (TERI, 2016).

Production process

The production process in the clusters uses a wide range of raw material to produce different customized shape, size and unshaped refractory mass. Refractory production process primarily consists of die/mould preparation, crushing, grinding, mixing, shaping (pressing/casting) of products, drying and firing. A typical production process followed in these clusters is shown in figure 1. (TERI, 2016)

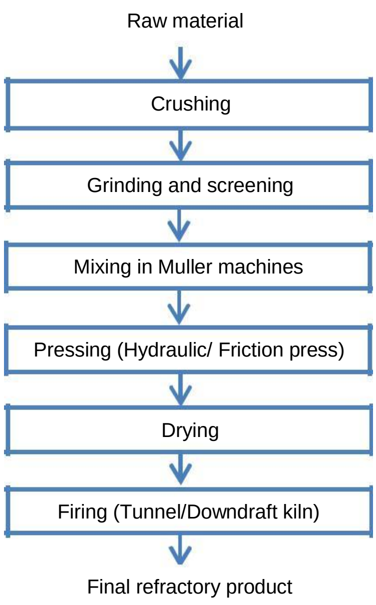

Figure 1: Process flow chart

The refractory units procure basic raw materials such as plastic clay and other ingredients as lumps or powder which are generally tested in laboratories to match customer requirements. Jaw crushers are used to reduce the size of lumps before they are sent for grinding. Grinding is a batch process for reducing the size of batch materials. It ensures homogeneity of the material being processed. Ball mills are used for grinding process. Mixing of raw materials is done in a muller machine. The product is shaped using dies, which are normally outsourced and kept ready in stock for use the production. The green products are stacked inside sheds to allow slow and uniform drying in DD kiln based units.

The dried products are manually loaded in the kilns for further firing. Tunnel kilns are equipped with dryers which utilize waste heat available in flue gases for removal of moisture from moulded products. Firing involves sintering or densification process in which refractories are thermally consolidated into a dense, cohesive body of fine and uniform grains. Generally, the firing temperature inside the kiln is 1150–1200°C; a few special products may require a temperature of more than 1400°C (TERI, 2016).

Firing is the most energy intensive process step in refractory production process, accounting for about 98% of total energy consumption (TERI, 2016).

Downdraft kiln technology

DD kilns are batch type systems, wherein loading and unloading of refractory products and firing is carried out manually (figure 2). Coal is the fuel used in downdraft kilns.

Figure 2: Downdraft kiln

There are a number of technical issues with the DD kiln adopted in these clusters, major ones are:

- Design specification of kiln, lining material and flue gas path layout are improper
- The fuel, coal is not uniformly sized, with irregular loading pattern as well as quantity
- Layout of existing coal grates and their capacities are unscientific thereby allowing less residence time for flame/ flue to remain inside the kiln which drastically affects the heat transfer
- Dampers for furnace draft control are provisional arrangement without proper maneuvering lever in place, leading to negative draft

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- Measurements of furnace temperature are not being done; a few units use pyrometers for measuring furnace temperatures
- There is no control of combustion air passing through coal grate which is always kept open. This makes it difficult to control (increase/ reduce) the airflow as required during kiln firing
- Carry-over of flameto chimney base was observed indicating high flue velocity and low residence time resulting in higher coal consumption
- High surface temperature at loading/unloading area, which needs suitable insulation with movable fixture for repeated use

DD kilns of two to three different sizes are used in each unit (internal diameter 16–26 feet) to cater to varying production volumes. The dimensions of a flue path in DD kiln (size and length) depend on individual site layout and chimney location, which are generally observed to be unscientific. The batch duration depends upon kiln size, quantity of refractory stacked, product mix in the stack (solid, hollow or mix of solid and hollow) and type of material under firing. The total cycle that includes stacking of green refractory, firing, cooling and unloading is about 20 days.

Rationale behind the study

There is no reported study pertaining to Chirkunda and Asansol refractory clusters. A walk-through survey undertaken by TERI in 2016 and discussions with industry stakeholders in both clusters showed that more than 95% of refractory units use DD kilns; only a handful of units use energy efficient tunnel kiln technology. Similar to DD kilns in other refractory clusters, the kilns in Chirkunda and Asansol cluster also exhibit low level of energy efficiencies and poor control over product quality. These factors have attributed to poor kiln designs as well as improper operating practices.

The paper presents performance and energy balance of existing DD kiln and potential energy saving options along with cost benefit and GHG reduction potential.

MATERIAL AND METHODS

The study was carried out with a number of field visits using semi-structured interviews and questionnaires conducted in 2016-17. The detailed methodology followed for cluster study is as follows:

- Meetings and discussions with key stakeholders such as MSME-Development Institute (DI), District Industry Centre (DIC) and industry associations to understand about cluster details such as number of units, products manufactured, market, technology use, etc.
- Field visit to representative industry units to cover various technologies/ processes and collect data pertaining to production, process followed, energy consumption, energy conservation measures adopted, etc.
- Discussions with local service providers (LSPs) to understand the level of skill availability.
- Analysis of cluster level data such as capacity utilisation, energy costs, energy consumption at unit level and cluster level.
- Assessment of energy conservation measures based on technology use vis-à-vis best available technology.

The data collated was technically verified, multiple discussions with entrepreneurs and technology suppliers were conducted. Based on these interactions and TERI's experience in the field of MSME sector, the potential energy saving options was identified.

RESULTS AND DISCUSSIONS

The methodology was adopted and detailed survey was conducted in six units in the two refractory clusters. The specific energy consumption (SEC) of the DD kilns varied between 0.292 to 0.227 tonnes of oil equivalent (toe) per tonne of product, according to the size of the kiln and operating practices adopted. The correlation between size of kiln and its SEC is shown in figure 3.

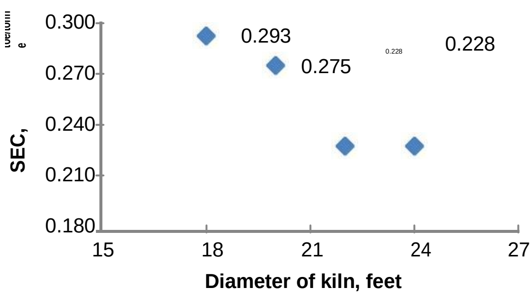

Figure 3: Downdraft kiln

The performance of a kiln can be evaluated using its thermal efficiency, which is the ratio of heat delivered to a material and heat supplied to the kiln. Data collation was done with respect to fuel consumption, material output, excess air quantity, temperature of flue gas and surface temperature to estimate the thermal efficiency of the kiln.

Based on data collated, interactions with progressive entrepreneurs and studies in similar clusters (TERI

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2013 and TERI 2000), a typical heat balance of DD kiln was established. It revealed that the thermal efficiency of the kiln was as low as 5%. The low energy efficiency level may be attributed to major energy losses in the kiln: losses in hot flue gases, structural losses (opening & surfaces), heat absorbed by structure of the kiln and cooling air losses. The typical heat balance of the DD kilns is presented in figure 4.

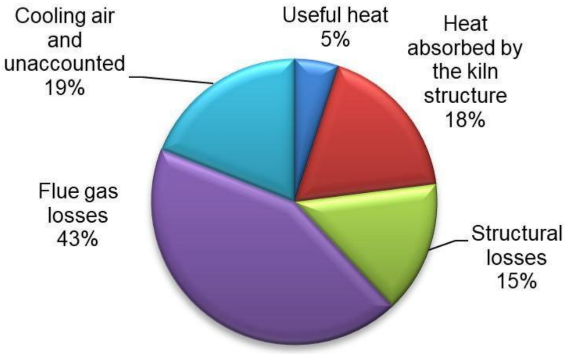

Figure 4: Heat balance of typical DD kiln

The study revealed that there is significant scope of energy saving potential by adopting energy efficient technologies, retrofits and or improving operating practices. A few of energy saving options identified are summaried in table 1. The types of issues in different refractory units were observed to be similar and hence the energy saving measures are suitable for both the clusters.

Table 1: Energy saving options

LOSSES	RECOMMENDATION	LEVEL
Flue gas losses	• Tunnel kiln • Coal gasification • Waste heat recovery	• Technology change • Technology change • Retrofit
Cooling air losses	• Preheating of green refractory	• Layout modification
Structural losses	• Improved refractory and insulation • Improvement in damper system	• Retrofit • Retrofit

Technology Change *(High investment option)*

A number of energy saving options for technological change are applicable which include (1) adoption of tunnel kiln technology and (2) use of coal gasification technology.

(1) *Adoption of tunnel kiln*: The SEC of tunnel kilns is estimated to be 865 kcal per kg as against 2750 kcal per kg in DD kilns (*data collated from the two clusters*). By switching over from traditional DD to tunnel kilns while keeping the same product volume, the potential reduction in SEC is estimated to be 60 – 70%. Other advantages with adoption of tunnel kilns include automation in kin operation, better monitoring & control, higher yield and enhanced production volumes. Typical energy saving and cost benefit for switch over to tunnel kiln is shown in table 2. (TERI 2000)

Table 2: Tunnel kiln cost benefit

PARTICULAR	UNIT	VALUE
SEC of DD Kiln	kCal/kg	2750
SEC of tunnel Kiln	kCal/kg	865
Typical production	tonne/year	850
Annual coal saving	tonne/year	247
Monetary saving	Rs lakh/year	22.2
Typical investment	Rs lakh	100
Simply payback	Years	4.5

(2) *Coal gasification*: With the existing type of firing of coal in DD kilns, significant heat is lost due to improper mixing of coal with combustion air leading to formation of unburnt coal and carbon monoxide which affects the thermal efficiency of the system. Coal gasification is one of the potential technology for the refractory kilns units for efficient coal utilisation. Coal gasification is the process of producing syngas, which is a mixture of hydrogen (H_2), methane (CH_4), carbon dioxide (CO_2) and other constituents. The syngas can be effectively utilized in DD kilns for firing of refractory and close control of kiln temperatures can be achieved thus leading to higher thermal efficiencies.

Layout modification *(High investment option)*

The DD kilns used in MSMEs are not scientifically designed. The higher length of chimney leads to a high negative draft in the furnace. The damper arrangements are not suitable for draft control. These constraints lead to high flue gas losses. There is no waste heat recovery system in place. The flue gases can be routed in such a way that it is directed from current source kiln to an adjacent kiln, which is loaded with green refractory and is next in line for firing. The sensible heat in the hot flue gases will help in preheating of green refractory thus ensuring waste heat recovery. The flue gas will lead out to atmosphere from chimney of the second kiln. This option would lead to substantial fuel saving in kiln firing. The layout modification proposed to achieve this is shown in figure 5. Typical energy saving and cost benefit is shown in table 3 (TERI 2016).

Table 3: Layout modification cost benefit

PARTICULAR	UNIT	VALUE
SEC of DD Kiln	kCal/kg	2750
SEC after modification	kCal/kg	1850
Typical production	tonne/year	850
Annual coal saving	tonne/year	118
Monetary saving	Rs lakh/year	10.6
Typical investment	Rs lakh	10.0
Simply payback	Months	11

Retrofit *(Medium investment option)*

Insulating refractory: Traditionally, the linings of DD kilns are made mainly with low-grade refractory bricks. The thickness of refractory inside walls is high, leading to increased heat absorbed by the structure. It is recommended to use insulating refractory to reduce structural heat losses. Ceramic fibre blankets can be added between bricks of bottom layer, side wall and the crown to further help reduce heat losses. Typical energy saving and cost benefit is shown in table 4 (TERI 2016).

Table 4: Insulation improvement cost benefit

PARTICULAR	UNIT	VALUE
Loss due to poor insulation	%	15
Saving potential	%	5
Annual coal saving	tonne/year	20
Monetary saving	Rs lakh/year	1.8
Typical investment	Rs lakh	1.5
Simply payback	Months	10

Damper system: The DD kilns use locally precast circular ceramic material as damper system which is of crude design. These dampers do not have appropriate fixtures for manouveing of kiln draft. Existing damper control leads to high negative draft and very high heat losses in flue gases. It is suggested to use ceramic board based damper system along with mechanical arrangement to enable movement of damper plate to increase or decrease the draft as per kiln requirements. This would further improve ease of work for firemen.

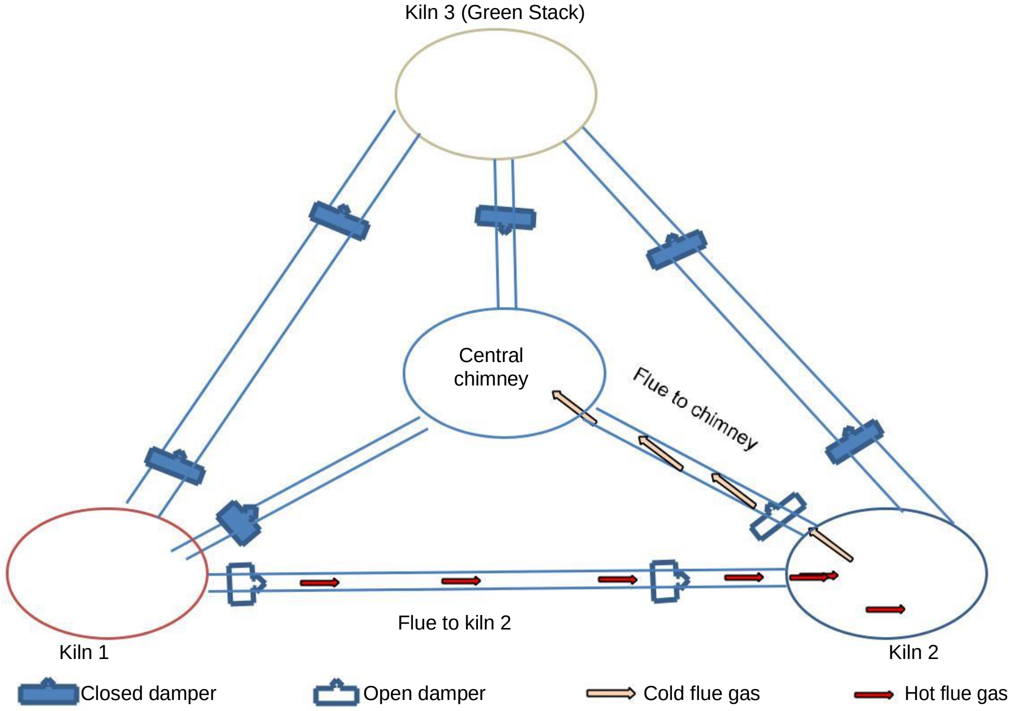

Figure 5: Schematic layout of integrated DD kilns with central chimney

Operating practices *(Low or no investment option)*

Fuel sizing Coal is the primary energy source in DD kilns. It was observed that (1) large quantity of coal is fed into the kiln without monitoring the furnace temperature during the batch and (2) coal lumps of varying sizes are fed into the kiln. These lead to drastic variation in air-fuel ratio, which is most often insufficient for proper combustion, resulting in thick black smoke from chimney (figure 6). The refractory units must (1) use coal of about ¾ to 1 inch size before feeding and (2) maintain appropriate fuel feeding frequency based on requirements of the kiln to ensure complete combustion of fuel i.e. coal and avoid formation of black smoke from chimney.

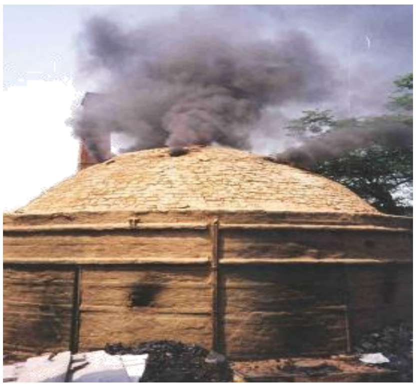

Figure 6: Smoke due to improper fuel sizing

Temperature indicators: A majority of the refractory units in the cluster do not use temperature indicators for monitoring and controlling of furnace temperatures. At present, furnace temperature and fuel firing is done mainly through human judgement and skill level of firemen. This can lead to substantial variations in furnace temperatures vis-à-vis actual requirements for different products. This would result in (1) over-firing resulting in higher fuel consumption and potential damage to products, and (2) under-firing leading to sub-standard product quality. The refractory units may install on-line temperature sensors in three locations at crown level.

Typical energy saving by implementing operating practices vary between 3 – 5 %.

ESCO financing mechanism

A DD kiln unit is faced with a number of barriers for adopting EE technologies with financing being major one. Energy Service Company (ESCO) is one of the options that would cater to the the financing needs of EE projects in refractory units. An ESCO offers EE technologies/services to a manufacturing unit with guaranteed energy and monetary savings through a mutually agreed measurements and verification (M&V) protocol. An ESCO typically can be either a technology manufacturer/supplier or consultancy/service oriented firm. By availing the services of ESCO, the refractory units can implement high investment energy saving options.

CONCLUSION

The present level of technologies adopted and operating practices followed in Chirkunda and Asansol refractory clusters are low leading to poor efficiency levels. The energy performance of small-scale refractory industries in these clusters can be enhanced with options such as layout modifications of downdraft kilns and energy efficient tunnel technology, etc. along with adoption of best operating practices. The cluster-level energy saving potential in Chirkunda and Asansol is significant. The existing DD kilns in the cluster have two options for improving energy efficiency: Option-1 To adopt modifications in the layout and best practices, which would involve low-to-medium investments, Option-2 Switchover to tunnel kiln technology involving high investments as shown in table 5.

Table 5: Cluster level energy saving potential (toe/year)

PARTICULAR	CHIRKUNDA	ASANSOL
OPTION-1		
Modification in layout	7,740	7,580
Best operating practices	950	930
OPTION-2		
Switch to tunnel kiln	14,760	14,540

The overall performance improvement of both clusters would require a long-term holistic approach that would enable sustainable adoption of technologies and best practices in these small-scale refractory clusters.

ACKNOWLEDGEMENT

This study was conducted as part of project "Scaling-up Energy Efficiency in Small Enterprises" being undertaken by TERI with the support of the Swiss Agency for Development and Cooperation (SDC).

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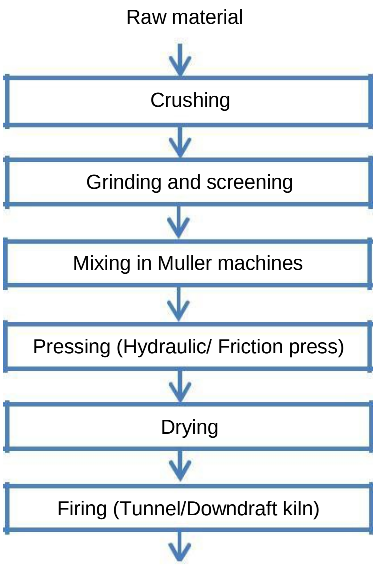

Figure 1: Process flow chart

The refractory units procure basic raw materials such as plastic clay and other ingredients as lumps or powder which are generally tested in laboratories to match customer requirements. Jaw crushers are used to reduce the size of lumps before they are sent for grinding. Grinding is a batch process for reducing the size of batch materials. It ensures homogeneity of the material being processed. Ball mills are used for grinding process. Mixing of raw materials is done in a muller machine. The product is shaped using dies, which are normally outsourced and kept ready in stock for use the production. The green products are stacked inside sheds to allow slow and uniform drying in DD kiln based units.

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Downdraft kiln technology

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There are a number of technical issues with the DD kiln adopted in these clusters, major ones are:

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- Layout of existing coal grates and their capacities are unscientific thereby allowing less residence time for flame/ flue to remain inside the kiln which drastically affects the heat transfer
- Dampers for furnace draft control are provisional arrangement without proper maneuvering lever in place, leading to negative draft
- Measurements of furnace temperature are not

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SUSTAINABLE ENERGY EFFICIENCY THROUGH DIGITALIZATION

Amal Apurv Jaiswal, Siemens Ltd., India

Keywords: Digitalization, Data Analytics, Sustainability, Intelligent Infrastructure

ABSTRACT

Digitalization and Automation plays a key role when it comes to improving the energy efficiency of buildings. As the world moves towards smart cities and the Internet of Things (IoT); digitalization and automation is vital in energy data analytics and energy conservation.

Buildings generate huge volumes of structured and unstructured data which if collected analyzed and interpreted correctly, will provide important insights into how those buildings are performing. Using advanced data collection and analytics, buildings can be made more efficient and sustainable, facilitating reinvestment into profit generating activities.

One such advanced digital/automation technology by Siemens is Demand Flow™. Siemens Industry Inc., has developed a patented and proven chiller plant optimization technology that offers 20% to 50% energy savings with rapid investment payback while reducing long term maintenance costs and extending the life of the plant equipment. Demand Flow™ combines many improvement measures used in the past but achieves savings with a new, balanced, holistic approach that provides a dramatic effect on the energy consumption of the entire chilled water system. Combined with the cloud based energy monitoring and data analytics systems - Navigator™, this solution is the perfect example of energy savings and sustainability through digitalization and automation.

Demand Flow™ and Navigator™ are great examples of sustainability through Digitalization. Advanced algorithms in Demand Flow™ enables each energy consuming component in a chiller plant to run precisely at the right frequency; and remote monitoring and expert data analytics via Navigator™ further enhance the performance and sustainability of buildings.

BACKGROUND OF THE INVENTION

Field of Invention

The invention relates generally to chilled water comfort cooling and industrial process cooling systems and in particular to methods and apparatus for efficiently operating chilled water cooling systems.

Related Art

Many commercial and other buildings and campuses are cooled by chilled water plants. In general, these chilled water plants produce chilled water which is pumped to air handlers to cool building air. Chillers, air handlers, and other components of a chilled water plant are designed to operate at a specific chilled water entering and leaving temperature, or Delta T. At design Delta T, these components are at their most efficient and can produce cooling output at their rated capacity. Low Delta T, which occurs when the entering and leaving temperature become closer than the design Delta T, reduces efficiency and cooling capacity of the chilled water plant and causes the chilled water plant to use more energy than required for a given demand.

Chilled water plants are designed to meet a maximum possible cooling demand of a building, campus, or the like, also known as the design condition. At the design condition, chilled water plant components are at the upper end of their capacity, where the system is most energy efficient. However, it is rare that such a high demand for cooling is necessary. In fact, almost all chilled water plants operate below design conditions for 90% of the year. For example, cool weather conditions can cause cooling demand to drop considerably. As cooling demand is reduced, Delta T is often also reduced. This means that for the majority of the time, almost all chilled water plants are operating at low Delta T and less than optimal efficiency. This chronic low Delta T, is referred to as Low Delta T Syndrome.

Many mitigation strategies have been developed to address Low Delta T Syndrome, such as through the use of sophisticated sequencing programs and equipment ON/OFF selection algorithms, but none have proven to completely resolve this phenomenon. In most instances, the chilled water plant operator simply pumps more water to system air handlers to increase their output, but this has the compounding effect of further reducing the already low Delta T. Also, increased pumping in the secondary loop results in higher than necessary pumping energy usage.

From the discussion that follows, it will become apparent that the solution under discussion addresses the deficiencies associated with the prior art and additionally improves system performance and sustainability through advanced automation and complex algorithms.

DETAILED DESCRIPTION OF THE INVENTION (ALGORITHM)

In the following description, numerous specific details are set forth in order to provide a more thorough description of the present invention. It will be apparent, however, to one skilled in the art, that the present invention may be practiced without these specific details. In other instances, well-known features have not been described in detail so as not to obscure the invention.

Demand Flow, as described herein, refers to methods and apparatus to reduce or eliminate Low Delta T Syndrome and to improve chilled water plant efficiency. Demand Flow may be implemented in retrofit projects for existing chilled water plants as well as new installations or designs of chilled water plants. As used herein, chilled water plant refers to cooling systems utilizing chilled water to provide comfort cooling or chilled water for some process need. Such chilled water plants are typically, but not always, used to cool campuses, industrial complexes, commercial buildings, and the like.

In general and as will be described further below, Demand Flow utilizes variable flow or pumping of chilled water within a chilled water plant to address Low Delta T Syndrome and to substantially increase the efficiency of a chilled water plant. Variable flow under Demand Flow maintains a Delta T for chilled water plant components which is at or near the design Delta T for the components. As a result, Demand Flow substantially increases the operating efficiency of chilled water plants and components thereof resulting in substantial savings in energy costs. The increased efficiency provided by Demand Flow also provides the benefit of reduced pollution. Furthermore, Demand Flow also increases the life expectancy of chilled water plant components by operating these components near or at their specified entering and leaving chilled water temperatures, or design Delta T, unlike traditional variable or other pumping techniques.

Demand Flow provides increased efficiency regardless of cooling demand or load by operating chilled water plant components in a synchronous fashion. In one or more embodiments, this occurs by controlling chilled water and condenser water pumping at one or more pumps to maintain a Delta T at particular components or points of a chilled water plant. In general, Demand Flow operates on individual condenser or water pumps to maintain a Delta T across a particular component or point of a chilled water plant. For example, primary chilled water pumps may be operated to maintain a Delta T across a chiller, secondary chilled water pumps may be operated to maintain a Delta T across plant air handlers, and condenser water pumps may be operated to maintain a Delta T across a condenser.

The control of individual pumps (and flow rate) in this manner results in synchronized operation of a chilled water plant. This synchronized operation balances flow rates in the chilled water plant, which significantly reduces or eliminates Low Delta T Syndrome and related inefficiencies.

In traditional chilled water plants variable flow is controlled according to a minimum pressure differential, or Delta P, at some location(s) in the chilled water plant or system. Demand Flow is distinct from these techniques in its focus on Delta T, rather than Delta P. With Demand Flow, an optimal Delta T can be maintained at all chilled water plant components regardless of load conditions (i.e. demand for cooling). The maintenance of a constant or steady Delta T allows for wide variances in chilled water flow, resulting in energy savings not only in pumping energy but also in chiller energy consumption. For example, the Delta T of a chiller may be maintained, via control of flow rate through chilled water or condenser water pumps, near or at the chiller's design parameters regardless of load conditions to maximize the efficiency of the evaporator and condenser heat exchanger tube bundles of the chiller.

In contrast, traditional variable flow schemes vary the flow within much narrower ranges, and thus are incapable of achieving the cost and energy savings of Demand Flow. This is because traditional flow control schemes control flow rate to produce a particular pressure difference, or Delta P, rather than Delta T. In addition, traditional variable flow schemes seek only to maintain Delta P only at some predetermined system location, ignoring low Delta T. This results in flow rates which are much higher than required to generate and distribute the desired amount of cooling output, in large part, to compensate for inefficiencies caused by low Delta T.

Because flow rates are controlled by Demand Flow to maintain a Delta T and not to maintain Delta P or a particular cooling output at plant air handlers, there may be situations where the flow rate is too low to produce the desired amount of cooling output in certain areas based on system diversity. To address this, Demand Flow includes a feature referred to herein as a critical zone reset which allows the Delta T maintained by Demand Flow to be reset to another, typically lower, value based on a specific need of the system that is not being fully met at the required flow rate of the system. This can be due to inadequate piping, incorrectly sized air handlers for the load being served, or any number of unforeseen system anomalies. As will be described further below, this allows additional cooling to be provided by maintaining a new or reset Delta T generally by increasing chilled water flow. The application of Demand Flow has a synergistic effect on air handlers as well as chillers, pumps, and other components of a chilled water plant. This results in reduced net energy usage while maintaining or even increasing the rated capacity for the chilled water plant. As will be described further below, under Demand Flow, little or no excess energy is used to provide a given level of cooling.

Preferably, the Delta T maintained by Demand Flow will be near or at a chilled water plant component's design Delta T to maximize the component's efficiency. Advantages of maintaining Delta T may be seen through a cooling capacity equation, such as

$$\text{TON} = (\text{GPM} * \Delta T * K) \qquad (1)$$

As this equation shows, as Delta T is lowered, so is cooling capacity.

Advantages of maintaining Delta T can be seen from the following example. For a constant value of 24 for K, 1000 Tons of capacity may be generated by providing a 1500 GPM flow rate at a 16 degree design Delta T. 500 Tons of capacity may be generated by providing 750 GPM at 16 degrees Delta T. However, at a low Delta T such as commonly found in traditional systems, a higher flow rate would be required. For example, at an 8 degree Delta T, 500 tons of capacity would require a 1500 GPM flow rate. If Delta T is lowered further, such as to 4 degrees, cooling capacity would be 250 Tons at 1500 GPM. Where chilled water plant pumps, or other components, may only be capable of a maximum 1500 GPM flow rate, the chilled water plant would not be able to meet the desired demand of 500 Tons, even though, at design Delta T, the chilled water plant is capable of 1000 Tons capacity at 1500 GPM.

Low Delta T syndrome

Low Delta T Syndrome will now be described with regard to FIG. 1 which illustrates an exemplary decoupled chilled water plant. As shown, the chilled water plant comprises a primary loop **104** and a secondary loop **108**. Each loop **104**,**108** may have its own entering and leaving water temperature, or Delta T. It is noted that Demand Flow also benefits direct/primary chilled water plants (i.e. non-decoupled chilled water plants) as well, as will be described further below.

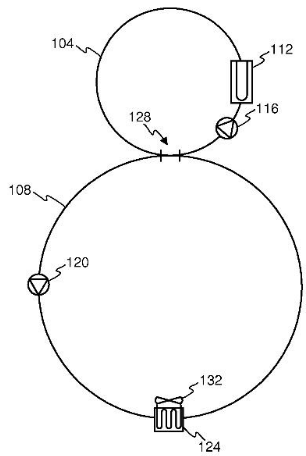

Figure 1

During operation of a decoupled chilled water plant, chilled water is produced in a production or primary loop **104** by one or more chillers **112**. This chilled water may be circulated in the primary loop **104** by one or more primary chilled water pumps **116**. Chilled water from the primary loop **104** may then be distributed to a building (or other structure) by a distribution or secondary loop **108** in fluid communication with the primary loop **104**. Within the secondary loop **108**, chilled water may be

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circulated by one or more secondary chilled water pumps **120** to one or more air handlers **124**. The air handlers **124** allow heat from the building's air to be transferred to the chilled water, such as through one or more heat exchangers. This provides cooled air to the building. Typically, building air is forced or blown through a heat exchanger if air handlers 124 to better cool a volume of air. The chilled water leaves the air handlers **124** returning to the secondary loop **108** at a higher temperature due to the heat the chilled water have absorbed via the air handlers.

The chilled water then leaves the secondary loop **108** and returns to the primary loop **104** at the higher temperature. As can be seen, both the primary loop **104** and secondary loop **108** (as well as the chilled water plant components attached to these loops) have an entering water temperature and a leaving water temperature, or Delta T. In an ideal situation, the entering and leaving temperatures for both loops would be at their respective design Delta Ts. Unfortunately, in practice, the chilled water loops operate at chronic low Delta T.

Low Delta T occurs for a variety of reasons. In some cases, low Delta T occurs because of an imperfect design of the chilled water plant. This is relatively common due to the complexity of chilled water plants and difficulty in achieving a perfect design. To illustrate, air handlers **124** of the secondary loop **108** may not have been properly selected and thus chilled water does not absorb as much heat as expected. In this case, the chilled water from the secondary loop **108** enters the primary loop **104** at a cooler temperature than expected resulting in low Delta T. It is noted that, due to imperfect design and/or operation, a chilled water plant may be operating at low Delta T under various loads, including design condition loads.

Low Delta T also occurs as cooling output is lowered to meet a load that is less than the design condition. As output is lowered, chilled water flow, chilled water Delta T, and other factors become unpredictable often resulting in low Delta T. In fact, in practice, it has been seen that traditional Delta P flow control schemes invariably result in low Delta T at some, if not all, chilled water plant components.

For example, to reduce cooling output from design conditions, one or more chilled water valves of the chilled water plant's air handlers **124** may be closed (partially or completely). This reduces chilled water flow through the air handlers **124** and thus less cool air is provided. However, now that the chilled water valves are partially closed, the chilled water absorbs less heat from the air as it flows through the air handlers **124** at a higher rate than necessary as evidenced by the lower than design Delta T. Thus, the chilled water leaving the air handlers **124** is not as “warm” as it once was. As a result, the chilled water leaving the secondary loop **108** for the primary loop **104** is cooler than desired causing low Delta T in both loops.

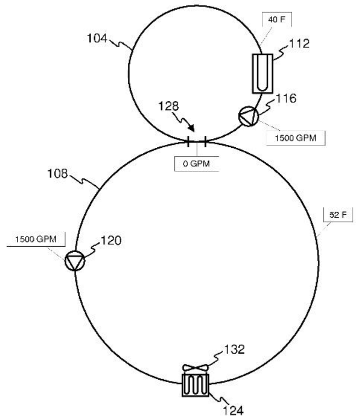

Figure 2

To illustrate with a specific example, an exemplary chilled water plant is provided in FIG. 2. In the example, the chilled water produced in the primary loop **104** is 40 degrees. As can be seen, chilled water leaving the air handlers **124** may be at 52 degrees instead of an expected 56 degrees because the chilled water valves have been closed and the flow rate of the chilled water is too high for the present load. Because there is no excess distribution flow in the bypass **128**, the leaving chilled water temperature of the secondary loop is still 40 degrees. Assuming the system has a 16 degree design Delta T, there is now a low Delta T of 12 degrees which is 4 degrees lower than the design Delta T. It is noted here that the low Delta T itself reduces capacity and causes excess energy to be used to provide a given cooling output. As can be seen by the capacity equation,

$$\text{TON} = (\text{GPM}^*\Delta\text{T}^*\text{K}) \qquad (2)$$

To compensate, a higher flow rate or GPM would be required leading to excess use of pumping energy for the given cooling demand.

Referring back to FIG. 1, another cause of low Delta T is bypass mixing caused by excess flow within the primary loop **104**, the secondary loop **108**, or both. Bypass mixing and excess flow are known causes of low Delta T and have traditionally been extremely difficult to address, especially with Delta P flow control schemes. In fact, one common cause of excess flow is over pumping of chilled water by inefficient Delta P control schemes (as shown by the above example). For this reason, flow imbalances and bypass mixing are commonplace in chilled water plants utilizing Delta P flow control schemes. It is noted that bypass mixing can even occur at design condition because, as with any complex machinery, chilled water plants are rarely perfect. In fact, chilled water plants often are designed with primary chilled water pump flow rates which do not match secondary pump flow rates.

In decoupled chilled water plants, a decoupler or bypass **128** connecting the primary loop **104** and secondary loop **108** is provided to handle flow imbalances between the loops. This typically occurs as a result of excess flow or excess pumping in one of the loops. The bypass **128** accepts the excess flow from one loop generally by allowing it to circulate to the other loop. It is noted that excess flow is not limited to any particular loop and that there may be excess flow in all loops in addition to a flow imbalance between them.

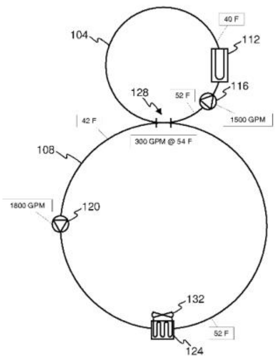

Figure 3

Excess flow generally indicates too much energy is being expended on pumping chilled water, as will be described later via the Affinity Laws, and also exacerbates the problems of low Delta T. To illustrate using FIG. 3, which illustrates an exemplary chilled water plant having excess flow, chilled water from the air handlers **124** and secondary loop **108** mixes with supply water from the primary loop **108** in the bypass **128** when there is excess primary or distribution chilled water flow. The resultant mix of these two water streams yield warmer than design chilled water which is then distributed to the air handlers **124**.

In many cases, these measures (e.g. increased chilled water pumping, opening of air handler water valves, increased air supply air movement) do not fully compensate for the artificial reduction in cooling capacity caused by low Delta T. Thus, the chilled water plant is simply unable to meet the demand for cooling even though this level of demand may be below its rated chilling capacity. In situations where such measures are able to compensate for the artificial reduction in capacity, such as by starting additional chillers, the chilled water plant is utilizing substantially more energy than necessary to provide the desired cooling output with much of the excess energy being expended on compensating for the effects of low Delta T.

It will be understood that low Delta T also occurs in direct-primary chilled water plant configurations (i.e. non-decoupled chilled water plants), even though such configurations generally do not have the problem of mixing building return water with production supply water. Direct-primary systems invariably have a plant or system bypass, 3-way valves, or both in order to maintain minimum flow through the system. For example, FIG. 4 illustrates an exemplary direct-primary chilled water plant having such a bypass. Similar to a decoupled chilled water plant, excess flow can occur in these bypasses or 3-way valves. Thus, the problems of low Delta T, such as excess chiller energy, excess pumping energy, and reduced system capacity are also present in direct-primary configurations. In fact, the problems of low Delta T are the same regardless of the plant configuration. This has been shown in practice by the fact that Low Delta T Syndrome occurs in both types of chilled water plants.

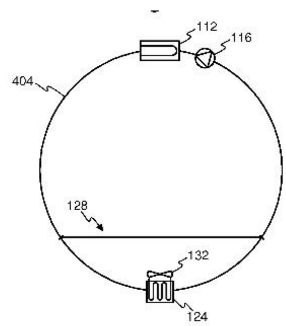

Figure 4

The effect of low Delta T with regard to chillers will now be further described. FIG. 5 illustrates an exemplary chiller **112**. For illustrative purposes, the dashed line of FIG. 5 delineates which components are part of the exemplary chiller **112** and which are not, with components within the dashed line being part of the chiller. Of course, it will be understood that a chiller may include additional components or fewer components than shown.

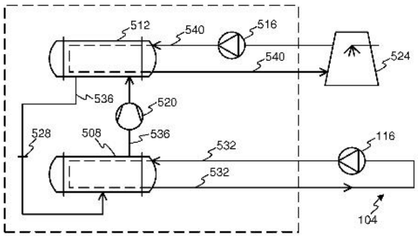

Figure 5

As can be seen, the chiller **112** comprises a condenser **508**, a compressor **520** and an evaporator **512** connected by one or more refrigerant lines **536**. The evaporator **512** may be connected to a primary or other loop of a chilled water plant by one or more chilled water lines **532**.

In operation, chilled water may enter the evaporator **512** where it transfers heat to a refrigerant. This evaporates the refrigerant causing the refrigerant to become refrigerant vapor. The heat transfer from the chilled water cools the water allowing the water to return to the primary loop through the chilled water lines **532**. To illustrate, 54 degree chilled water may be cooled to 42 degrees by transferring heat to 40 degree refrigerant within an evaporator **512**. The 42 degree chilled water may then be used to cool a building or other structures, as described above.

In order for the refrigeration cycle to continue, refrigerant vapor produced by the evaporator **512** is condensed back into liquid form. This condensation of refrigerant vapor may be performed by the condenser **512**. As is known, the refrigerant vapor can only condense on a lower temperature surface. Because refrigerant has a relatively low boiling point, refrigerant vapor has a relatively low temperature. For this reason, a compressor **520** may be used to compress the refrigerant vapor, raising the vapor's temperature and pressure

The increased temperature of the refrigerant vapor allows the vapor to condense at a higher temperature. For example, without compression the refrigerant vapor may be at 60 degrees, whereas with compression the vapor may be at 97 degrees. Thus, condensation may occur below 97 degrees rather than below 60 degrees. This is highly beneficial because it is generally easier to provide a condensing surface having a temperature lower than the increased temperature of the refrigerant vapor.

The refrigerant vapor enters the condenser **508** where its heat may be transferred to a condensing medium, causing the refrigerant to return to a liquid state. For example, the condenser **508** may comprise a shell and tube design where the condensing medium flows through the condenser's tubes. In this manner, refrigerant vapor may condense on the tubes within the condenser's shell. As discussed herein the condensing medium is condenser water, though it will be understood that other fluids or mediums may be used. After condensing, the refrigerant then returns through a refrigerant line **536** and pressure reducer **528** back to the evaporator **508** where the refrigeration cycle continues.

The condenser **508** may be connected to a cooling tower **524** or other cooling device by one or more condenser water lines **540**. Because the condenser water absorbs heat from the refrigerant vapor, the condenser water must be cooled to keep its temperature low enough to condense the refrigerant vapor. The condenser water may be circulated between the condenser **508** and cooling tower **524** by one or more condenser water pumps **516**. This provides a supply of cooled condenser water which allows continuous condensation of refrigerant vapor. It is noted that though a cooling tower **524** is used to cool the water in the embodiment of FIG. 4, other supplies of condenser water may be used.

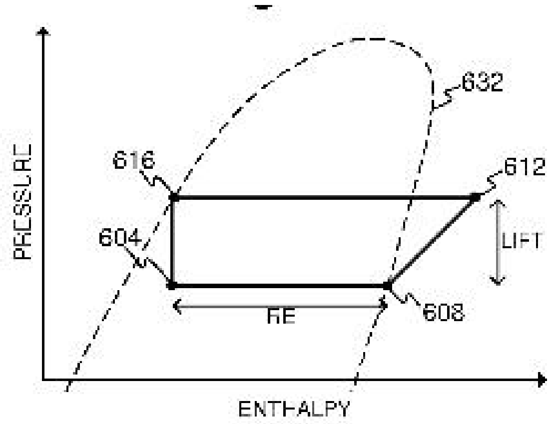

Figure 6

Operation of a chiller may also be shown through a pressure-enthalpy graph such as shown in FIG. 6A. In the graph, pressure is represented on the vertical axis while enthalpy is on the horizontal axis. At point **604**, the refrigerant may be in a heavily saturated or principally liquid state in an evaporator. As the refrigerant absorbs heat from chilled water in the evaporator, its enthalpy increases turning the refrigerant into refrigerant vapor at point **608**. The portion of the graph between point **604** and point **608** represents the refrigeration effect of the chiller. During this time, the absorption of heat from the chilled water by the refrigerant cools the chilled water.

A compressor may then be used to increase the temperature and pressure of the refrigerant vapor from point **608** to point **612**. This is known as "lift." This lift allows the refrigerant vapor to condense in the condenser, such as described above. Between point **612** and point **616**, the refrigerant vapor transfers heat to condenser water and condenses in the condenser, turning the vapor into liquid once again. The refrigerant then passes through a pressure reducer between point **616** and point **604**, which reduces both the temperature and pressure of the liquid refrigerant such that it may be used in the evaporator and continue the refrigeration cycle.

Problems associated with low Delta T in the condenser often result in chiller failure due to lack of minimum lift at partial load conditions. When the pressure differential between the condenser and evaporator drops too low a condition known to the industry as "stacking" occurs. This is a condition where the refrigerant builds up in the condenser, dropping evaporator saturated pressure and temperature to critical points. Refrigerant also has a high affinity for oil and stacking will therefore trap a good portion of the oil charge in the condenser causing the chiller to shut down on any number of low pressure, low evaporator temperature, or low oil pressure problems.

Because most traditional condenser water pumping systems operate at constant volume cooling towers are at full flow conditions as well. As the load on the cooling tower decreases the operating range remains relatively constant, reducing the efficiency of the tower. Conversely in variable flow condenser water systems the operating range decreases with the flow. This allows for lower condenser water entering temperatures and the associated reduction in chiller energy and cooling tower fan energy described further below in this narrative.

Low Delta T also results in very inefficient condenser water pump efficiency (KW/Ton) and limits the amount of refrigerant sub-cooling available to the chiller through seasonably low condenser water entering temperatures. At a given load, for every degree condenser water entering temperature is reduced, compressor energy is reduced by about 1.5% and nominal tonnage of the chiller is increased by about 1%. Thus, as will be described further below, operating the chillers at the lowest possible condenser water entering temperature is highly desirable.

In addition, low Delta T at the evaporator reduces the refrigeration effect of the refrigeration cycle, this reduces the temperature of refrigerant vapor produced by the evaporator.

DEMAND FLOW™

In general, Demand Flow comprises systems and methods for addressing Low Delta T Syndrome while increasing chilled water plant and system efficiency. As demonstrated above, traditional chilled water system control schemes lead directly to energy and capacity inefficiencies evidenced by Low Delta T Syndrome, high KW/Ton, and reduced air side capacity. The above description, also demonstrates that there is a direct conflict between most traditional control schemes and optimizing system energy and deliverable capacity. This is most clearly evidenced by pressure differential, or Delta P, chilled water pumping control schemes, which ignore increased energy usage and reduced system capacities. Traditionally designed Delta P based pumping schemes inevitably yield a system that performs with Low Delta T Syndrome as the system load varies.

In a perfect world, the chilled water Delta T would be the same in the primary, secondary, and any tertiary or other loops of a chilled water plant. Operating chilled water plant components at their selected or design Delta T always produces the most deliverable capacity and highest system efficiencies. Thus, in a perfect world, chilled water Delta T would match design Delta T. To generate this ideal situation, chilled water plant component selection, design, installation and pumping control algorithms must be perfect. Unfortunately, this perfection is extraordinarily rare or never achieved in practice, and disparities in design, load, and installation of chilled water plants are ever-present.

Unlike traditional control schemes, a core principle of Demand Flow is to operate as close to design Delta T as possible with emphasis given to meeting cooling demand, as will be described below with regard to critical zone resets. This allows a chilled water plant to operate at a high efficiency, regardless of cooling load. This is in contrast to traditional control schemes, where operating at partial or even design loads utilizes substantially more energy than

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necessary because of Low Delta T Syndrome which plagues these traditional systems.

In addition, because pumps are controlled to maintain a Delta T as close to or at design Delta T, the chilled water plant utilizes energy efficiently regardless of the load on the plant. When compared to traditional control schemes, energy usage is substantially lower under Demand Flow as can be seen from the following chart. Values indicated on the chart have been taken from actual measurements of an operational Demand Flow implementation.

CWE Temperature	**61.00**	**64.97**	**67.20**	**75.00**	**78.00**	**80.00**	**83.00**
CWL Temperature	**75.00**	**79.59**	**81.20**	**89.00**	**92.00**	**94.00**	**97.00**
Chilled Water Pump KW	46	54	65	49	55	59	48
Condenser Water Pump KW	26	27	31	27	28	29	29
Chiller KW	1027	1217	1321	1423	1555	1605	1571
Tower Fan KW	228	198	118	57	33	23	18
Total Plant KW	1327	1496	1535	1556	1671	1696	1666
System Tons	2130	2364	2409	2193	2353	2356	2201
System KW/Ton	0.623	0.633	0.640	0.680	0.710	0.720	0.757
Chiller KW/Ton	0.482	0.515	0.549	0.649	0.661	0.681	0.714
CWP KW/Ton	0.012	0.011	0.013	0.012	0.012	0.012	0.013
CHWP KW/Ton	0.022	0.023	0.027	0.022	0.023	0.025	0.022
CT Fan KW/Ton	0.107	0.084	0.049	0.026	0.014	0.010	0.008
System KW/Ton	0.623	0.633	0.637	0.710	0.710	0.729	0.757
Online Chiller Capacity %	59%	70%	75%	81%	87%	91%	93%
Online Chiller Capacity Tons	3641	3401	3232	2724	2705	2603	2367
Increased System Efficiency	18%	16%	16%	6%	6%	4%	0%
Increased Chiller Efficiency	32%	28%	23%	9%	7%	5%	0%
Increased Chiller Capacity	54%	44%	37%	15%	14%	10%	0%

Table 1

To illustrate, TABLE 1 is a chart of an actual Demand Flow application that shows the energy reductions achievable by reducing the condenser water entering temperature. FIG. 8 is a pressure-enthalpy diagram comparing constant volume condenser water pumping **804** and Delta P chilled water pumping schemes to Demand Flow pumping **808**. As can be seen, lift is reduced while the refrigeration effect is increased by sub-cooling **812** and refrigerant superheat **816** as compared to traditional constant volume pumping **804**.

Demand Flow has a measurable, sustainable, and reproducible effect on chilled water plants because it is grounded in sound scientific fundamental principals that, as such, are both measurable and predictable. The gains in efficiency and deliverable capacity resulting from applying Demand Flow will be described as follows.

A fundamental premise of pumping energy efficiency with variable flow chilled water plants known as the Affinity Laws consist of the following laws:

Law 1: Flow is proportional to shaft rotational speed, as shown by the equation

$$Q1*Q2 = N1*N2 \qquad (3)$$

Law 2: Pressure or head is proportional to the square of shaft speed, as shown by the equation

$$H1*H2 = (N1*N2)*2 \qquad (4)$$

Law 3: Power is proportional to the cube of shaft speed, as shown by the equation

$$P1*P2 = (N1*N2)*3 \qquad (5)$$

The Affinity Laws state that chilled water pressure drop (also referred to as TDH or as H in the above) is related to change of flow rate squared, while energy utilization is related to change of flow rate cubed. Therefore, in Demand Flow, as flow rate is reduced, cooling capacity or output is reduced proportionally but the energy utilization is reduced exponentially.

Demand Flow seeks to keep flow rate for a given cooling output on the Delta T line **904**. This results in substantial efficiency gains (i.e. energy savings) while meeting demand for cooling. In contrast, the flow rate determined by traditional control schemes is higher, often substantially, than that provided by the Delta T line **904**. This has been shown in practice and is often recorded in the operational logs of traditional chilled water plants. FIG. 7 illustrates an exemplary logged point **908** showing the flow rate as determined by traditional control schemes, and a Demand Flow point **912**. The Demand Flow point **912** represents the flow rate for a given cooling output under Demand Flow principles.

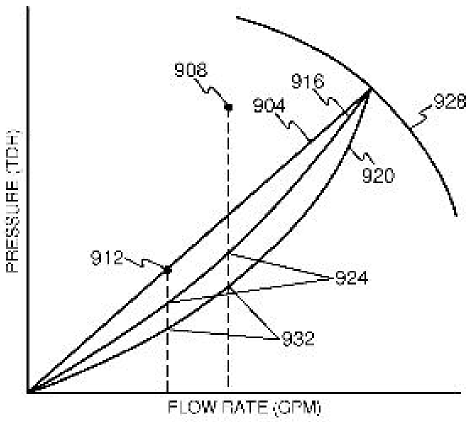

Figure 7

With Demand Flow, flow rate is adjusted along the Delta T line **904**, linear to load, which means that the chilled water plant, and components thereof, operate at or near design Delta T. In this manner, low Delta T is eliminated or significantly reduced by Demand Flow. Thus, the desired demand for cooling may be met at a lower flow rate and cooling output as compared to traditional control schemes. This is due in large part because the chilled water plant does not have to compensate for the inefficiencies of low Delta T.

The energy curve **920** as shown represents energy usage on its vertical axis and shaft speed (which as stated has been shown to be linearly proportional to flow rate) on its horizontal axis. Under the Affinity Laws, the energy curve **920** is a cube function. Thus, it can be seen that as flow rate is reduced, energy usage is reduced exponentially, even more so than TDH. Stated another way, energy usage increases exponentially according to a cube function as flow rate increases. For this reason, it is highly desirable to operate system pumps such that the minimum flow rate necessary to achieve a particular cooling output is provided.

It can be seen that a substantial amount of energy savings occurs when operating a chilled water plant with Demand Flow. FIG. 7 highlights the differences in energy usage between the Demand Flow point **912**, and the logged point **908**. As can be seen by the energy curve **920**, at the cooling output indicated by these points, excess energy usage **932** between the logged point **908** and the Demand Flow point **912** is substantial. Again, this is because of the exponential increase to energy usage as flow rate increases.

FIG. 7 also highlights the differences in TDH between the Demand Flow point **912** and the logged point **908**. As can be seen, the logged point **908** once again has a substantially higher TDH than is necessary to meet current cooling demand. In contrast, at the Demand Flow point **912**, TDH is much lower. As can be seen by the pumping curve **916**, excess TDH **924** between the logged point **908** and the Demand Flow point **912** is substantial. Thus, substantially less work is expended by chilled water plant pumps under Demand Flow as compared to traditional control schemes. This is beneficial in that less strain is placed on the pumps extending their service life.

OPERATIONAL STRATEGY – DEMAND FLOW™

The operational strategy may be embodied and/or implemented by one or more control devices or components of a chilled water plant. FIG. 8 illustrates an exemplary controller which may be used to implement the operational strategy. In one or more embodiments, the controller may accept input data or information, perform one or more operations on the input according to the operational strategy, and provide a corresponding output.

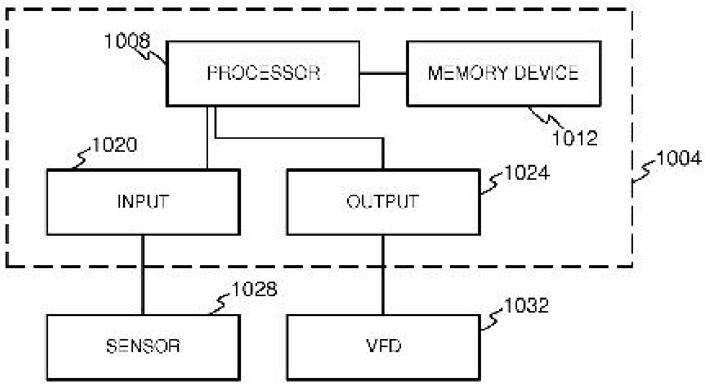

Figure 8

The controller **1004** may comprise a processor **1004**, one or more inputs **1020**, and one or more outputs **1024**. The input **1020** may be used to receive data or information from one or more sensors **1028**. For example, information about chilled water, condenser water, refrigerant, or operating characteristics of chilled water plant components detected by one or more sensors **1028** may be received via an input **1020**.

The processor **1004** may then perform one or more operations on the information received via the one or more inputs **1020**. In one or more embodiments, the processor may execute one or more instructions stored on a memory device **1012** to perform these operations. The instructions may also be hard wired into the processor **1004** such as in the case of an ASIC or FPGA. It is noted that the memory device **1012** may be internal or external to the processor **1004** and may also be used to store data or information. The instructions may be in the form of machine readable code in one or more embodiments.

The operational strategy may be embodied by the one or more instructions such that, by executing the instructions, the controller **1004** can operate a chilled water plant or component thereof according to Demand Flow. For example, one or more algorithms may be performed to determine when increases or decreases to chilled/condenser water flow rate should be performed to keep chilled/condenser water pumping on or near a Delta T line. Once, the instructions are executed on the information from the one or more inputs **1020**, a corresponding output may be provided via one or more outputs **1024** of the controller **1004**. As shown, an output **1024** of the controller **1004** is connected to a VFD **1032**. The VFD **1032** may be connected to a chilled, condenser, or other pump or cooling tower fan (not shown). In this manner, the controller **1004** can control pumping at chilled water plant pumps.

It is noted that the operational strategy may be thought of as providing external control operations which control a chilled water plant's components. For example, in the case of a retrofit, a controller **1004** or the like may apply Demand Flow to a chilled water plant without requiring alterations to the plant's existing components. The controller **1004** may control existing plant VFDs and pumps for instance. In some embodiments, VFDs may be installed on one or more chilled water, condenser water, or other pumps to allow control of these pumps by the operational strategy. One or more sensors may also be installed or existing sensors may be used by the controller **1004** in one or more embodiments.

FIG. 9 is a flow diagram illustrating exemplary operations which may be performed by a controller **1024** to perform the operational strategy. It will be understood that some steps described herein may be performed in different order than described herein, and that there may be fewer or additional steps in various embodiments corresponding to various aspects of the operational strategy described herein, but not shown in the flow diagram.

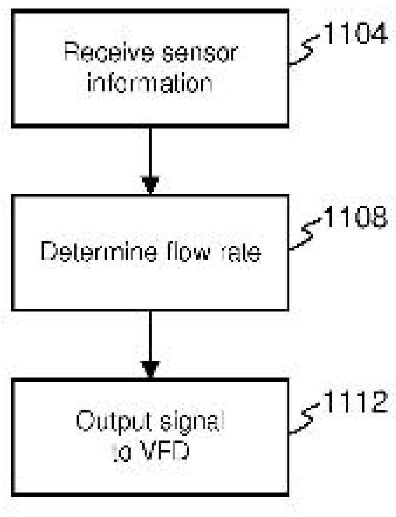

Figure 9

In the embodiment shown, sensor information is received at a step **1104**. For example, sensor information regarding entering chilled water temperature, leaving water temperature, or both of a chilled water plant component may be received. Refrigerant temperature, pressure, or other characteristics may also be received. Also, operating characteristics such as the position of chilled water valves at air handlers, the speed or output of VFDs, the speed or flow rate of pumps, as well as other information may be received.

At a step **1108**, based on the information received in step **1104**, the controller may determine whether to increase or decrease at one or more pumps to maintain a Delta T that is preferably near or at design Delta T. For example, referring to FIG. 1, if leaving chilled water temperature at an air handler **124** indicates low Delta T, the flow rate in the secondary loop **108** may be adjusted by a secondary chilled water pump **120** to maintain design Delta T across an air handler **124**.

At a step **1112**, an output may be provided, such as to a VFD or other pump controller, or even to a pump directly to increase or decrease flow rate as determined in step **1108**. In this example above, by reducing flow rate, chilled water remains in the air handler **124** for a longer period of time. This causes the chilled water's enthalpy to increase because it is exposed to warm building air by the air handler **124** for a longer period of time.

The increase in the chilled water's enthalpy raises the leaving chilled water temperature of the air handler **124**. As the water leaves the secondary loop **108** the leaving water temperature of the secondary loop is raised. In this manner, Delta T may be increased to near or at design Delta T (reducing or eliminating Low Delta T Syndrome).

Though the above example describes maintaining Delta T at an air handler **124**, Delta T may be maintained in this manner at other chilled water plant components, including primary, secondary, or other loops as well as within components of the plant. For example, in one or more embodiments, a controller of a chilled water plant may alter the flow rate of one or more condenser water pumps to maintain a Delta T across a chiller component, such as the chiller's condenser.

Chilled Water Pump Operation

The operational strategy controls such chilled water pumps such that their flow rate is on or near the Delta T line described above. As described above with regard to the graph of FIG. 7, the operation of chilled water pumps according to a Delta T line results in substantial energy savings especially when compared to traditional control schemes.

Operation of chilled water pumps according to a Delta T line may be accomplished in various ways. In general, such operation keeps flow rate at one or

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more pumps on or near the Delta T line. The operational strategy may utilize different methods depending on the location or type of chilled water pump. For example, different operations may be used to control flow rate of a chilled water pump depending on whether the pump is on a primary, secondary, tertiary, or other loop. In one or more embodiments, flow rate provided by a chilled water pump may be controlled by a variable frequency drive (VFD) connected to the pump. It will be understood that other devices, including devices of the chilled water pumps themselves, may be used to control flow rate, pumping speed, or the like.

Typically, but not always, the operational strategy controls flow rate through one or more chilled water pumps to maintain a temperature at one or more points in the chilled water plant. One or more sensors may be used to detect the temperature at these points. Flow rate may then be adjusted to maintain a temperature according to temperature information from the sensors. In this manner, a Delta T may be maintained at one or more points in the chilled water plant.

Referring to FIG. 1, in one embodiment, the operational strategy may control secondary chilled water pumps **120** to maintain a Delta T, preferably at or near design Delta T, across the air handlers **124**. This operates the secondary chilled water pumps **120** according to the Delta T line and ensures that the air handlers **124** can provide their rated cooling capacity while operating efficiently. As stated above, a particular Delta T may be maintained by increasing or decreasing flow rate via the secondary chilled water pumps **120**.

The operational strategy may control primary chilled water pumps **116** to maintain a Delta T at one or more points of the chilled water plant as well. For example, primary chilled water pumps **116** may be operated to maintain a Delta T for the primary loop **104**, secondary loop **108**, or both. Again, this may be accomplished by increasing or decreasing the flow rate of one or more primary chilled water pumps **116**.

It is noted that other ways of eliminating bypass mixing may be used in one or more embodiments. In one embodiment, primary chilled water pumps **116** may be controlled to maintain a temperature within a bypass **128** of the chilled water plant. Because the temperature within the bypass **128** is the result of bypass mixing, maintaining the temperature within the bypass also controls bypass mixing. In this manner, the bypass mixing, and its compounding effect on low Delta T, may be greatly reduced and, in many cases, effectively eliminated. In one embodiment, the temperature maintained may be such that there is an equilibrium or a near equilibrium between the primary and secondary loops **104**,**108**, reducing or eliminating bypass mixing.

To illustrate, excess flow in the secondary loop **108** may be determined by measuring the temperature of chilled water within the bypass **128**. If the bypass temperature is near or equal to the return water temperature from the air handlers **124**, there is excess secondary flow and the primary chilled water pump **116** speed may be increased until chilled water temperature in the bypass drops to near or at the temperature of chilled water in the primary loop **104**. If the bypass temperature is near or equal to the supply chilled water from the primary loop **104**, there is excess primary flow. Primary chilled water pump **116** speed may be decreased until the bypass temperature drops to a midpoint between the return chilled water temperature from the air handlers **124** and the primary loop **104**. Bypass temperatures in this "dead band" have no reset effect on primary pump speeds. In one or more embodiments, the primary chilled water pump **116** speed may not decrease below the Delta T set point of the primary chilled water pump.

Condenser Water Pump Operation

Condenser water pumps provide a flow of condenser water to allow condensation of refrigerant within a chiller. This condensation is an important part of the refrigeration cycle as it allows refrigerant vapor to return to a liquid form to continue the refrigeration cycle. In one or more embodiments, application of the operational strategy causes condenser water pumps to be operated according to a Delta T line resulting in substantial energy savings.

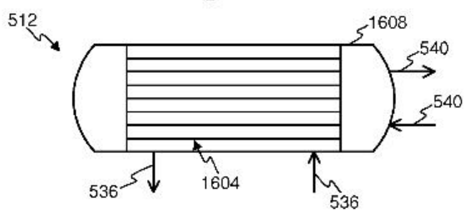

Figure 10

FIG. 10 illustrates an exemplary condenser **512** comprising a plurality of condenser tubes **1604** within a shell **1608**. Refrigerant vapor may be held in the shell **1608** such that the refrigerant vapor contacts the condenser tubes **1604**. In operation, condenser water flows through the condenser tubes **1604**, causing the condenser tubes **1604** to have a lower temperature than the refrigerant vapor. As a result, the refrigerant vapor condenses on the condenser tubes **1604** as heat from the vapor is transferred to the condenser water through the condenser tubes.

The operational strategy influences the temperature of the refrigerant and the condenser water by controlling the flow rate of the condenser water through the condenser tubes **1604**. Lowering the flow rate of condenser water causes the water to remain within the condenser tubes **1604** for a longer period of time. Thus, an increased amount of heat is absorbed from the refrigerant vapor causing the condenser water to leave the condenser at a higher temperature and enthalpy. On the other hand, increasing the flow rate of the condenser water reduces the time the condenser water is within the condenser tubes **1604**. Thus, less heat is absorbed and the condenser water leaves the condenser at a lower temperature and enthalpy

In operation, the operational strategy may control one or more condenser water pumps, such as through a VFD, to maintain a Delta T across the condenser. Consequently, a condenser water leaving temperature at the condenser and lift in the chiller are also maintained.

Demand Flow's operational strategy may also be configured to beneficially influence the mass flow, lift, or both at a chiller **112** by operating condenser water pumps **516** according to a Delta T line. In general, mass flow refers to the amount of refrigerant circulated within a chiller for a given load, while lift refers to the pressure/temperature differential the refrigerant has to be transferred across. The amount of mass flow and lift dictate the energy usage of a chiller's compressor **520**. Thus, the operation of condenser water pumps **516** according to the operational strategy provides efficiency gains by reducing compressor energy usage.

A chiller's compressor **520** may be thought of as a refrigerant vapor pump which transfers low pressure and low temperature gas from the evaporator **508** to the condenser **512** at a higher pressure and higher temperature state. Energy used in this process may be expressed by the equation,

$$E = MF * L*K \qquad (6)$$

As can be seen from this equation, lowering mass flow or lift decreases energy usage.

The mass flow (or weight of refrigerant) that must be circulated through a chiller, to produce the required refrigeration effect (RE) for a given amount of work or output (Tons) may be described by the formula,

$$MF = Tons * K*RE \qquad (7)$$

Simply stated, this formula says that increasing the refrigeration effect lowers the weight of refrigerant, or mass flow, that needs to be circulated through the chiller for a given amount of work. Increasing the refrigeration effect also increases the deliverable capacity of a chiller while reducing compressor energy for a given amount of work.

Additionally, because traditional condenser water pumping systems operate at a constant volume, cooling towers are always at full flow conditions, even at partial load conditions. In a constant flow control scheme, as the load on the cooling tower decreases the operating range or Delta T at the tower decreases, which reduces the efficiency of the tower. In contrast, with the operational strategy Delta T at the cooling tower is maintained, at or near the tower's design Delta T via the condenser water pumping algorithms previously described. This is significant in that lower tower sump temperatures are achievable for the same amount of cooling tower fan energy because efficiencies have been increased. The lower tower sump temperatures correspond to lower condenser water entering temperatures at the condenser. It is important to note that condensers and cooling towers are selected at common Delta T design points, typically 10 degrees, as an industry standard.

In the operational strategy, minimum cooling tower fan energy is maintained, for a given sump temperature set point by controlling the condenser water pump to a constant Delta T algorithm as previously described. This method of controlling cooling tower efficiency, regardless of tower load, via condenser water pumping is unique to the industry. There is a synergy that develops between the chiller, condenser water pumping and cooling tower sub-systems by operating them under the Demand Flow strategy that reduces net system energy.

Compressors

Reductions in compressor energy derived via the application of a Demand Flow operational strategy are best quantified by calculating the associated shift in the Coefficient of Performance of the Refrigerant (COPR). COPR is the measure of efficiency in the

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refrigeration cycle based on the amount of energy absorbed in the evaporator as compared to the amount of energy expended in the compression cycle. The two factors that determine the COPR are refrigeration effect and heat of compression. Heat of compression is the heat energy equivalent to the work done during the compression cycle. Heat of compression is quantified as the difference in enthalpy between the refrigerant entering and leaving the compressor. This relationship may be stated as

$$COPR = RE * HC \qquad (8)$$

For optimal COPR, the refrigerant superheat should be as high as possible and the refrigerant sub-cooling should be as low as possible. Using chilled water pumping, condenser water pumping, and cooling tower fan subsystems to achieve optimal COPR is unique to the industry and fundamental to Demand Flow Technology.

<u>SPECIFIC ADVANTAGES UNIQUE TO DEMAND FLOW.</u>

How is this technology different from conventional technologies in the market? Following are few unique points that make this solution stand out:-

- Utilizes external control operations in chilled water production pumping subsystems to optimize evaporator refrigerant superheat, or refrigerant enthalpy leaving the evaporator thus beneficially influencing the mass flow component of compressor energy usage. Controlling chilled water pumps, such as through VFDs, to near or at manufacturer designed evaporator Delta T (e.g. design Delta T) using Demand Flow chilled water pumping operations controls refrigerant superheat to chiller manufacturer design conditions regardless of the load percent on a chiller at any given time. This optimizes refrigerant enthalpy leaving the evaporator and reduces chiller compressor energy as compared to a chiller operating at less than design Delta T (i.e. low Delta T).
- Utilizes external control operations in condenser water pumping and cooling tower fan subsystems to optimize condenser refrigerant sub-cooling, or refrigerant enthalpy leaving the condenser (and entering the evaporator). In this manner, mass flow component of the compressor energy equation, as described above, is beneficially influenced. Demand Flow control operations in condenser water pumping and cooling tower fan subsystems generally determine the final operating saturated pressure/temperature differential between the evaporator and condenser in the chiller (i.e. lift). This beneficially influences the mass flow and lift components of the compressor energy equation, discussed above.
- Utilizes external collaborating control operations between production and distribution loops in order to balance flow between the loops, minimizing or eliminating the excess flow and bypass mixing which contribute to Low Delta T Syndrome, such as in a decoupled chilled water plant. This produces the most deliverable air side capacity at any given chilled water flow rate. This also allows primary or production loop pumping to meet varying load conditions of the distribution pumping system. Under Demand Flow, Low Delta Syndrome is reduced to its lowest achievable level, if not effectively eliminated.
- Utilizes critical zone resets to meet increases in cooling demand while controlling chilled water pumping according to a Delta T line. Critical zone resets may also be used to decrease cooling output by resetting the Delta T line.
- Operates the chilled water plants and components thereof at minimal partial load pumping pressures to minimize chilled water valve bypass and the resultant overcooling, thus decreasing system load.
- Produces a synergistic reduction in chilled water plant energy utilization as well as an increase in deliverable capacity by synchronizing chilled water pumping, condenser water pumping, compressor operation, cooling tower operation, and air side operation.

While various embodiments of the invention have been described, it will be apparent to those of ordinary skill in the art that many more embodiments and implementations are possible that are within the scope of this invention. In addition, the various features, elements, and embodiments described herein may be claimed or combined in any combination or arrangement.

NAVIGATOR™

In addition to the unique Demand Flow technology; the Navigator plays a vital role with energy optimization. Navigator is a cloud based energy monitoring and data analytics platform. As a single, integrated, cloud-based platform, Navigator provides powerful analytical and reporting capabilities. It gives visibility into the long-term performance of your facilities and infrastructure.

Customised

Navigator's customisable suite of applications helps you monitor building system performance, energy demand and energy supply more effectively and efficiently. It provides transparency, giving your team and the Siemens experts who support you full insight to make critical improvements. And using a central platform, you can maintain total control over a single building, a campus or your entire portfolio.

Dashboards
Provide a general overview of performance to anyone with access to system through the use of customized dashboards that allow continual monitoring of key performance indicators (KPIs)

Environment
Automates environmental reports including a greenhouse gas inventory, compliance reporting and sustainability analyses

Efficiency
Compare performance based on energy consumption data within a building, amongst equipment or across your enterprise

Performance
Obtain analyses and reports designed to provide a precise understanding of system performance, using analyses for a detailed insight into hardware performance.

Supply
Gain a clear insight into energy supplier invoices, energy costs and energy market pricing

Projects
Give your team the ability to track, manage and evaluate improvement options for projects

Navigator is a brilliant tool for data collection. Any energy consuming component that can communicate data through internet can be connected with Navigator.

Data get transferred to the Siemens cloud via a secured IP connection. This data can then be accessed from anywhere in the world; using the Navigator platform. The platform comes within built applications; which are capable of various energy data analytics. Both the user and Siemens are able to view this data.

Siemens energy experts view and analyze this data to come up with energy efficiency measures. Data structured in the form of graphs and table; via unique Navigator applications, is valuable information. This can be used to identify energy conservation measures from a facility.

The navigator is also a great energy measurement and verification tool. The savings from Demand Flow (or any energy savings solution) can be continuously monitored and verified using this platform.

Following are some screen shots of the actual tool:-

Image 1

Image 2

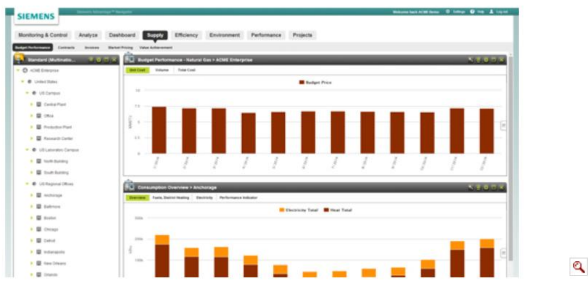

Image 3

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CASE STUDY: TAJ LANDS END, MUMBAI

Taj Lands End Mumbai is a classic example of energy conservation through digitalization and automation.

The Customer

Taj Lands End, Mumbai offers the best of both worlds – breathtaking views of the sea and the energy of the city life. An integral part of the global chain Taj luxury hotels, Taj Lands End offers some of the city's finest accommodation and comprehensive conferencing and banqueting facilities. The hotel has 493 rooms, including 33 Suites, among the largest in the city, all overlooking the Arabian Sea. Taj Lands End Mumbai offers an ideal blend of business and leisure, and like all Taj hotels, reflects India's warm and heartfelt traditions of hospitality.

The Challenge

With such a wide array of customer offering, managing energy consumption and increasing efficiency was the key challenge. How could it be resolved without compromising on unparalleled standards of hospitality? The goal was to optimize performance of the HVAC system, while ensuring the highest levels of comfort and efficiency. The customer was contemplating to replace existing old chillers that were high on energy consumption. But such a solution meant shutting down chiller plant for considerable time, which is clear "no" for the hotel as it operated at nearly full capacity throughout the year.

The Solution

After a detailed collection and careful assessment of energy data, Siemens presented Taj Lands End with Demand Flow solution from Building Technologies portfolio.

As a holistic approach for optimizing the entire chilled water system, Demand Flow specialized algorithms can deliver chilled water system efficiencies to any existing building automation system. While conventional offerings in the market cater to the chillers only, the patented Demand Flow system is a comprehensive solution for complete chiller plant room. The features include chilled water optimization solution, control and sequencing operation of the entire chilled water plant, condenser water pump and cooling tower. It optimizes temperature and pressure set points for chiller water and condenser water, while controlling pump and fan speed to maintain the optimal energy balance.

Moreover the solution did not require replacement of the hotels' existing old chillers, as it was independent of chillers make and type. With a planned, micro level shutdown and coordination between the Siemens and Taj teams, the solution was implemented smoothly without any inconvenience to the guests or to the hotel operations.

What is Demand Flow doing at Taj Lands End

- Demand Flow™ **controls and sequences** the operation of the **entire chilled water plant** including the Chillers, chilled water supply pumps, Condenser Water Pumps and cooling towers.

- Demand Flow **optimizes** temperature and pressure set points for chilled water and condenser water, while controlling pump and fan speeds to maintain the **optimal energy balance**.

- **Varies the water flow** through chiller evaporator and condenser utilizing VFD's (variable frequency drives), on the chilled water pump motors and the condenser water pump motors.

- Because of its **balanced approached** to all components of the chilled water system it does not obtain savings in just one area or utilize more energy in another area, like other solutions that have been presented to the industry in the past.

Following table illustrates the before and after Demand Flow scenario at the Taj Lands End:-

Pre-implementation Scenario	**Post Demand Flow Implementation Scenario**
4 nos. Water Cooled Chillers (3nos. McQuay make Chillers with capacity of 500 TR each + 1 no. Carrier make Chiller of 600 TR capacity).	No changes on the Chillers except varying the water flow through evaporator and condenser within the limits prescribed by OEMs.
8 nos. manually operated water flow Isolation Valves on evaporator and condenser on individual Chiller.	1. Replacement of manual water flow Isolation Valves on evaporator and condenser with Motorized Valves on individual Chiller. 2. Provision of Temperature Sensors on individual Chillers and headers
4 nos. Constant flow Primary Chilled Water Pumps (3 nos. pumps with 30 HP each + 1 no. 60 HP).	1. Replacement of 60 HP Pump with 30 HP Pump. 2. Conversion of constant flow primary chilled water pumping system into Variable flow system by installing VFD drives for Primary Chilled Water Pumps (4nos of 30 HP).
14 nos. constant flow Secondary Chilled Water Pumps (total 14 nos pumps of various capacity serving 4 zones).	Conversion of constant flow secondary chilled water pumping system into Variable flow system by installing VFD drives for all 14 nos. Secondary Chilled Water Pumps.
4 nos. Constant flow Condenser Water Pumps (75 HP).	Conversion of constant flow primary chilled water pumping system into Variable flow system by installing VFD drives for Condenser Water Pumps (4nos of 75 HP).
4 nos. Cooling Towers with capacity of 600 TR each with constant speed fans.	Conversion of constant speed Cooling Tower Fans into Variable speed by installing VFD drives on the fans.
Manual Chilled Water Plant Operation.	Automatic Chilled Water Plant Operation using Siemens Desigo Control System.
Web based Chilled Water Plant Energy Monitoring using Siemens EMC solution.	Existing EMC parameters will be used for Measurement & Verification.

Highlights

- Implementation timeline: 3 Months
- Savings reported by client: 14,85,000 kWhr (1st year)
- >15% reduction in chiller plant consumption
- Payback period of 20 Months
- Peak load rebate offered by regional power utility for meeting energy efficiency levels entailing additional savings.
- Extended equipment life
- Improved indoor environmental quality
- Simplified system operations

The site is also connected to Navigator for remote monitoring and energy data analytics. Siemens energy experts monitor the facility at all times in order to identify more energy conservation activities. The navigator also helps is keeping track of savings from Demand Flow.

SOLUTION COST AND ROI

Each building, each project is unique. The same solution cannot be implemented in different building. On cannot expect energy savings if the solution is not customized to cater the unique characteristics of every building. We are an energy company and we realize that.

In order to build a solution we do a 2 stage energy analysis. The first stage analysis is a preliminary audit. Historic data is collected along with design data. This is then fed into a simulated version of the algorithm. The algorithm will indicate the current plant consumption and the estimated consumption post implementation of Demand Flow. If this preliminary savings number is appealing to both the client and Siemens – making a good business case; we qualify the project as GO (else NO-GO).

The second stage energy analysis is very crucial. Historic data for last 1 year is collected. Along with Design specifications, each component is tested and various parameters are measured in order to ensure its working post implementation of the algorithm. It is important to know how each of these components would react to the unique algorithm once implemented. This analysis takes anywhere between 3-4 months. Post the same a customized proposal for the building is offered. A detailed supply plan along with a detailed schedule and instrumentation layouts is shared with the client. Following are key components necessary to make Demand Flow happen:

- Server (PC)
- BMS Software (Base Platform)
- Demand Flow License
- 3rd Party Integration Controllers
- Interface Controllers
- Direct Digital Controllers
- Relevant Panels
- Variable Frequency Drives
- Valves
- Actuators
- Energy Meters
- Cables and Conduits
- Necessary Enclosure
- High Accuracy Industrial Grade Temperature transmitters
- High Accuracy Industrial Grade Differential Pressure transmitters
- Outdoor Temperature and Humidity Sensors

We ensure and end to end holistic solution. We shall implement the solution on a turnkey basis. There is no charge for the initial energy analysis. The cost includes Siemens ensuring the savings through Performance Assurance phase (which is up to payback period <2 years).

Approximate cost of solution in a commercial building ranges from INR 10MIO to 20MIO (up to USD 310,000/-). However the value of the project varies from site to site.

We estimate a payback of 2 years approximately.

CONCLUSION

Sustainability through digitalization is a very important topic. It is the future of how we will operate our facilities. It also covers volumes about how technology plays a vital role in energy conservation and profitability.

Siemens has unique solution to address and make a mark in this space. Demand Flow is a unique solution which can reduce energy consumption of at least 20% through digitalization and automation. The Navigator is a cloud – based platform to understand how our buildings are performing currently; and what the areas of improvement are. The unorganized and unstructured data produced by our building, on every second under operation; if managed and interpreted precisely has huge potential for savings. Data if managed well is valuable information.

NOMENCLATURE

TON = cooling capacity

GPM= Flow rate

ΔT= Delta T

K= Constant

Q= Volumetric Flow Rate

N= Shaft rotational speed

H= Pressure or head developed by the pump

P= Shaft power

E= Energy used

MF= Mass flow

L= Lift

COPR= Coefficient of performance

RE= Refrigeration effect

HC= Heat of compression

ACKNOWLEDGEMENT

Thank you, Siemens for giving me this platform. The energy industry in India is in an exciting stage. As India moves towards more and more smart cities – digitalization and automation is central in the scheme of energy conservation and improved performance. With the help of digitalization we can not only improve our building performance but also improve our non performing non-core assets into profitable once.

Thank you, AEEE for this wonderful opportunity and platform. This will encourage and spread awareness in many towards energy conservation. AEEE's focus on data driven and evidence based energy efficiency policies is also the core concept behind our invention and will further encourage many more to take steps towards this form of cheap, clean and fast energy conservation techniques.

RESPONSE TO COMMENTS

Firstly, thank you to the reviewers for their time and valuable feedback on our paper. We will try and address the comments to the best of our abilities and do justice to them. Following is our response to the comments by the reviewers:-

1. How does the simulation affects on multi-flows; i.e. primary, secondary, condenser etc. Give example.

A. The crux of the solution is to integrate all the energy consuming components of a chiller plant and treat the chiller plant as a single identity. This makes it feasible for the algorithm to control the various components of the chiller plant by varying the frequencies of each pump; to match the exact load requirement. For example, in conventional solutions, only the secondary pump is equipped with VFD, which is integrated with BMS and the AHUs. In Demand Flow all the components are integrated and are equipped with VFD; which are continuously modulating to support the load requirement precisely. Another example is the coordination between the primary and the secondary pumps. In order to keeps the water mixing through bypass (decoupler) to the minimum; the primary and the secondary need to work at a frequency to balance (cancel) each other out. This ensures no bypass mixing and savings through modulating frequencies across these pumps. This also supports addressing the low delta T syndrome.

2. 'Make Neutral' in the main body.

A. While we have addressed and acknowledged the manufacturer in the acknowledgement, it is difficult not to cover the same in the main body of the paper. This technology is unique to Siemens and is closely linked to the Digitalization philosophy the company has adopted.

3. Coverage of Major Works/Publications closely related to the topic.

A. Certainly Sir/Ma'am. The topic here is sustainable energy efficiency through digitalization. This is a very important subject as it integrates two key aspects of our industry – Energy Conservation and Digitalization. Siemens has a gamete of solutions in this space; and the particular paper covers a unique solution – Demand Flow. While we would be very keen to share projects and related works executed by Siemens in a public forum; we have publication permissions only from Taj Lands End project executed by us. The same has been covered in reference.

4. Case Study to cover more vital parameters/fact about the project.

A. Necessary additions to address the same have been added in the Case Study section.

5. Concept of PID vs. Relational logic to be covered more in detail.

A. Thank you so much for this suggestion. We wanted to cover the same. However, this would take away the basic idea that we are trying to drive from this paper. We have tried to keep the paper more about the technology under discussion, and how it is unique to Siemens; with the help of various technical parameters and logic. However, we have tried to address this point in the case study section. Wherein we have indicated before and after scenarios at the Taj Lands End for your reference. We hope this helps.

6. You are highlighting the issue of 'Low Delta T Syndrome' but this is more so in District Cooling Plants with Large Delta T. Also, you must also point out that Low Delta T needs to be addressed at the Load & can only be mitigated at the Plant Room level

A. An excellent point. Over the last 2 years, we have surveyed and audited over 200 chiller plants in India. These chiller plant belong to hospitality, airport, automobile manufacturing units, commercial space segments. The average plant room capacity is 1500 TR. We have observed a low delta T syndrome in most of these applications. This is what qualifies them for our solution. In comparison to the design delta T; the observed delta T is much lesser. Therefore this challenge is not just limited to district cooling (we have also implemented this solution at WAFI, Dubai – a district cooling application as well).

Furthermore, you rightly said the low delta T needs to be addressed at the load, which can be mitigated at the plant room level. While Demand Flow enables that; additionally we also have a solution from the same family for the HVAC low side – AirOptiControl. This helps to address part of that challenge.

7. Case Study should have discussed the real differences in controls more in details to be educative and informative.

A. We have made the necessary additions in the Case Study.

8. Highlight the differences between 'before' and 'after' approach and also highlight how the inside conditions were not compromised to get savings

A. We have covered the ‘before’ and ‘after’ scenario in our case study.

Furthermore, we have a very unique M&V program called the Performance Assurance (PA) Phase. Post execution, the project moves to a PA phase wherein daily reports are shared with the clients to record savings on the previous day. The Efficiency in terms of kW/TR is observed very closely and the consumption is compared with the baseline to generate reports daily, weekly and monthly. The same is acknowledged by the clients.

We hope the above addresses your queries and comments. We have tried our best to address them. However, in case of any gaps in the same; we would love to interact with you in person to further address them during the conference. Thank you once again for this wonderful opportunity and platform.

ENERGY EFFICIENCY IMPROVEMENT IN REFORMER OF HYDROGEN UNIT AT NUMALIGARH REFINERY, INDIA

A Case Study

Geetali Kalita, Numaligarh Refinery Limited, India

Keywords: Energy efficiency improvement and energy conservation

ABSTRACT

Proper selection of Heat exchangers plays vital role in improving energy efficiency in process units. It also plays an important role in managing personnel and process safety.

Numaligarh Refinery was experiencing lower energy efficiency in Reformer of the Hydrogen Unit (HGU). One of the major issues prevailing was the un-satisfactory performance of Cast Air Combustion Air Pre-heater (CAPH) in the Reformer flue gas duct. The CAPH was experiencing air leakages for a long time. This resulted in various operating constrains in reformer, that includes low air preheat temperature , in-adequate air flow, high pressure drop across the Heat exchanger, Off gas flaring due to high ID fan suction pressure & load, low draught in Reformer Chamber etc. The CAPH was attended by Inspection and Maintenance during multiple opportunities and planned shutdowns and carried out repairing jobs to the extent possible. However, no significant improvement was observed, which affected the Reformer flame pattern, skin temperature even threatened capacity utilization of the plant.

After a detail technical feasibility study, it was proposed to replace the cast CAPH with PLATE TYPE HEAT EXCHANGER (PHE) and replacement was carried out in April 2015 within a short time span with meticulous micro planning.

This paper attempts to highlight detail of the implementation phase including root cause analysis, problem faced with CAPH and improvement in performance of the unit after installation of the PHE. It shall be worth to share it as a Case Study for the overall efficiency improvement of the HGU reformer with an aim that similar schem

es can be replicated by refiners experiencing HGU's underperformance.

I INTRODUCTION

The Hydrogen generation plant installed at Numaligarh Refinery, Assam is designed for production of 48,600 Tonne of Hydrogen per annum .The plant uses either Natural Gas or Naphtha as feedstock as well as fuel.

Naphtha/Natural Gas is Steam Reformed in Hydrogen Plant to produce high purity Hydrogen for Hydro cracker Unit. Hydrogen Plant is broadly divided into 4 sections:

i) Desulphurization & Sulphur Adsorption
ii) Reforming
iii) CO Conversion
iv) Purification of Hydrogen

The Desulphurization & Sulphur adsorption section removes sulphur compounds which will otherwise poison the catalysts. Naphtha/ Natural Gas enters the hydrogenator where sulphur compounds are hydrogenated and subsequently these sulphur compounds are adsorbed in the Sulphur Adsorber. Thereafter , feed enters in the reforming section. In reforming section the feed is converted into synthesis gas - H2, CO, CO2. The synthesis gas leaving the reformer is cooled before entering the Shift Converters. In the Shift Conversion section , the CO is converted to CO2 and generating Hydrogen Gas. Separation of H2 from the mixed gases takes place in the Gas Purification Section (PSA Unit). The process gas is cooled and then fed to PSA Unit where 99.99 % pure H2 is produced. The hydrogen gas is sent to Hydro Cracking Unit.

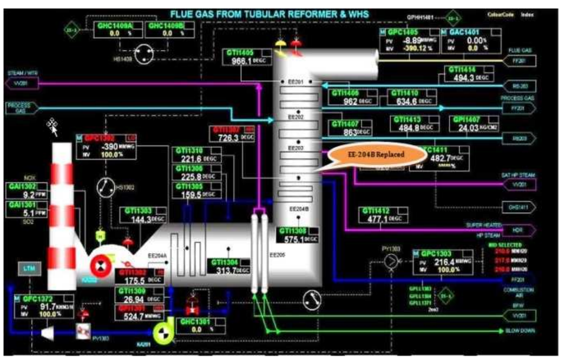
WASTE HEAT SECTION:

Combustion air is supplied by combustion air blower and preheated to 450degC in the reformer convection section.

Flue gas flow is upward with outlet near the top of the radiant chamber.The flue gas under slight vacuum and with an outlet temp of 1060 degC. Flue gas enters the reformer convection section where the sensible heat of the flue gas is recovered and used for:

1) Feed preheating :Heating of hydrocarbon/steam mixture from prereformer(05-EE-201) before entering the tubular reformer; preheating of hydrocarbon /steam mixture to the prereformer(05-EE-202).
2) Steam superheating : Superheating of steam(05-EE-203)
3) Air preheating : Heating of combustion air (05-EE-204A/B)
4) Steam generation : Generation of 42kg/cm2 g steam(05-EE-205)

In the reformer section,the temp of the flue gas is decreased to 150 degC .The combustion air preheating coil 05-EE-204A/B bring about the final cooling of the flue gas which is designed so that the metal in contact with the flue gas keeps a reasonable margin to the acid dew point. The flue gas leaving the reformer convection section passes through the stack by the induced draught fan 06-KA-002.



GRAPHICS DIAGRAM OF THE FLUE GAS DUCT AND WASTE HEAT SECTION

Numaligarh Refinery experienced lower efficiency in Hydrogen Unit Reformer five years back from now. One of the major issues was with the performance of Air Preheater (APHE) for preheating the combustion air in the Reformer duct before atomising with Fuel in burners of the Reformer. The fin type APHE in the Reformer duct exchanges heat with the duct flue gas. This APHE was experiencing Low Air preheat temp and flow and high pressure drop across the HE .This has led to overall low differentail pressure (dP) across the duct ,Off gas flaring ,Low draught in reformer chamber and high amperage of FD fan motor.

III) PERFORMANCE EVALUATION OF CAPH (CAST AIR PREHEATER):

Operations and technical team evaluated the performance of the CAPH with the evaluation criteria

Base case Vs actual deterioration of the parameters as tabulated below:

Parameter	Base case	Actual case	Performance effect
Specific Energy ,Gcal/Knm^3	3.14	3.23	Higher Sp energy consumption
% false air ingress	1	3	Higher Fuel & power in ID
Combustion air temp,degC	450	420	Higher power in FD
Reformer inlet temp, degC	630	600	Lower heat exchange with duct flue gas
Reformer Outlet temp, degC	875	855	Limiting fuel combustion in reformer
Stack temp, degC	150	165	Higher flue gas temp
% Excess air	10	12	Tends to more fuel requirement

Analysis and evaluation :The inspection and Maintenance team closely monitored the malfunctioning APHE

Root cause analysis:

1) Due to blockage of the flue gas path at the upstream of combustion air pre-heater (EE-204B) by carried over broken refractory material ,glass wool etc.
2) False air ingress

Action taken by maintenance:

1) Blockage flue gas path has been thoroughly cleaned during shutdown
2) Sealing of false air ingress points
3) Combustion air preheat cold end corrosion refurbishment during opportunity shutdown
4) EE Tube block replacement done

EQUIPMENT HISTORY (CAPH)

The cast air preheater (05-EE-204B) was installed in the reformer section flue gas duct during pre-commissioning. This was inspected time to time by maintenance. During 2010 shutdown for revamp of Hydrocracker Unit, few tube cracks were observed in some tubes along with breakage of some fins on the upper most layer while viewing from the top in the flue gas side. Accordingly necessary maintenance and repairing was done.

In 2012 Refinery shutdown, considerable long cracks developed, whole tube assembly got considerable bend at edges and tube assembly got dislodged slightly from original position. Hence it was repaired again and 27 nos. of tubes were replaced. Though slight improvement was observed, still pressure drop across the Air preheat exchanger was in higher side resulting in high ID fan load as well as energy loss. ID fan load increase affects the Reformer burner as well as capacity utilization.

PROPOSAL FOR REPALCEMENT:

Further, a detailed technical feasibility study was carried out and a proposal was put up to replace the cast APHE by PLATE TYPE APH. CAPH was replaced with Plate type heat exchanger in September'2015.

Merits of Plate type Exchanger are-

1) The corrugation in the plates creates high turbulence which tend to scour the surface and keep it clean.
2) Plate Heat Exchangers can have large amounts of effective heat transfer surface in a small footprint.
3) Plate heat exchangers are almost 90% smaller in size than the equivalent shell and tube unit. Their compact size and high efficiency makes them ideal for installations where space is limited.
4) The other main advantage of the plate heat exchanger is its flexibility. By varying the number of plates, their type and the number of flow paths, a plate heat exchanger can be tailor made for each particular application in terms of power, rating, operating temperature and pressure drop.
5) With regards to maintenance the plate heat exchanger does not require large maintenance areas (no tube withdrawal required) and no heavy lifting gear is required as the unit in comparison is lighter.
6) Chemical cleaning can take place with the unit installed and as the storage volume is low, chemical usage is kept to a minimum. As the volume of water stored is low this can also mean that a plate heat exchanger is exempt from the Pressure Equipment Directive (PED).

PLANNING AND EXECUTION

In Refinery Turnaround in 2015, the existing fin type exchanger EE-204B (Flue Gas / Combustion Air) was replaced with a new plate type exchanger. The replacement activities were started soon after the plant shutdown. To evacuate the old EE-204B, the combustion air duct was cut and removed for creating proper access to the exchanger. The new plate type exchanger has been properly fixed by installing the bellows in air side. After completion of EE-204B installation within a short period of 21 days, the combustion air duct has been fixed by furnishing a coat of paint inside the duct. Also defective Combustion Air (CA) dampers have been replaced.

External painting of EE204B along with heat resistant silicon coating was done in Combustion Air duct.

COST OF APH

The total expenditure of the APH including dismantling and erection was INR 2.1 crores.

During dismantling of old APH module

PERFORMANCE ANALYSIS AND ECONOMICS RESULT:

The performance and efficacy of the new plate type EE-204B is better than the previous fin type exchanger. The analysis has been made by focussing on following parameters.

1) DP across flue gas duct
2) ID fan current and suction pressure
3) Combustion air flow & temperature at the inlet of reformer
4) Reduction in NG fuel consumption
5) FD fan current and discharge pressure

Performance analysis was made by comparing pre-shutdown and post shutdown data at same average plant load and full Natural Gas mode (i.e. both as Feed as well as fuel).

Comparison was carried out with plant data from September-October 2014 (pre-RTA period) and June-July 2015 (Post RTA period).During these periods average plant load was 75% and plant was running in 100% Natural Gas mode.

Pre and post HGU performance of different parameter is tabulated below:

Description	Pre shutdown	Post Shutdown	Performance Increase
Combustion air temp to Reformer. Deg C	399.2	511.7	Increased by 28%
ID fan suction pressure, mmwc	383.1	249.6	Reduced by 35%
Reformer draft, kg/cm2	-4.5	-5.6	Increased by 25%
Natural Gas fuel flow, Kg/h	845.5	449.4	Reduced by 47%
ID fan energy consumption, (Ampere)	48.6	43	Reduction by 12%
Combustion air flow, knm3/h	87	75	Reduced by 14%
PSA Off Gas flaring, %	10-15%	0%	Flaring Nil
Dp across the duct (difference of ID fan suction pressure and Reformer draft, mmwc)	378.6	244	Reduced by 35%

Note:

Pre shutdown period : Sept-Oct 2014

Post Shutdown period : June-July 2015

ECONOMICS AND GRAPHICAL ILLUSTRATION:

Basis of calculation: 1 hr period;

Cost of generation of power = Rs. 3.2 per KWh (as per the annual report 2015-16) ,

V= Voltage; 6.6KV Cosø = phase lag; 0.8 ,

NG price =2.5$/ MMBTU (April'2017) = Rs 10.0/kg (GCV=8848Kcal/scm, SG=0.5613)

(Average of six months-Henry Hub price of NG)

1. Cost benefit analysis due to ID fan current reduction is presented below: (*Refer to Graphical fig 1)*

ID fan current reduction savings	**Pre-installation**	**Post installation**
Average Amperage load	48.6	43
Power consumption, KW	444	393
Saving, Rs in Lacs,(per annum)	-	13.0

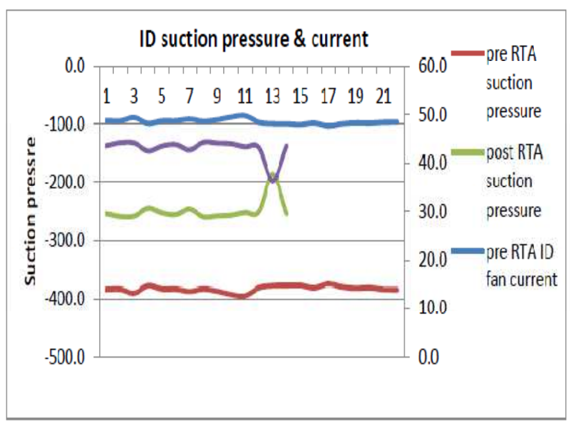


Fig 1 : ID fan current and suction pressure

2) Dp across the duct (difference of ID fan suction pressure and Reformer draft, mmwc) represented graphically fig 2.

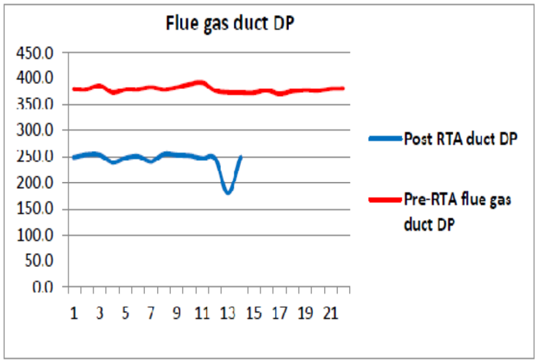


Fig 2: DP across flue gas duct

3) Cost benefit analysis due to increase in combustion air temperature as shown below: Refer to table 3 & fig 3.

Table 3 : Combustion air temp increase

Combustion air temperature Increase	Pre Shutdown	Post Shutdown
Average CA temperature Deg oC	399.1	511.7
Average Flow of combustion air, KNm3/h	86.7	75.3
Increase in heat input, Gcal/h		1.32
Equivalent NG Fuel saving, Kg/h		116
Saving , Lacs per year		**93.0**

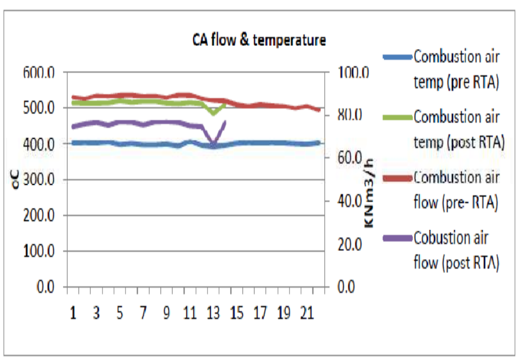


Fig 3: Combustion air flow & temperature at the inlet of reformer

4) In addition to the increase in combustion air temperature, fuel NG consumption is reduced also due to the more consumption of off gas after reduction of ID fan current and suction pressure. Cost benefit analysis due to reduction in NG as shown in the following table 4 & fig 4

Table 4 : Reduction NG fuel

Reduction in NG fuel	Pre shutdown	Post shutdown
Fuel NG @ equal average plant load, kg/h	845.5	449.4
Savings in SRFT/Yr (standard Refinery Fuel in Ton per Year)		3580

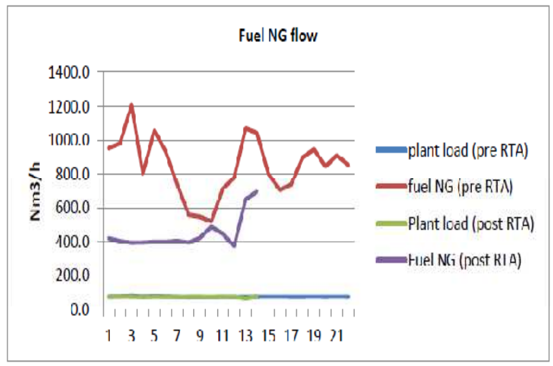


Fig 4: Reduction in NG fuel

5) Cost benefit analysis due to FD fan current reduction is tabulated below: Table 5 & fig 5

Table 5: FD Fan Current reduction

FD fan current reduction parameter	Pre RTA	Post RTA
Average amperage load	39.5	35.2
Reduction in power consumption, KW		38.9
Saving , Rs/h		124.5
Saving , Rs in Lacs/Yr		10.0

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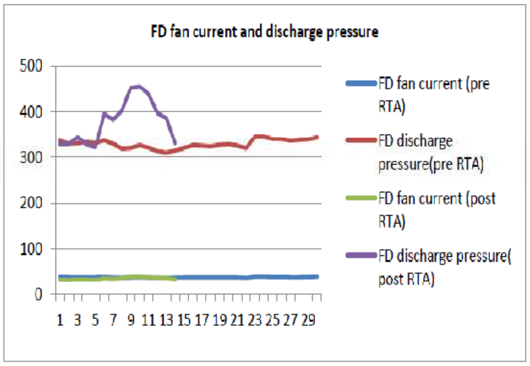

Fig 5 : FD fan current and discharge pressure

Net benefit realization post evaluation of Plate Type Air preheater is Rs 113.0 Lacs/annum with a payback period of 1.8 year.

CONCLUSION:

Hydrogen Plant operational assessment and related optimization has led to appreciable savings. Close monitoring and timely action bridged the gap in specific energy consumption to match with the global best by improving the performance energy efficiency of the Reformer significantly at 90% vs 85% in pre-installation. Also timely development and adoption of suitable technologies helped Numaligarh Refinery in meeting the challenges encountered in past. Thus, the overall energy efficiency of the new PHE has significantly improved with reduction in energy usage in the Reformer. The practical solution shall allow defining a roadmap for the refinery investments by replicating similar units in those Hydrogen units experiencing constrains due to underperformance.

ENERGY AUDIT –TOOL FOR ENERGY EFFICIENCY

I V Ramesh Kumar, Maruti Consultants, India

Keywords: Energy, Audit, Efficiency, benchmark

ABSTRACT

It has been observed that energy audits have been conducted in a rather routine way without a proper baseline and targets. There are issues right from energy accounting and billing, demand side management of energy and operations. This is equally applicable to all energy users be it industries, buildings etc. The energy efficient equipment has been installed without an insight into why and what are the expected benefits. Some of the recommended measures do not meet the required standards (illumination, temperature, environment etc.). The inference therefore is merely installing an energy efficient equipment does not mean the industry or building is energy efficient.

This paper therefore proposes to draw upon the experience gained in auditing various industries, buildings etc. on the expectations, failures and key take away. The paper aims to begin with the energy accounting and billing system and the lacunas and corrective measures. Then the issues related to establishing base lines and bench marks will be analysed and measures to improve them will be detailed.

The paper then analyses the need, selection and installation of energy efficient equipment and systems. The paper also highlights the importance of proper energy efficient system (rather than equipment) and monitoring tools / procedures

The concluding part of the paper details, what to expect from an energy audit, how to specify the requirements of the audit and the way forward. Supporting case studies has been analysed as per requirement.

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INTRODUCTION

India has initiated several measures for improving energy efficiency. Some of the initiatives are developing a team of professional experts (Accredited Energy Auditors, Certified Energy Auditors and Managers), Star Rating of Energy Efficient Appliances etc. Energy Audit is seen as a tool for evaluating the present level efficiencies. The savings are often committed even in the pre-audit phase by the auditors. The clients also (industries, commercial buildings etc.) expect savings in the pre-audit stage. This is not the desired procedure.

The audits should have a clear-cut scope, focus areas and deliverables. The audit should also aim to link energy consumption with process / building operations.

It is essential to specify in energy audit, the focus areas, expected deliverables baselines and targets, implementation road map, measurement and verification procedures.

The base for any energy auditing programme is energy bills and their analysis. In the analysis of energy bills, it is essential a proper analysis of Power Demand/ seasonal variations and time of day variations are done. The electricity bill analysis should include electricity received from public utility, open access, standby power, power from other sources. In many cases the data given / analysed is being done only for power received from utilities.

Based on the extensive energy auditing experience of the author, the above issues are discussed through appropriate case studies. The case studies are diverse in nature giving a broad overview of the issues involved. These have been drawn from various energy audits conducted by the author.

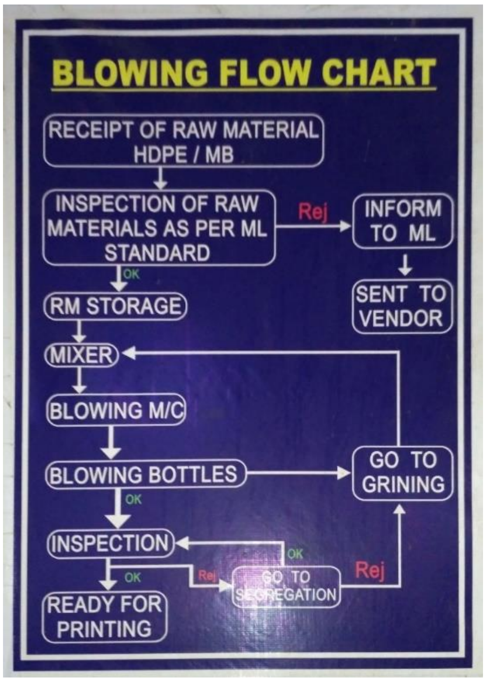
BENCHMARKING ENERGY CONSUMPTION-HDPE BOTTLE MAKING PLANT

This unit produces High-density Poly Ethylene (HDPE) bottles through Blow Moulding process. The bottles are then filled with vegetable oil and marketed. The raw material is virgin HDPE granules, recycled cut material and rejects from the moulding process. These are mixed in a particular proportion, ground to the required size and is moulded. The excess material is cut and reused. The moulding lines use heaters and chilled water for cooling the moulded bottles.

The bottles are then taken for printing the labels and finally to the filling and capping lines.

The basic flow diagram is given below.

Figure 1 Basic Flow Diagram



Present System:

The industry has been linking monthly energy consumption with the kL of oil bottled every month. The energy is spent on making the bottle/bottle caps and printing. The average specific energy consumption is 173.88 kWh/kL of oil filled. The specific energy consumption has varied from 132.01 kWh/kL to 251.21 kWh/kl- a wide variation. On analysis, it was found that the unit was accounting only the Electricity consumption from Public Utility. This unit also has captive wind mill power and occasionally power from standby DG sets.

Study Recommendations:

The study concentrated on collecting the data on electricity used from all sources public utility, wind power and standby DG power. The manufacturing process is for making bottles and oil is only filled. Further the size of the bottles varies and also the number of bottles. Therefore, it was recommended to monitor the energy in terms of raw material feed. The specific energy Consumption is given below as kWh/kg of raw material feed.

The average specific energy consumption is 2.11 kWh/kg of raw material feed. The specific energy consumption has varied from 1.78 kWh/kg to 2.63 kWh/kg. The unit has started now monitoring on the above procedure.

This data analysis led to another finding that 25% of the moulded product was in trimming the bottle and process rejects. This is recommended to be targeted to 20% in the first year and finally down to 5%. This could be achieved by better monitoring and also by improved mould design. This is estimated to save Rs.10.70 lakhs per annum with a very meagre investment on energy metering. The details are given below:

Table 1 Energy Savings- Reducing Re-cycle

Gross Production (kg/hr)	27.89
Nett Production (kg/hr)	15.16
Total wastage (kg/hr)	6.97
% wastage	25%
Target Wastage	20%
Avg. Sp. Energy Consumption Gross(kg/kwh)	0.60
Savings in Sp. Energy Consumption (kgs/kWh	0.1
Avg. Production per machine/hr	27.89
Savings/machine/hr (kwh)	3.34
No. of machines	7
No. of working machines	6
Annual hours of operation	7000
Total Energy Savings (kwh/Annum)	140327
Cost per unit (Rs. /kwh)	7.68
Annual Energy Savings (Rs. Lakhs/Annum)	10.78
Investment (Rs. Lakhs)	0.5
Payback in years	<1

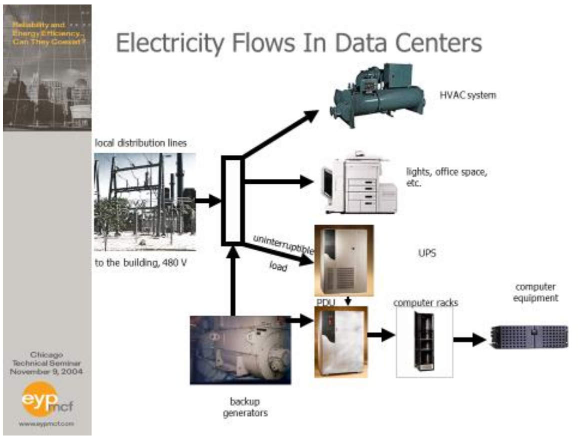
The key take away from this case study is to understand the process and not end product.

ENERGY MONITORING- DATA CENTRE

Present System:

The schematic of the energy use in the data centre is given below:

Figure 2 Energy Use – Data Centre

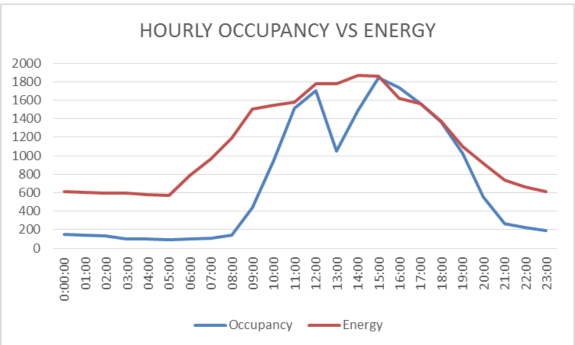


The energy is presently monitored based on the built-up area. This is 255.74 kWh/M^2/annum.

Study Recommendations

It was decided to evaluate the energy consumption with occupancy of the building. This data was not readily available with the data centre. This was collected on a sample basis for one day. Therefore, a representative data was collected for one day (based on card swiping). The same is given below

Figure 3 Energy vs Occupancy



The energy consumption is about 3.0 to 3.2 kWh/occupant/hr. This data if monitored regularly can control energy depending on occupancy levels as per the above curve. The key learning point from the above case study is to enhance monitoring and analytical capabilities- apart from routine monitoring in terms of kWh/M^2/annum.

DEMAND SIDE MANAGEMENT OF ENERGY:

Present System:

The Contracted Maximum Demand (CMD) of the data Center facility is 2600 kVA. The recorded demand has varied from 1350 to 2248 kVA. The demand charges have been charged for 80% of the CMD for most of the months.

Study Recommendations:

The study recommended to reduce Contracted Maximum Demand (CMD) to 2000 kVA and the cost savings are detailed below

Table 2 Cost Savings - Reduce CMD to 2000 kVA

Contracted Maximum Demand (kVA)	2600
Observed Demand -2014-15(kVA)	1942.1
Observed Demand -2015-16(kVA)	1761.6
Estimated Demand -working days (kVA)	1777.3
Proposed Demand (kVA)	2000
Demand Charges (Rs/kVA)	370
Billed Demand (kVA) 2015-16	2080
Demand Charges paid (Rs/annum)	9235200
Expected Demand Charges (Rs/Annum)	7821430
Cost Savings (Rs. Million/annum)	1.41

The facility operator was aware that he has excess Contracted Demand. There was a doubt in his mind whether power will be made available once the CMD is reduced. The audit measurements and analysis convinced him to initiate action to reduce CMD.

UTILITY ENERGY CONSUMPTION CHILLED WATER-PVC PIPE PLANT:

In any project utilities viz. chilled water, brine, compressed air are used. In most of the cases, the utility requirement is given on adhoc basis. The equipment supplier supplies only the equipment and not the system (in this case the chiller). The specific consumption of the chiller system for a screw chiller is around 0.8 kW/TR. All the manufactures specify the chilled water temperature as 7ºC. In this case, the required cooling temperature is 20ºC for cooling the extruded pipe.

This being at the project stage, the following actions were taken:

- Estimation of chilled water temperature and process cooling load.
- Assessment of variations in process chilled water demand depending on process requirements.
- Proper design of chilled water piping, pumps and insulation
- Selection of pumps on base load and variations in operating load.
- Discussions with the supplier on the specific energy consumption parameters
- Confirmation from the supplier on specific consumptions. The expected specific consumptions are given below:

Table 3 Specific Energy Consumption – Manufacturer Data

Load %	**Capacity (TR) @15ºc water temp**	**Compressor Power (KW)**	**IKW/Ton**
25.00 %	30.4 TR	24.4	0.802
50.00 %	40.1 TR	28.6	0.713
75.00 %	55.6 TR	36.6	0.66
100.00%	78 TR	47.7	0.611

The above measures resulted in savings of 25% over the existing system in the present plant. The key learning point is to get the proper data from the equipment supplier to suit process requirement.

<u>COMPRESSED AIR OPTIMIZATION –MACHINE TOOLS PLANT:</u>

In a light engineering industry which has Computer Numerically Controlled (CNC) and Vertical Machining Centers (VMC) apart from other machine tools. The machine tools have pneumatically operated solenoid valves. In order to design a proper compressed air system, the following data is required.

- Compressed Air flow (M^3/hr. Free Air Delivery-FAD).
- Compressed Air Pressure

The manufacturer was able to give only the nozzle size and the pressure. Therefore, the flow was estimated based on the nozzle size. With allowable utilization factors the compressed air requirement is 43 to 50 M3 /hr. (CMH) free air delivery at a gauge pressure of 6 kg/cm^2 at the user end. The unit was using an air compressor rated to deliver 115.5 CMH. The study recommended replacement of the existing compressor with an air compressor having Variable Frequency Drive (VFD) with the following benefits.

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Table 4 Cost Benefits – Air Compressor with VFD

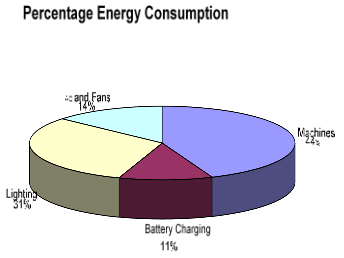
Expected Power (kW)	12.40
Power Savings (kW)	8.90
Annual Hours of Operation	4000
Energy Savings (kWh/annum)	35600
Energy Savings (TOE/annum)	3
Cost of Electricity (Rs./kWh)	8.23
Annual Cost Saving (Rs. Lakhs/yr.)	2.93
Investment (Rs. Lakhs)	6.23
Pay Back Period (yrs.)	2.12

The conclusion from the above case study is to insist on the Original Equipment Manufacturer (OEM) to provide the required utility data.

ENERGY EFFICIENCY PRIORITIES:

This study is for a railway workshop. The workshop undertakes a periodic overhaul of coaches. The energy consumption pattern was analyzed for each and every feeder.

Figure 4 Energy Consumption Pattern



As per the above lighting, AC and fans account for 45% of the energy consumption and the energy consumption by Machines 44% of the total monthly consumption. The expectations before the energy audit were that the energy consumption by the machine tools will be very much higher. On further investigations and study of the machine tools operation data, it was inferred that the machine tools were operated for few hours in a month whereas the energy consumption by lights were fixed.

Based on the report review and discussions with the Railway Officials, apart from routine interventions on lights, AC and fans, the following interventions were proposed and accepted.

- Replace the existing motors with energy efficient motors. This required an investment of Rs.5.00 lakhs with a payback period of above 4 years.
- Replacement of EOT cranes with a far higher investment with very long pay back periods. The Railways decided to book this under capital expenditure.

ENERGY SAVINGS EVALUATION-LIGHTING

The lighting savings are generally estimated based on the number of lamps to be replaced and assumed hour of operation as 12hours and 365 days. This is generally found erroneous based on the data below:

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Table 5 Savings Evaluation – Municipal Street Lighting

		Case1	**Case 2**
	Units		
Present Lamp		FTL	FTL
Present Wattage (inclusive of Ballast)	W	30	30
Proposed Lamp		LED	LED
Expected Wattage	W	18	18
No of Lamps		1112	1112
No of Working Lamps		no data	992
Total Power Savings	kW	13.3	11.9
Annual Hours of Operation	hrs	4380	4196
Energy Savings	kWh/annum	58447	49949
Cost of Energy	Rs/kWh	8.23	8.23
Value of Energy Savings	Rs. Lakhs/annum	4.81	4.11
Investment	Rs. Lakhs		
Cost of LED	Rs.	900	900
Total Investment	Rs. Lakhs	10.008	10.008

Table 6 Monthly Lighting Hours

Schedule	1	Regular Schedule											
TOU period	*Jan (Hrs)*	*Feb (Hrs)*	*Mar (Hrs)*	*Apr (Hrs)*	*May (Hrs)*	*June (Hrs)*	*July (Hrs)*	*Aug (Hrs)*	*Sep (Hrs)*	*Oct (Hrs)*	*Nov (Hrs)*	*Dec (Hrs)*	*Total (Hrs)*
Total	427.8	354.2	356.5	310.5	285.2	241.5	285.2	320.9	345	392.2	414	463.5	4196.4

In case 1, the data presumes all lamps are working pre-implementation and the hours of operation is considered as 12hours and 365 days operation i.e. 4380 hrs. /annum. In case 2 the number of working lamps are average data over 12 months by counting working lamps. The hours of operation are based on monthly dark hours based on weather data.

The key take away from the above case study is to collect the key data – in this case –hours of operation.

MEASUREMENT AND VERIFICATION:

It is very important to detail how the measurement and verification needs to be carried out for implementing the energy auditing measures. There should be a measurement and verification protocol before the implementation of recommendation and after implementation. The investment should include adequate instruments for measurement and verification. The savings should be normalized to the prevailing conditions before implementation (illumination levels, hours of operation, weather (for HVAC), process conditions etc. Therefore, appropriate adjustment factors need to be specified. It is also desired to monitor and sustain the savings.

WAY FORWARD:

Most of the audit studies are not defined properly. It is essential that the focus areas of the audit should be well defined. In a process industry, it is the process and linking it with energy use. Many audits focus on lighting and HVAC which may not be the focus area. The audit should focus on system instead of equipment. Many audits recommend replacement of existing pump with an efficient pump. Whereas the focus should be on water flow /cooling requirements of the process, piping etc. Similarly, it is illumination level as per standard should be the focus area instead of one to one replacement of the lamp.

There is also no need to specify energy audit for the entire facility. The audit can focus on specific areas like power distribution, utilities, process on a case to case basis. The audit also needs to focus on clear deliverables, constraints in implementation measurement and verification etc.

The select diverse case studies discussed above can hopefully give a generic guideline on the audit expectations, focus areas and way forward.

To conclude it is essential to have a proper energy monitoring mechanism in relation to your operations viz. commercial buildings, process industries or engineering industries. This will help in proper focus areas of energy audit and will ensure that the recommendations are implementable. It is essential that audits are followed by proper implementation plan, measurement and verification protocol. Well this should be the roadmap to make energy audits studies failsafe.

OPTIMIZING ASSETS FOR BEST PERFORMANCE

Pushkar Kumar, EcoEnergy, Canada

Keywords: Analytics, Asset performance optimization for Steel Manufacturer, Energy Savings

ABSTRACT

Manufacturing/Process industries today have yet to reach maturity levels in terms of capturing and using data related to energy, process or maintenance. SCADA and other intelligent systems help manufacturing plants capture information and store it. These systems generate a large amount of data on a daily basis and it builds over time. Many organizations do not know how to use this data effectively.

Manufacturing organizations will have several assets in place and it is immensely difficult to monitor the energy efficiency of these assets closely. There is a limitation to measure, monitor and analyse the energy of these assets in real time. One of the reasons for this limitation is the ability to collect data from multiple systems like SCADA, MES, and MMS, etc and have them collated on to a common platform for further analysis. What is needed is a technology platform that can integrate with almost all data aggregation layers to collect asset level information. This data can then be analysed to look for any deviations from operating standards. Acting on the deviations, ensures the efficiency of the assets.

A case study will be used to discuss an approach that we have followed to address the key issues faced by one of the integrated steel manufacturer and how our analytics helped them to optimize the assets for best performance.

INTRODUCTION

Industrial manufacturing is one of the biggest users of energy – the potential impacts of energy efficiency measures are very large. These industrial manufacturing organizations historically had been at the very forefront of adopting the use of data driven technologies to improve their operations – be it the use of SCADA system for managing a portion of the production or the use of automation systems for defect reduction/quality improvement or even designing layouts and equipment. However, in recent times the manufacturing organizations have fallen behind those in Retail, Hospitality etc., in use of innovative data driven technologies to drive down energy costs

without incurring massive capex needed for machines upgrades.

Even though there are massive opportunities, we have always felt following were the three key areas, which usually slow down a successful implementation:

- Proprietary nature of certain areas of manufacturing process
- Lack of a consistent data capture strategies adopted by the organization; including inadequate existing information capture
- Inherent mistrust of any recommendations of these data driven technologies by shop floor operators

At EcoEnergy, we have delivered savings to multi-billion dollar businesses in the Retail and Buildings sector across the globe. These vast experiences allow us to not just use the best and cheapest available technologies but also take the responsibility of delivering results and any associated implementation risks.

Steel manufacturers are a major consumer of energy & utilities with over a third of cost being spent on them and as such have a lot to gain from a successful implementation. However, it’s a very old industry with set processes with sometimes only pockets of data available for analysis from a single source. We were faced with not just the issues of analysis of vast amount of untrusted data but also challenges from non-believers from operational team, set very well into their regular tasks.

EcoEnergy`s task was to evaluate the entire plant, select area for maximum impact, deploy the solution and use it to provide actionable insights for water and energy conservation. This was accomplished over a 7 month of execution period, wherein we isolated easily implementable issues in the areas of utilities affecting both process and support systems for Hot Strip Mill, recommended actionable insights and provided ongoing performance monitoring for the period.

ABOUT ECOENERGY

EcoEnergy is part of UTC Climate, Controls &

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Security, a unit of United Technologies Corp -A $56.5 Billion, a fortune 50 Company, with 197,200 employees serving 180 Countries worldwide). At EcoEnergy, we use the latest technologies like IoT, big data and analytics to provide intelligent and sustainable solutions for enterprise-wide energy, operations and efficiency management.

EcoEnergy is the industry path leader in analytics-led Energy Savings programs and a '100 Most Promising Big Data Solution Providers 2016' as recognized by CIO Review. This solution offering is very scalable, is managing energy consumption, and spend for some of the world's largest organizations. To deliver this solution we first enable sites to capture granular data, link it to our platform, which then analyses it. The output is then used by Energy Operations Center to provide intelligent and actionable insights to the customers. The granularity of big data is providing us valuable insights that are being leveraged for energy savings, reducing asset maintenance costs, and enhancing customer experience.

We have built analytical models and correlation logics to deliver data analytics outputs supporting energy efficiency and operational improvements measures for plant & utility managers. Our analytics capabilities coupled with its ability to harness the power of IoT, bridges the gap between information and action, to achieve the high cost savings. We leverages our centralized Energy Operations Center to uncover energy saving opportunities 24x7 and plug them immediately. So far, it has served its clients with over 1.8 billion kWh in energy savings and over $100M real money saved.

We provide industrial manufacturing customers with the following services:

. Compliance monitoring and Operation analytics

- Enterprise level monitoring of compliance
- Platform based reporting of Compliance & Operation performance

. Energy efficiency Performance management

- Analytics based management of process and asset operations in sites
- Actionable insights for operations team to act

Maintenance management and Analytics service

- Analytics based model to migrate to condition based maintenance
- Remote & guided maintenance recommendations for operational teams in plant .Peak demand management service Analytics based demand management and monitoring service
- Manage demand without compromising on standard requirements

We typically start these services for support assets like HVAC&R and then move to key operations assets depending on the comfort of the customer.

EcoEnergy also takes end-to-end responsibility for delivering the desired results and prices its services, for its Industrial customers, based on their needs.

BACKGROUND, CHALLENGES& SOLUTION

In past few years, falling commodity prices and a general slowdown in economy has resulted in significant push to further optimize the operational costs. The same was true with one large integrated steel manufacturer with which EcoEnergy worked with. We at EcoEnergy worked with their Americas business unit and used our proven methodology to help them with operational & utilities cost management. In this particular case, the plant that we worked with was further faced with additional challenges in form of rising water costs due to local draught situation.

The key aspect, during solution initiation, in a very large plant situation is to identify an area, which is most likely to have savings impact before full rollout. For this customer, we jointly zeroed in at an area that used significant amount of water, electricityand other utilities, so that any reduction in utilities cost will be immediately visible and thus make rest of the implementation more acceptable with all stakeholders. During deep dive of the process and the support infrastructure for this area – we identified over 200 assets that needed to be monitored and analyzed for effective energy, operations & water cost management recommendations.

The assets included a mix of operational and support systems like:

1. Pumps
2. Furnaces including specialized reheat-furnaces
3. Cooling Towers
4. Cooling Tower fans
5. Descaling Jets
6. Finishing and Roughing Mills
7. Conveyor rollers, etc.

For all the assets, we worked collaboratively with the manufacturer to identify the key process parameter & the ones that are readily available; we also then worked with the customer to identify the database (or system) that is most likely to capture and store this desired information. In this case, we saw that we needed to integrate both online & offline information from multiple databases (L2/ L3 and SAP or production system). Certain data points were directly available from SCADA system, but we decided to work with L2 & L3 systems due to the sensitivity involved with the SCADA systems.

Once the data collection sources are identified, the team then worked to establish an online & offline data collection methodology. Typically, we have observed that plants can be grouped into four groups based on their maturity with the automation / data driven technologies – ranging from manual operations to highly automated and data driven.

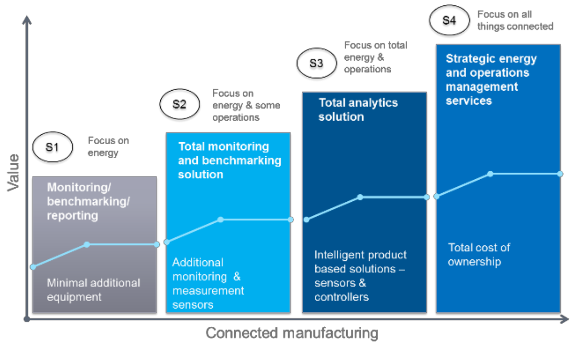


Figure 1: lant maturity model

Based on a plant`s position on the maturity curve, EcoEnergy devises a lowest cost connectivity and data capture solution to progressively give the organization quick wins and generate returns. We usually advise a progressive upgrade of plant with sensors & sub-meters as full integration with 100% real-time analysis may become very costly solution to start with for many manufacturing organizations that are still beginning their Digital / connected manufacturing journey.

Just collecting data or having software to analyse does not mean that one would be able to figure out the savings. Analytics capability requires collaboration between data analysts and domain experts. In addition, given that, data is voluminous, structured methods and toolset is necessary for complete analysis across all sites.

Our methodology is thus typically a mix of offline and online data aggregation & subsequent transfer to the EcoEnergy platform for analysis. Post the initial data collection – we spend time to perform preliminary analysis. A preliminary analysis of the data is done in order to identify parameters affecting energy consumption. In industrial manufacturing environment, EcoEnergy has found that majorly, the factors affecting energy consumption are as listed below:

- Production of goods (plant output)
- Physical units (produced/shipped)
- Value added
- Capacity utilization
- Technologies in place
- Operations costs and cost of energy
- Asset operations performance data

APPROACH

EcoEnergy deploys its program over the engagement period utilizing three major saving levers. These are simple saving levers but with our experience, we understand that these are powerful tools and the structured approach helped us to deliver savings to our customers.

1. **ashboards and visibility**: Better data visibility helps the organization to make the informed decision. For this at EcoEnergy, we provide both depth and breadth in both time and space to deep dive further. Key Performance Indicators (KPI) are identified and mutually agreed with the customers and dashboards are used to monitor the performance over time.
2. **eviation and Problem management**: Here we focus savings identified through rule based deviation management and delivering savings through short-range analytics. Any deviation from the policies, schedules , mode of operations are detected by platform and the adherence to the same enforced by informing to the operations team at plants at the earliest so that they can act on it .
3. **Advanced analytics**: The analyses of the richer and long-term data helps to maximize the effectiveness of the deployed savings levers and the identification of new and more granular saving strategies. EcoEnergy uses sophisticated tools and techniques beyond those of standard Business Intelligence to discover deeper insights, make predictions and generate recommendations.

PLATFORM BASED ANALYSIS AND INTELLIGENT INSIGHTS

Our energy & operations models, sets us apart from any other energy management system by distributing the facility/process into Service Consumption Areas (SCAs) & Meter Service Areas (MSAs). An SCA is an area/process, which is receiving the similar kind of energy service and has a standard operating policy. The MSA is a group of SCAs, assimilation which can provide us an understanding of the quantum of energy consumption through meters & sub-meters.

The data points (raw data) that are pulled from the site through the SCADA, different data base systems and /or data aggregator are processed through the algorithms & intelligence built into the EcoEnergy platform to give processed information and subsequent intelligent insights to plant engineer or plant manager.

The challenges remain post pulling the data from different sources, these typically are related to:

1. Mismatch of information leading to incorrect inference and subsequent recommendation
2. A time-consuming job of interpreting each data, converting them to same format and then processing it on an ongoing basis
3. Different data sources will typically have different data capture frequency, which if not matched properly will again result in incorrect inferences

Different data bases or sensors will collect data differently (or even erroneously) and thus will be subject to different type of errors – each thus needs to be thus handled differently

Once the system is set up for churning out utility & operational improvement recommendations the typical issue faced is that from operations management team of the plant. This we typically manage by early involvement of the key representatives of the operations team and who become a part of the joint project governance team. We typically recommend the two tiered governance structure, as was in this case too:

a. Project Operations: Meets bi-weekly and includes the key decision-makers of the business area to be involved.

b. Steering Committee: Meets monthly and generally involves project champion and the project executor

RESULTS

The results of the project were exemplary and key being the following:

1. Low cost actionable recommendation for energy savings with furnaces alone at over 2.5% for Hot Strip Mill.
2. Recommendations for up-to 5 % savings in Utility consumption Hot Strip Mill and Water treatment system.
3. Recommendations for Connected & Intelligent operation for the Hot Strip Mill process & Waste Water treatment

Key for all our recommendation was that it did not involve any additional CAPEX or production process changes and yet they achieved the desired outcomes.

USE CASE

EcoEnergy collected historical data for a period of three months from the PIMS Databases for the reheating furnace, in an integrated Steel Plant. The data was then exported to EcoEnergy platform along with the plant operational policies and standard operating procedures.

For Reheating Furnaces, EcoEnergy team performed advance analytics through the platform on the following four parameters that the platform had identified as most significant parameters:

- Furnace temperature
- Residence time
- Slab physical details
- Operational policy
- Energy consumption (Fuel)

Platform then identified that the slabs were running with significant temperature variation and an average pf over 13 degrees were noticed which is depicted in the below trend, with a significant portion of slabs running over 50C higher than needed (as specified by operating procedure):

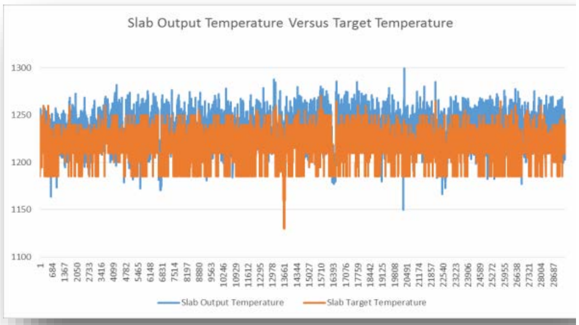
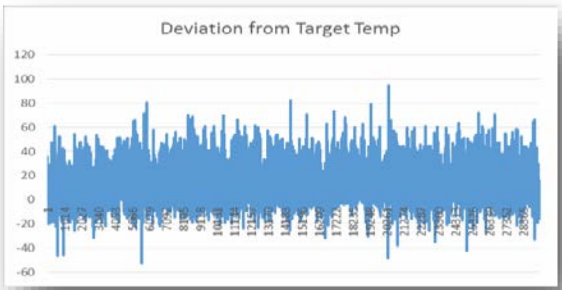


Figure 2: Furnace performance Slab Output Temperature, Target Temperature speriod

Following outcomes were measured through the platform:-

- Average Output Temperature = 1233 °C
- Average Target Temperature = 1220 °C
- Average Slab residence time = 3.4 hours
- Average Slab T 1000 °C

Hence the slabs remained 2.65 minutes more than required.



Calculations:-

- Total time lost per hour = (47 * 2.65) = 124.55 minutes = 2.07 hours
- Throughput lost per hour = (2.07/3.4) slabs = 0.61 slabs
- Average slab mass = 24.4 tons
- Throughput lost per hour = (24.4 * 0.61) = 14.9 tons
- We then worked with the team to understand if can try to make sure that the extra time & energy lost due to overheating could be managed – giving the client both cost management opportunity and a throughput increase. We suggested through our data-analytics that just in this reheating furnace step they could save over 2.3% (a significant non-capex operational improvement) of energy without unduly stressing the downstream machinery.

CONCLUSION

The Industrial Manufacturing sector has many data already in place for effective use of data driven efficiency measures. However just data analytics alone never yields a desired "efficiency outcome". A successful implementation needs an implementation partner who can work with multiple online & offline data sources, effective inclusive strategy for all key stakeholders, has a pedigree of a proven analytics platform and an implementation team which has a mix of data analysts and subject matter experts that understand a plant implementation environment. This partner has to be able to combine all aspects, use analytics and then provide an actionable insight.

The use of the new age IoT, data driven analytics technologies can add a lot of value, as was illustrated by our successful implementation at one of the largest steel manufacturer. The organization was easily and quickly able to visualize energy & efficiency leakages and plug them by way of our actionable insights. This was achieved without changes to their production process and focusing initially at the utilities and the support infrastructure

Typically, the manufacturing organizations can easily reduce upwards of 5% of energy costs; reduce over 5% of maintenance costs and improve upon compliance /quality. Further, the organizations such as Pharmaceutical and Food & Beverage manufacturers that consume many utilities in support assets (like HVAC / R, boilers etc) stand to realize these efficiencies gains the fastest.

NOMENCLATURE

SCADA = Supervisory Control And Data Acquisition

PIMS = Production Information Management System

MES = Manufacturing Execution System

MMS = Maintenance Management System

L2 = Level 2 information

L3 = Level 3 information

UTC = United Technologies Corporation

IoT = Internet of Things

HVAC&R = Heating, Ventilation, Air Conditioning and Refrigeration

CAPEX = Capital expenditure

ENHANCING UPTAKE OF COMMERCIAL FINANCE FOR ENERGY EFFICIENCY AT MSMEs IN INDIA

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Keywords: Energy efficiency, Resource efficiency, Cluster, MSME, Revolving fund, Loan

ABSTRACT

Traditionally, Indian Micro, Small, & Medium Enterprises (MSMEs) have been demarcated as technology deprived, resource in-efficient, lack financial acumen, but off late, the new age entrepreneurs are defeating the said notions. “with rising competition and shrinking margins, MSMEs need to lower their input costs, upon analysis from experts, its figured out that energy is one of the major input costing the overall production cycle” said Samir Sood, Managing Director of India Forge. A smart entrepreneur, Samir realized that old and inefficient manufacturing practices would eventually make him uncompetitive and hit his bottom line. Being in an energy intensive sector, he was keen to lower costs through judicious energy consumption, but he was not aware as to where he must go or whom to approach for such solutions. This is where the project ‘Financing Energy Efficiency at MSMEs’ (FEEM) pitched in. The Government of India, in 2010 launched this project with an objective “to increase demand for energy efficiency investments in MSME clusters and to build their capacity to access commercial finance”, which was also supported by the World Bank’s Global Environment Facility (GEF) program with a grant funding of US$ 11.30 million. The project is jointly implemented by Small Industries Development Bank of India (SIDBI) and Bureau of Energy Efficiency (BEE). This particular project builds upon the success of the World Bank Global Technical Assistance Project "Developing Financial Intermediation Mechanisms in China, India and Brazil".

INTRODUCTION

The concept of ‘Resource-Efficiency’ (RE) is nothing new to the Indian manufacturing sector. Thanks attributing to energy shortages, rising costs, increasing automation, and freakish threats out of rising pollution levels and climate change, one can rightly assume that almost every manufacturer have embraced eco-efficient strategies in their production processes. It has, perhaps, became a critical trend in the recent years. Yet, the manufacturing production range is so vast that its supply chain is one of the most and complex one that one solution can’t fit all. It involves production and fabrication of raw materials (aluminum, chemical, steel, plastics, thread, etc.), semi-finished materials (cloth, dyes, wiring, cable, hardware, etc.) and suppliers of components and subsystems extending up to three tiers. The auto components industry, textiles and chemical sector in particular, are dominated by SMEs (Small and Medium Enterprises) and are highly fragmented. Need to improve one’s bottom line is critically important given the ‘Internationalization or globalization’ of every component or process, thus leading to ‘survival of the fittest’ theory. Any sustainability and resource management initiative in the MSME sectors are bound to remain dormant without an active participation of micro, small and medium-scale suppliers. The FEEM project is a step towards this direction where industries are provided not only technical support to identify and implement resource efficiency measures but at the same time, innovative financial methods too, which help them embrace these solutions with full confidence.

SIMULATION AND/OR EXPERIMENT

In a bid to bridge the gap between MSMEs, energy auditors, technology suppliers and financial service providers on energy efficiency projects, the Global Environmental Facility (GEF) under its Programmatic Framework for Energy Efficiency in India took up this initiative in the form of a project to increase the demand for energy efficiency investments in targeted MSME clusters and to build their capacity to access commercial finance.

As a part of BEE’s larger campaign of Energy Efficiency and SIDBIs commitment to strengthen the financial landscape in the MSME sector , this project engaged in focused efforts in five targeted clusters of forging, chemical, and mixed industries – Ankleshwar (Gujarat), Faridabad (Haryana), Kolhapur (Maharashtra), Pune (Maharashtra), and Tirunelveli (Tamil Nadu). It mobilized a large group of ‘decision-ready’ units in partnership with local

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financial institutions in specific clusters. Based on the findings of project-supported energy audits, enlisted units receive support in preparation of bankable Detailed Project Report (DPR) or application documentation to process loan applications under current or new lending schemes and hand-holding support in reaching financial closure for identified investments.

The beneficiaries of the project are not just the participating MSMEs, but financial sector stakeholders, energy professionals, and industrial associations are also seizing new business opportunities. The small manufacturing units are increasingly becoming cognizant of financial returns gained because of energy efficiency investments and are acting as a model to emulate by similar other industries.

Six more clusters were identified for the next phase of the project – Delhi NCR, Varanasi (Uttar Pradesh), Ludhiana (Punjab), Mumbai-Thane ((Maharashtra), Sri Ganganagar (Rajasthan), and Dehradun (Uttarakhand). Here, smaller but potentially high energy intensive industries were targeted which readily adopted the said measures. This time, the focus was more on resource efficiency including lean manufacturing practices & cleaner production options, which not only increased the overall investment size but made the industries ready to enhance their business perspective in the international markets.

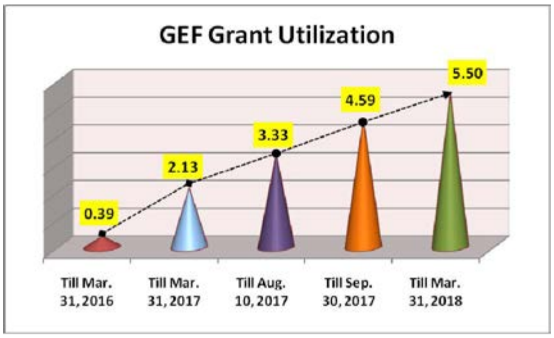
DISCUSSION AND RESULT ANALYSIS

The project carried out walk thorough audits in more than 1000 units of the five clusters selected in the first phase. Energy efficiency measures were identified and resulted in formulating 600 Investment Grade Detailed Project Reports (IGDPRs). As this was a learning phase for the project team also, the focus on energy efficiency (EE) alone resulted in lower investments on EE measures to the tune of average INR 11 lakh per unit. In addition, the industry was also not coming forward to implement big ticket solutions identified in the audits. The project devised an innovative financial mechanism namely 'Performance Linked Grant – PLG' to bring some momentum but because of low average investment identified, fuller potential was not realized.

In the second phase, when the efforts moved from EE to resource efficiency (RE) with lean manufacturing (LM) & cleaner production (CP), makes a foray into the IGDPRs. The industry saw the benefits coming with these measures were interested in taking up the implementation forward. SIDBI meanwhile was strengthening the lending portfolio and developed one programme i.e. End-to-End Energy Efficiency (4E) program and is able to channelize financing at a good number of industries on pan India basis. As a fantastic result of 4E programme which was basically formulated under the FEEM project with GEF grant amount of US$ 3 million (Out of total grant funding of 11.30 million), the average investment size has enhanced significantly from INR 11 lakh to INR 81 lakh. This sudden jump in the EE investment is due to several factors a) Financing of process related energy efficient machines as technology up-gradation & modernization measures alongwith retrofit based EE projects after conducting detailed energy audits and preparation of DPRs b) offering highly competitive rate of interest (lower than commercial lending), interest subsidy from 2.05 to 3.85% depending on PLR and credit rating of MSME c) maximizing the coverage of loan amount upto 90% of total project cost. If we look at overall achievements of FEEM project as on Mar 31, 2017, out of the 3,200 Investment Grade Energy Efficiency Improvement Measures (EEIMs), about 2,500 have been implemented by 650 MSMEs with an Investment of around INR 130 Crore out of total committed INR 200 Crore. These investments are resulting into energy savings of 14800 TOE/Yr which is almost 11% reduction in total energy consumption of these MSMEs and giving a monetary savings of INR 100 Crore. That have helped to achieve lifetime (15 years) emission reduction of 1.12 million tons of CO_2 through direct interventions, which is further expected to increase upto 1.5 million tCO_2.

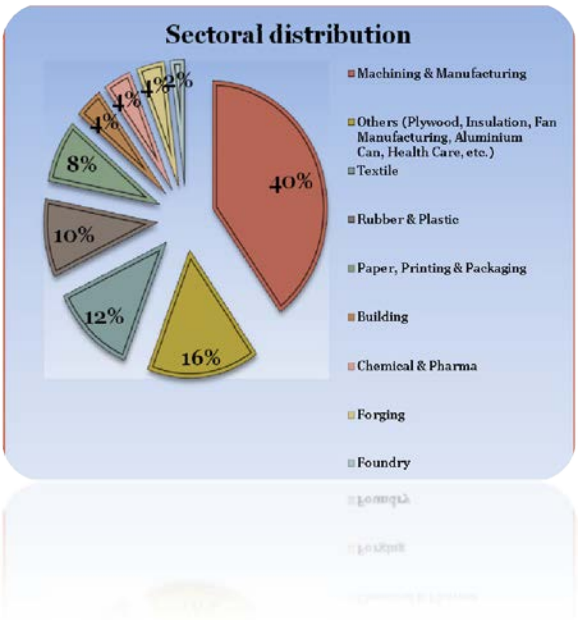
NUMBERS SPEAK

Till March 31, 2016, a very small fraction of total Revolving Fund was utilized (GEF part) i.e. US$ 0.39 million. Till March 31, 2017, the utilization has increased to US$ 2.13 million. Till Aug 10, 2017, the investment has not in increasing trend i.e. US$ 3.33 million. If we look at the frequency of such loan requirements at all India level from around 25 branches of SIDBI is now taking momentum. Another newer cases amounting to US$ 1.26 million are under appraisal at these branches, which is expected to be sanctioned by end of Sept 2017. Balance US$ 0.91 million is still to be utilized during additional financing phase. Based on results, achievements, gains, feedbacks from various



stakeholders like MSMEs, Industry Associations etc., the World Bank and GEF has further extended the project with an additional grant funding of US$ 5.19 million to cover 230 more MSME units in 16 different cluster locations till 2019. This additional grant also consist a top-up amount for 4E scheme to the tune of US$ 2.5 million. With this additional grant total FEEM project outlay is US$ 16.49 million consisting of 4E financing scheme fund of US$ 5.5 million. This 4E grant fund of US$ 5.5 million has been further topped-up by SIDBI with US$ 16.5 million (three times), making total outlay of 4E financing fund of US$ 22.5 million.

ANALYSIS ON LOAN SANCTIONED CASES UNDER RF



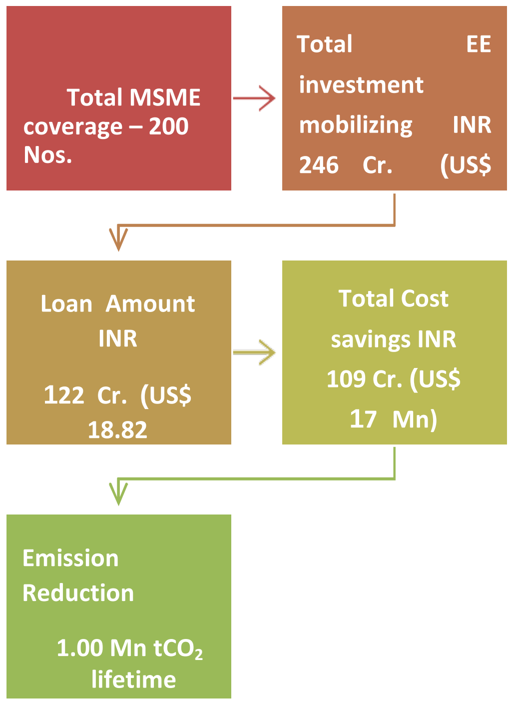
If we look at sector-wise distribution of cases covered, machining units are on top which are mostly auto ancillary units manufacturing different variety of products like tube assemblies with fittings, hose assemblies, hydraulic fittings, Precision turned auto components for Two wheeler & Four wheeler automobiles, diesel fuel injection pumps & its parts for engineering and automobile industries, etc. followed by a category of others which are manufacturing different type of products like plywood, insulation, fans, aluminium cans etc. then textile, plastic, rubber, packaging, building, chemical

INNOVATION IN FINANCIAL INSTRUMENT – SUM UP

- Providing Technical End-to-End Hand holding support along with financial assistance to MSMEs (First time in any financing scheme).
- Resource Efficiency covering Cleaner Production and Renewable Energy projects along with EE retrofits and technology up gradation
- Competitive rate of interest as on current market conditions due to blending concept used for concession in rate of interest
- Term loan upto 90% of project cost max. 1.5 Cr.; borrower contribution is only 10%; which is otherwise normally be 25%.
- Rolling out the scheme at all India level through its associate company called India SME Technology Services Limited (ISTSL); (Promoted by SIDBI and four other nationalized banks viz. State Bank of India, Oriental Bank of Commerce, Indian Bank, Indian Overseas Bank) with its empanelled consultants on pan India basis around 70 consultants.
- Verifying the actual results through independent third party agency by Measurement and Verification audits after implementations.
- Significant reduction in GHG emissions through Resource Efficiency.

WHAT NEXT?

The project got featured in the India's Intended Nationally Determined Contribution (INDC) document complimenting it for substantial energy savings, quality improvements and enhanced competitiveness for the Indian MSMEs. Overall expected result from utilization of US$ 5.5 million till March 31, 2018 in addition to FEEM project:-



CONCLUSION

Making the production processes and operations more energy efficient is likely to evolve as a new norm in the Indian manufacturing sector. With the vision of 'Industry 4.0' and 'Smart Manufacturing' pitching in, the scope for industrial energy efficiency is wide open. Application of information and communication technologies (ICT) in the energy management will offer real-time monitoring and data analytics. However, the structural challenges faced by SMEs in access to low-cost finances and technologies are still huge. What the project has achieved is just a small portion of this larger MSME segment. There is a need for systematic support and patronage from all major stakeholders involved in the MSME support system. Financial agencies and energy professionals need to imbibe what SIDBI & BEE has done and probably devise out mechanisms to identify and finance those proposals from SMEs. In this regard, knowledge sharing and awareness, along with training and skill development, becomes important. With enhanced performance and competitiveness, enabled by energy management systems, SMEs can engender sustainability in their businesses, both in terms of environmental impacts and business model.

REFERENCE

The project, in its website www.indiasavesenergy.in , created a 'knowledge bank' that lists out all suggested energy efficiency technology interventions and retrofits, along with a long list of vendors who can supply those solutions and financing schemes, as a commitment towards knowledge building and awareness. Newsletters, YouTube videos, and media advertisements have are also helped the project reach among a wider base of MSMEs.With such motivation, the project is entering a new phase where it is working with 16 energy intensive heterogeneous clusters with a budget of USD 5.19 million. The project is also aligning with Govt. of India's initiative like ZED and Skilling India to carry forward the message of Zero Defect and Zero Effect as well as job ready work force that India needs as Make in India program achieve success.

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MODERNISATION OF INDIAN BRICK MANUFACTURING SECTOR: USE OF ENERGY EFFICIENT TECHNOLOGIES

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Keywords: Clay-fired brick, coal consumption, energy efficiency

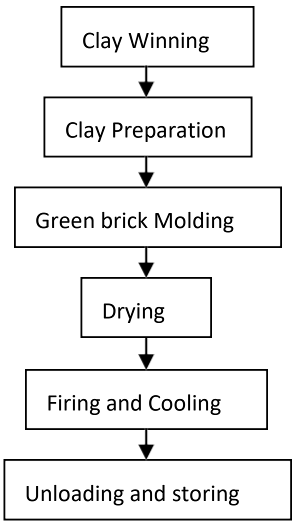
ABSTRACT

Construction is the second largest economic activity in India and has contributed around 8% to the nation's GDP during 2006/07 to 2010/11. It has been estimated that 70% of the building stock in the year 2030 would be built during 2010 – 30. Clay-fired bricks are one of the oldest known building materials and an important constituent of construction sector. In-spite of competition from a number of alternate building materials in the market, bricks are the preferred walling material in India. Brick manufacturing is one of the prominent industries positioned in Micro, Small and Medium Enterprises sector in India. The industry is labour intensive and typically characterised by use of inefficient manufacturing technologies. Brick manufacturing consumes 220-280 billion tonnes of coal annually and is among the highest coal consuming industry sub-sector in the country. The industry faces a number of challenges that impedes its modernisation process. The paper discusses options for energy saving and futuristic technologies relevant for modernisation of Indian brick manufacturing sector.

INTRODUCTION

Construction is the second largest economic activity in India and has contributed around 8% to the nation's GDP (at constant prices) from 2006-07 to 2010-11 (Niti Aayog, 2015). The Government of India has taken various initiatives to improve India's residential and transport infrastructure (Smart Cities project, Housing for All by 2022, Atal Mission for Rejuvenation and Urban Transformation and easing of FDI norms in 15 sectors including real estate and construction). Mckinsey (2009) have estimated that total floor space requirement by commercial as well as residential sector in India by 2030 would be 41 million square meter, an increase of 583% from requirement in 2005. The on-going initiatives and estimates indicate that the infrastructure development and related construction activities in the country are expected to rise in future. Brick along with steel and cement is an important constituent of the construction sector.

Brick manufacturing is one of the prominent MSME sub-sectors in India. Clay-fired bricks are among the oldest known building materials; both mud bricks and baked bricks were used in the construction of the Indus civilisation's large cities, such as Harappa, Mohenjo-Daro, KotDiji, Ganweriwala, Rakhigarhi, and Lothal (Kumar et al., 2017). Traditionally, the word 'brick' is exclusively associated with building units made of burnt clay (BDA, 1974). Bricks are manufactured in 'brick kilns' that are mostly located in clusters and are spread throughout the country. Brick manufacturing is a seasonal activity and to avoid rainy season, brick kilns are generally operated during November to June in a year. Brick manufacturing provides significant employment opportunities to the rural poor during non-harvesting season. It is estimated that brick industry employees



more than 10 million workforce, most of which is migratory and consists of unskilled personnel.

The raw materials for brick manufacturing are clay and water. Depending upon the availability, brick kiln uses different types of solid fuels for firing of green bricks (freshly molded brick with moisture). These include coal (different grade and quality), pet-coke and biomass (firewood, sawdust, mustard stalk,

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rice husk, etc.). However, coal is the main fuel being used in brick manufacturing process in India (Kumar, et al., 2017). Almost entire brick production in the country is in the form of solid bricks and so far the industry has witnessed limited level of mechanisation.

The basic principles of brick manufacturing are fairly uniform throughout the country. It essentially consists of mixing ground clay with water, forming it into the desired shapes followed by drying, firing and cooling (figure 1). An individual unit may undertake certain variations to adjust to their particular raw material and method of operation. Several types of kilns are used for firing of green bricks. Based on nature of operation, the brick kilns are classified into intermittent and continuous categories. In intermittent kilns, green bricks are placed along with fuel in a particular pattern and fired. The bricks are then allowed to cool. The kiln is emptied, refilled with green bricks and a new fire is started for each load of bricks. In this type of kiln, the heat contained in the hot flue gases and the fired brick is lost. In continuous kiln, fuel is fed continuously/ periodically and bricks are being warmed, fired and cooled simultaneously in different sections of the kiln. Heat available in flue gas is utilised for pre-heating green bricks and the heat in fired bricks is used for heating air for combustion. Therefore, continuous kilns are more energy efficient as compare to intermittent kilns. Bull's Trench Kilns (BTKs) - continuous type of brick kiln, and clamp kiln - intermittent type of brick kiln, are the main brick firing technologies used for firing of bricks in the country. Use of BTK is more common in northern and eastern part apart from small pockets in central, western and southern India. The clamp kiln technology is prevalent in southern, central and western part of the country. More than 80 percent of the total bricks in the country are produced using continuous brick firing technologies. BTK is the most commonly used continuous type of brick firing technology in the country.

The paper discuss the energy consumption pattern in brick manufacturing sector in India and recommend the options that can help in reducing the resource consumption and make this sector more sustainable

ENERGY CONSUMPTION IN BRICK MANUFACTURING

Brick manufacturing is an energy intensive process. Being an un-organised activity, the industry specific parameters like size, energy consumption, production, turnover etc. are not readily available for this sector. A national level study undertaken by TERI during 2013-15 had estimated that industry account for sizeable share of coal consumption in the country (table 1).

Table 1: Brick production and resource consumption by Indian brick sector

SR NO.	PARAMETER	RESULT
1	Number of brick kilns**	190,000- 280,000
	Clamp kiln	147,000 - 232,000
	BTK	42,000 - 47,000
	Others	500 -1000
2	Annual brick production (billion)	220 - 280
3	Annual coal consumption (million tonnes)	29 - 35
4	Annual biomass consumption (million tonnes)	12 - 16
5	Annual top soil consumption (million m^3)	400 - 500
6	Annual water consumption (million m^3)	200 - 235

Source: TERI (2015a)

** The results are based on joint analysis by TERI and PSCST, **The estimate of number of clamp kilns in operation can vary significantly depending upon the market demand. Clamp kilns are not registered and are not members of any industry associations.*

The coal consumption by different industry sub-sectors in the country is shown in figure 2. It is evident from the figure that brick manufacturing is among the largest consumer of coal consuming sub-sectors in the country.

During brick manufacturing process, energy is needed to meet the following two basic requirements:

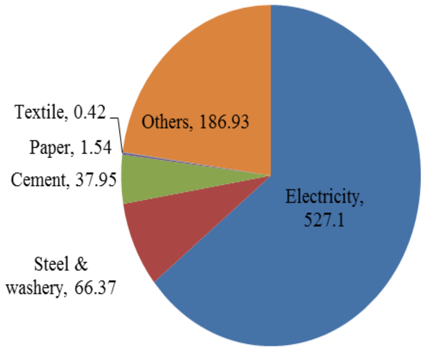

Figure 2: Industry wise consumption of raw coal in million tonnes (2014-15 (p))

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Source: CSO (2016)

- To remove the mechanical moisture, added during the green brick moulding process, from the green bricks
- To complete the irreversible chemical reactions such as decomposition of pure clay component, removal of combined water, decomposition of carbonates etc.

Majority of the brick kilns in India uses manual clay preparation, green brick molding and firing process and therefore use of electricity in the sector is quite low. Thermal energy in kiln section accounts for major energy consumption in brick manufacturing process. The typical specific energy consumption (SEC) of main brick firing technologies in India is provided in table 2. The large variation in SEC within a technology is due to difference in operating practices, variation in raw material and fuel quality etc.

Table 2: Specific Energy Consumption of different brick firing technologies

TYPE OF BRICK FIRING TECHNOLOGY	SEC (MJ/ KG-FIRED BRICK)
Clamp kiln	1.5 – 3.5*
BTK	0.95 – 1.82*
Vertical Shaft Brick Kiln (VSBK)	0.8 – 1.2#
Zig-zag kiln	0.91 – 1.15@
Down-draft	1.78 – 3.14*
Tunnel kiln (coal fired-Vietnam)	1.34#
Hoffman kiln	1.21 – 1.52@

**TERI (2014), PSCST (2013); #TERI (2005); @PSCST (2013)*

The efficiency (minimum energy requirement / total energy consumed) of main brick firing technology - BTK varies between 35-50%. The typical energy balance of a few brick kilns operating on BTK technology in different geographical locations of the country is provided in table 3. It is evident that more than half of the energy supplied to the BTK is not utilised gainfully and is lost to the atmosphere.

Table 3: Energy balance of BTKs (MJ/kg-fired brick)

	PARAMETER	WEST BENGAL*	PUNJAB*	UTTAR PRADESH**
	Energy input (SEC)	1.0	1.59	1.15
Useful energy	Irreversible chemical reaction in clay	0.47 (47%)	0.59 (37.2%)	0.44 (38.3%)
	Drying of bricks	0.1 (10%)	0.08 (4.7%)	0.085 (6.5%)
Measured heat losses	Flue gases	0.04 (3.8%)	0.09 (5.9%)	0.11 (9.6%)
	Surface	0.15 (15%)	0.37 (23.2%)	0.25 (21.7%)
	Sensible heat in fired brick	0.04 (3.9%)	0.06 (3.45%)	0.06 (5.1%)
	Unburnt carbon in ash	Negligible	0.02 (1.2%)	0.09 (8.2%)
Unaccounted heat losses	Ground and kiln structure	0.20 (20%)	0.39 (24.2%)	0.12 (10.6%)

*Source: *TERI (1999), **TERI (2015b)*

BARRIERS AND DRIVERS OF CHANGE

Indian brick sector is characterised by the presence of large number of brick kilns located in many geographical clusters spread throughout the country offering similar product- solid brick with exception of few clusters producing Resource Efficient Bricks (REBs) like perforated brick, hollow block etc.

Till mid-1990, the Indian brick sector had not witnessed any major change in production process. However, stack emission norms notified in 1996, to control the emission of suspended particulate matter (SPM) from brick firing process, were major driver of change in this sector. The moving chimney BTK[1]

[1] This type of chimney was made up of mild steel and was kept over stacked green bricks in the kiln. During kiln operation, the chimneys were moved manually over the kiln.

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operating at that time were mandated to adopt fixed chimney along with gravity settling chamber (GSC) as a mode of air pollution control devise. The transition from moving chimney to fixed chimney took 5-8 years. The introduction of improved fixed chimney design with large sized flues increased the draft that resulted in increased production and improved thermal efficiency of the kiln. The process of this change-over provided the opportunity to research institutes, academia, consultants and funding organisations to look more closely on this more or less neglected sector of economy. This gradually led to increased focus on different aspects of brick kiln operation in the country.

In recent years, the increasing fuel prices and the difficulty in sourcing labour has forced the brick kiln entrepreneurs to look for the alternatives in terms of better firing technologies that consumes less fuel, viable mechanical options for clay preparation and green brick moulding, and production of REBs in place of conventional solid bricks. The brick industry in the country is in the process of transition and it needs to transform itself by adopting more sustainable options. Some of the barriers that inhibit the transformation of Indian brick sector are highlighted below:

a) Low level of awareness among entrepreneurs and in-house capacities: A large number of brick kiln entrepreneurs are not aware of energy efficient and environment friendly technological options available within the country or at global level. Further, the in-house technical capacities of brick kiln units are quite low for technology adoption.

b) Limited availability of technology suppliers and local service providers: The brick sector is witnessing increased interest in adoption of mechanisation. The brick kiln entrepreneurs are looking for techno-commercially viable options for mechanisation of clay preparation and green brick production process. However, there is limited availability of indigenous equipment/machinery manufacturers/suppliers. The machinery manufacturers generally offer standard machines that have to be modified as per the specific site conditions. There is lack of technical backup support from the machinery supplier and there is complete absence of local service providers to extend required services to the sector. The technologies offered by European machinery suppliers are invariably expensive. Realising the large market base in the sector, some European technology suppliers like De-Boer, Verdes, etc. have set up equipment manufacturing facility in the country.

c) Absence of trained work-force: The brick kilns are operated by unskilled and illiterate workers hired on contractual basis. These workers migrate from their native places to work on the brick kilns. While working on the kiln, they learn the art of brick kiln operation. There is no formal training process that specifically focuses on important aspects like brick kiln firing and modern clay preparation and brick moulding techniques.

d) Lack of financing options: Due to un-organised nature of the industry, brick kiln entrepreneurs lack skills of record keeping and maintaining proper documentation. This makes it difficult for banks/financial institutes to provide financial assistance to brick kilns. There is a need for customised financing solution from banks/financial institutions that suits the brick manufacturing sector.

e) Lack of research and development (R&D): Considering the importance of brick sector in terms of energy consumption, employment generation, number of units, geographical spread etc. there is lack of focussed research in this sector. Government of India had initiated certain programs that focused on specific aspects like utilisation of fly ash for brick manufacturing, adoption of better firing technologies like zig-zag, VSBK etc. Similarly, bi-lateral and multi-lateral organisations had also intervened, on a limited scale, on specific aspects of this sector. However, the sector requires initiatives on ‘mission mode’ that focuses on its overall development and modernisation aspects.

ENERGY SAVING POTENTIAL AND FUTURISTIC TECHNOLOGICAL OPTIONS.

The various technological options that can help in reducing energy consumption of brick manufacturing sector are summarised in Table 4 and are discussed below.

Table 4: Technology options and energy saving potential in brick manufacturing sector

EXISTING PRACTISE	OPTION FOR IMPROVEMENT	ASSUMPTION	ESTIMATED INVESTMENT PER KILN (INR IN MILLION)	AVERAGE ENERGY SAVING POTENTIAL (MILLION TONNE OF OIL EQUIVALENT)	OTHER BENEFITS
BTK technology	• Adoption of best operating practices (BOP) • Improved kiln construction practices	• 10 - 20% fuel saving • 50% BTKs adopt BOP	0.08 – 0.1	1.32	• Reduced fuel consumption • Increased production of better quality bricks
	Adoption of Zig-Zag technology	• 20-30% fuel saving • 30% BTKs adopt Zig-Zag technology	1.5 – 2.0	1.32	• Reduced fuel consumption • Increased production of better quality bricks
Production of solid bricks	Switch over to perforated bricks/ hollow blocks	• 15 - 25% fuel saving • 30% BTKs produce resource efficient products	2 – 4	0.92	• Resource saving • Better thermal insulation in buildings • Reduction in dead load of building • Uniform size and shape of product
Clamp kiln technology	Adoption of improved clamp kiln design	• 35-45% fuel saving • 30% clamp adopt improved design	17 - 23	1.30	• Reduced fuel consumption • Improved brick quality • Increased production of better quality bricks
	Adoption of continuous brick firing technologies	• 45-55% fuel saving • 10% Clamps adopt BTK	0.9 – 1.1	0.54	
		• 45-55% fuel saving • 10% Clamps adopt VSBK	3.5 – 5.0	0.54	

Source: TERI analysis

SHORT TO MEDIUM TERM OPTIONS

Capacity Building of Firemen on Best Operating Practices

The firemen are responsible for feeding of fuel and firing of bricks in the kiln. The firemen are illiterate, un-skilled and generally learn and acquire skills related to brick firing techniques while working on the kiln. The firemen work under the supervision of a master-fireman, who provides supervisory services on firing operation to 3-4 brick kilns and arranges firemen for these kilns. Each brick kiln engages 4 to 6 firemen, who work in shift of about 6 hours per day. In each shift, 2-3 firemen feed the fuel and handles the kiln firing operation. The kiln output and product quality of fired bricks is dependent on the skills of these firemen. The firemen in BTKs handle a total of about 19 to 23 million tonnes of coal annually (table 5).

Table 5: Estimated quantity of coal being handled by firemen in BTKs

DESCRIPTION	VALUE
Number of BTKs	42000
Firemen employed in each kiln	4 to 6
Total number of firemen engaged in brick	168,000 to

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firing in BTKs	252,000
Average annual brick production per kiln	3.5 million
Average coal consumption per million fired bricks (tonnes)	130 to 150
Total coal handled by the firemen per year (million tonnes)	19 to 23

Source: TERI analysis

Through capacity building of firemen on better kiln operating practices, 10 to 20% of coal can be saved easily in addition to the improvement in product quality. There is a need to set-up an institutional mechanism and to build capacity of brick kiln firemen on continual basis on best kiln operating practices.

Adoption of Zig-Zag Firing Technology

Zig-zag firing process – a cleaner variant of the conventional BTK technology, was introduced as a high draught continuous kiln around 1970 by the Central Building Research Institute (CBRI). The zig-zag kiln is similar to the Habla kilns that were used widely in Germany and Australia (ESMAP, 2011). In the zig-zag kiln, the draft is provided by a fan, the products of combustion are channelized through a system of flues, and the flow of gases is controlled using dampers (Majumdar et al., 1989). The basic principle in this type of kiln is to prolong the travel path of fire and create turbulent conditions for proper mixing of air and fuel. This improves combustion and increases the thermal efficiency of the kiln, resulting in lesser fuel consumption for the same quantity of bricks being produced by the conventional BTK. Improved combustion in the zig-zag kiln also reduces SPM emissions from the kiln stack. In recent years, the zig-zag firing technology is being adopted by a large numbers of BTKs in major brick making clusters in the Indo-Gangetic belt, encompassing different states of India such as West Bengal, Bihar, Uttar Pradesh, Punjab and Himachal Pradesh (Kumar et al., 2017).

LONG TERM OPTIONS

Shift to Resource Efficient Products

With less availability of space due to increasing population and demand, the majority of construction in cities is taking place in the form of multi storey buildings with RCC (reinforced cement concrete) columns. With this change in the construction practices, the bricks are increasingly being used as filler material to fill the space between columns. Earlier, the bricks were mainly used as a load bearing material. This provides an opportunity to brick industry to modernise itself and start producing REBs like perforated bricks and hollow blocks. Production of REBs in place of conventional solid bricks offers number of advantages. Some of the benefits of producing REBs and using them in building construction are highlighted below (TERI, 2016a):

a) Resource savings: Clay and fuel (coal) are the main resources used for manufacturing REBs. The production of REBs results in substantial resource savings as compared to production of conventional solid bricks (figure 3).

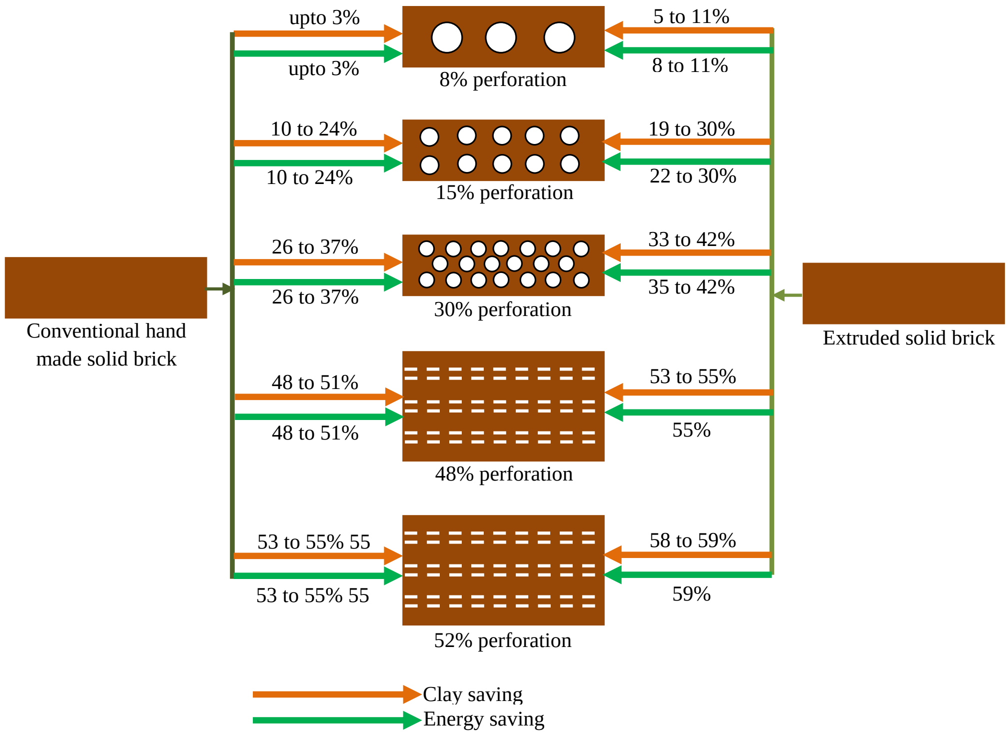

Figure 3: Resource saving due to REB production

Source: TERI, 2016a

b) Improvement in product quality: For manufacturing REBs, clay preparation and molding process has to be mechanised. The mechanization helps in proper homogenization of clay particles. The process also ensures production of bricks with proper size and shape. This leads to production of better quality of green as well as fired bricks and increased output of better quality (Class-I) bricks from the kiln.

c) Reduction in green brick wastage: During the brick-making season, about 20% of total green brick production of a kiln gets wasted due to rain. The green bricks prepared by mechanised process needs to be dried under shed. With installation of shed, the wastage of green bricks can be avoided.

d) Reduction in plaster and mortar requirement: REBs have uniform size and shape and can be used as such without any plaster on the surface. Hollow blocks (400x200x200 mm) are equivalent to 9 solid bricks (230x110x70 mm) and their use as walling material can help in 40%–70% savings in mortar requirements.

e) Reduction in steel requirements: The weight of REBs is less than the equivalent size of solid bricks. For same volume of walling unit, the weight of hollow block is about 60% less than solid bricks. Therefore, use of REBs results in reduced dead load of the building and a substantial reduction in requirement of steel as reinforcement.

f) Reduction in energy bills of buildings: The REBs have lower heat transfer coefficient, U-values (W/m2-k) as compared to conventional solid bricks; therefore, their use as walling material in buildings improves the insulating property and, depending upon the climatic zone, can reduce the energy bill by 1.5%–6.4%.

g) Flexibility in production: A mechanized brick production unit can adapt to variation in product type as per market demand which is not possible with hand-molding operation.

h) Improved skill set of workers: The operation/maintenance of machinery/equipment will help in upgrading the skills of workers and reduce the drudgery involved in manual clay preparation and the green brick molding process.

For production of REBs, the clay preparation and green brick production process has to be mechanised. Depending upon the clay quality, a specific set of equipment is required. The estimated investment cost for producing 4000 bricks per hour through mechanisation process is provided in table 6.

Table 6: Estimated investment cost for producing 4000 bricks per hour

DESCRIPTION	COST (INR IN MILLION)
Box feeder, fine roller, clay mixer, de-airing pug mill, vacuum pump, belt conveyor, automatic brick cutter, electric motors, electrification charges, foundation, errection and commissioning, generator	10.6
Machinery shed (6000 sq.ft.)	1.2
Drying shed (50000 sq.ft.)	5.0

Source: TERI, 2016 b

The monetary savings due to production of REBs is highlighted in table 7.

Table 7: Savings due to REB production

PARTICULARS	AMOUNT (INR IN MILLION)	REMARKS
Raw material (clay & coal)	0.78	Considering 20 hole brick ; 12% saving in clay and 15% in coal (due to perforations)
Wastage	0.86	Considering 20% wastage due to rain
Labor/Manpower reduction	1.72	Considering savings@ INR 200 per 1000 bricks
Better quality bricks	5.27	Increased share of first class Bricks

Source: TERI, 2016 b

The financial analysis of the project for producing 4000 perforated bricks per hour through mechanisation process indicates that simple payback period is 3.2 years (TERI, 2016 b).

Adoption of Tunnel kiln for brick firing

This type of continuous kiln was invented in Germany in 1877. Unlike other type of continuous brick firing technologies, in tunnel kiln brick moves inside the kiln and firing zone remains stationary. In tunnel kiln, bricks placed on cars (trolley) running on rails traverse a long rectangular chamber that is heated at the centre. The green brick on car entering from one end of tunnel first meet the products of combustion and afterwards passes through the cooling zone where they are cooled by air blown in from the opposite end. In developed countries tunnel kilns are extensively used for production of bricks. The tunnel kiln also offers the possibility of mechanising the loading, unloading and firing operation of the kiln.

CONCLUSION

Clay-fired brick is an integral component of construction sector. The Indian brick industry is characterized by use of conventional technologies and production of solid bricks to meet the demands of the construction sector. During past two decades, Indian brick industry had undertaken initiatives primarily focusing on improving its environmental performance. In contrast, the sector had put in limited efforts to address the issues related to high resource consumptions although it witnessed significant increase in energy and raw material costs over the years. The innovations in product diversifications has been completely absent in the industry which may be due to high labour intensity of the current production process. The options discussed in this paper can lead to modernisation of the brick manufacturing process in the country and help make it sustainable in terms of energy efficiency, environmental performance and resource consumption.

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THE NEED FOR A BUSINESS ENABLEMENT ENTITY FOR THE FLEDGLING INDIAN ESCO MARKET

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Keywords: ESCO, standard contract, standardised solutions, energy efficiency financing, measurement and verification

ABSTRACT

The Indian ESCO market has not lived up to its huge potential. While lack of financing, lack of a strong policy push and lack of trust within the ecosystem are frequently cited as significant reasons, these typically fall in place for any market once it matures to a minimum threshold. Unfortunately, that has not been the case with the Indian ESCO market.

A survey of 35+ active ESCOs in the country has revealed some interesting facts. While Thermal solution focused ESCOs talk about handling M&V disputes as their primary challenge, Electrical solution focused ESCOs talk about standardization of ESCO process as their biggest challenge. A subset of these ESCOs who provide simple solutions either feel lack of standard contractual frameworks or feel lack of access to financing as their first challenge. For the aspiring ESCOs, opportunity identification is itself a challenge.

The survey results clearly point out to the need for a market enablement entity to transform and create a multi-billion dollar ESCO industry in India. Such an entity should achieve three things. One, it should bring the entire ESCO community of service providers, technology providers, end users and financial institutions under one roof for effective collaboration and business connection. Two, the entity should catalyse the market through Solution standardization, Technical & Business assistance, M&V facilitation, Start-up incubation and ESCO accreditation. Three, the entity should leverage technology to create a platform for Benchmark development and build an Aggregated business app for addressing the needs of and enabling the ESCO ecosystem.

INTRODUCTION

The Energy Efficiency (EE) market potential in India is estimated to be around \$35 billion. Even very conservative estimates put this value at around \$10 billion (Source: Bhaskar Natarajan, 2008). However, an independent study conducted by Alliance for an Energy Efficient Economy (AEEE) points out that the actual combined revenues of the Energy Services Companies (ESCO) business is not expected to be more than \$150 million, excluding that of Energy Efficiency Services Limited's (EESL) revenues. There are 120+ registered ESCOs (Source: BEE India, 2017) with the Bureau of Energy Efficiency (BEE), but not more than 40 are active. Even within ESCO projects, "Shared savings model" is a tiny subset.

This gap is attributed to the absence of a credible market maker that can enable access to institutional financing for ESCO projects, work with the Government for a strong policy-level push, and reduce the inherent trust gap between ESCOs and End Users, a key characteristic of a nascent and emerging market.

AEEE has been interacting with ESCOs, Technology Providers, Consultants, End Users, Financial Institutions and Policy Makers in India to identify ways to transform the ESCO market. An exhaustive country-wide survey was conducted with 35+ active ESCOs across market segments. These interactions clearly point to the need for an industry-neutral organization to holistically look at and roll out execution methodologies at technological, business, financing and policy levels.

ENERGY EFFICIENCY MARKET

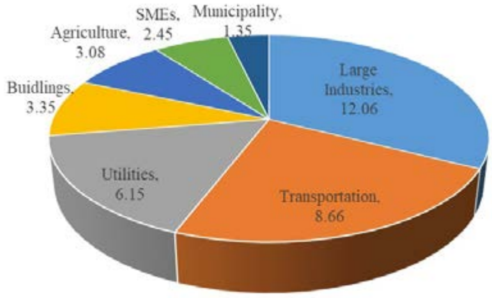

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Figure 1: Estimate of EE market in India 35 bn

The Energy Efficiency market in India is estimated to be anywhere between $10 billion and $35 billion. The above graph depicts the 5-year investment potential for the EE market in India (Source: Power Grid Corporation of India, 2014, INR converted to USD using an exchange rate of 65, market segments have been grouped from original report).

However, the Indian ESCO market is a miniscule percentage of what exists in similar size EE markets such as the US, Europe, China and Brazil. Though EESL has managed to disrupt the appliance oriented ESCO market (lighting, fans, pumps, room air-conditioners, etc.) in India, it barely scratches the surfaces for the vast EE potential that exists.

ESCO MARKET GAPS

The ESCO wheel spins around four spokes – ESCOs, End Users, Financial Institutions and Government. Each of these spokes has an important role to play in the ESCO ecosystem. However, there are certainly gaps in the way they are contributing to the ecosystem today.

ESCOs

- **Weak balance sheets –** There are not too many ESCOs in the country whose revenues cross $1 million. Combined with low margins, this reflects in their weak balance sheets that do not give confidence either to the end users consuming their solutions nor to the financial institutions that fund these solutions.
- **Lack of a long-term commitment –** Even though commitment is a reciprocal factor for market success, lack of a long-term strategy and commitment for energy services businesses within large energy management companies has contributed to the current light of the ESCO market.
- **Room for technical improvement –** End users constantly question the technical capabilities and large project management abilities of ESCOs especially when it comes to vertical-specific optimization that ties closely with the process.

End Users

- **Energy Efficiency not a priority –** While Indian CEOs understand that rising energy costs combined with inefficient use of energy affects their bottom line, improving their top line takes priority.
- **o-It- ourself mindset –** End users are happy getting an audit done by energy consultants and then implementing the energy savings projects internally at the cost of achieved savings. Some of the most energy-efficient companies in India rely on their in-house energy management teams to carry out projects through sub-contracts rather than outsourcing it to the ESCOs.
- **Lack of trust in energy services –** Because of the absence of references of the number and size of energy saving projects carried out by ESCOs, Indian end users do not want to place complete trust on ESCOs in executing energy saving projects.

Financial Institutions

- **Unwilling to take risks in a nascent market –** To invalidate the risks in a nascent market, financial institutions have historically chosen to stay away from financing EE projects.
- **Lack of innovations in financial instruments –** While the solution-oriented rather than product-oriented ESCO business makes collateral requirements complicated, innovative financial instruments have failed to emerge, for example the equity market is largely absent for energy efficiency in India.
- **Comple guarantee mechanisms –** Even within projects based on collateral and guarantee mechanisms (example, Partial Risk Sharing Facility, PRSF provided by SIDBI), the invoking of a guarantee coverage is extremely complex and a long-drawn affair. Even though it helps de- risking a financier, it does not necessarily de-risk an ESCO, who is still at the mercy of the end users in more than one way.

Government

- **Lack of holistic view of energy aspects –** Energy efficiency is not viewed in close conjunction with "Smart Cities" or "Power for All" kind of programs by the Government and this results in devising of policies that do not address the market in a holistic manner or at a scale that would help in faster evolution of the ESCO market.
- **Absence of bottom-up market detailing –** While there are many exercises that have tried to create the top-down market numbers for energy efficiency, the bottom-up detailing in terms of addressable opportunities, market sizing by solutions and by technologies have not happened at a country level.
- **Weakly sustained policy regulations –** Though some strong policy frameworks had been developed, the implementation of such frameworks has been weakly understood and sustained by the different stakeholders, Perform, Achieve and Trade (PAT) program for example.

MARKET INTELLIGENCE EXERCISE

Surveys

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Two rounds of surveys were conducted with ESCOs. The preliminary round screened the ESCOs to identify those implementing end-to-end solutions. In the detailed round, 37 qualified ESCOs were administered with a detailed survey that covered challenges faced, details on projects implemented, technologies and solutions worked on. Surveys were conducted either in person or through phone interviews.

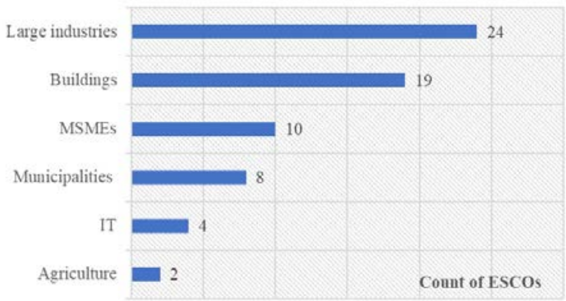

Figure 2: Surveyed ESCO profile by sectors served

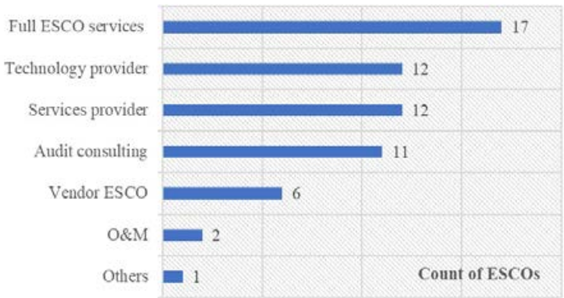

Figure 3: Surveyed ESCO profile by offerings

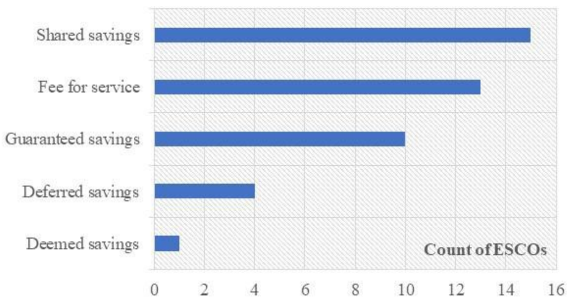

Figure 4: Surveyed ESCO profile by pro ect model

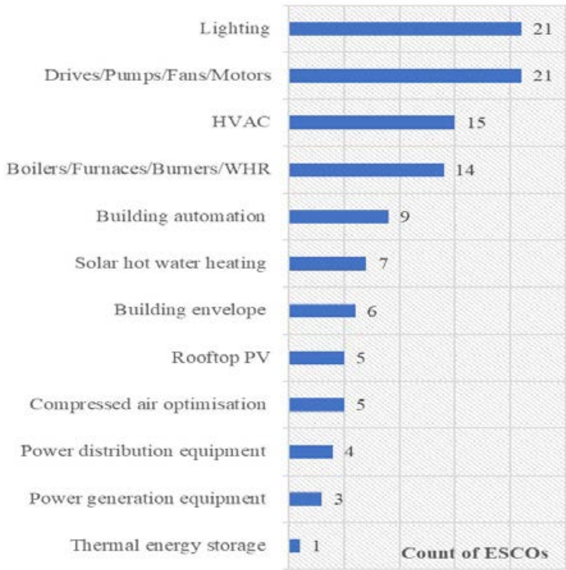

Figure 5: Surveyed ESCO profile by solutions

Workshops

Six workshops were conducted by AEEE in partnership with different stakeholders, over the last 6 months. These workshops facilitated direct interaction of ESCOs with financial institutions, government bodies, technology providers and end users. One workshop was conducted for identifying challenges and avenues for standardization in central plant optimization solutions. Another was conducted along with BEE for exploring growth measures for pumping optimization solutions. Third was conducted along with an ESCO (Smart Joules) for Hospital end users. Another three were conducted along with Yes Bank across three regions – Delhi, Bangalore and Hyderabad.

Meetings

20+ face-to-face meetings of ESCOs were conducted through roadshows in Delhi, Pune and Bangalore regions. The meetings focused on the current business of ESCOs, business roadmap, challenges faced by them and support required to disrupt their business.

CHALLENGES FACED BY ESCOS

The challenges faced by ESCOs are grouped under five segments of ESCO classification. The challenges are arranged in terms of the order of importance as communicated by the ESCOs and further assimilated by AEEE.

While Complex solution ESCOs that deal with Process and Thermal energy (e.g. Enzen, Thermax,

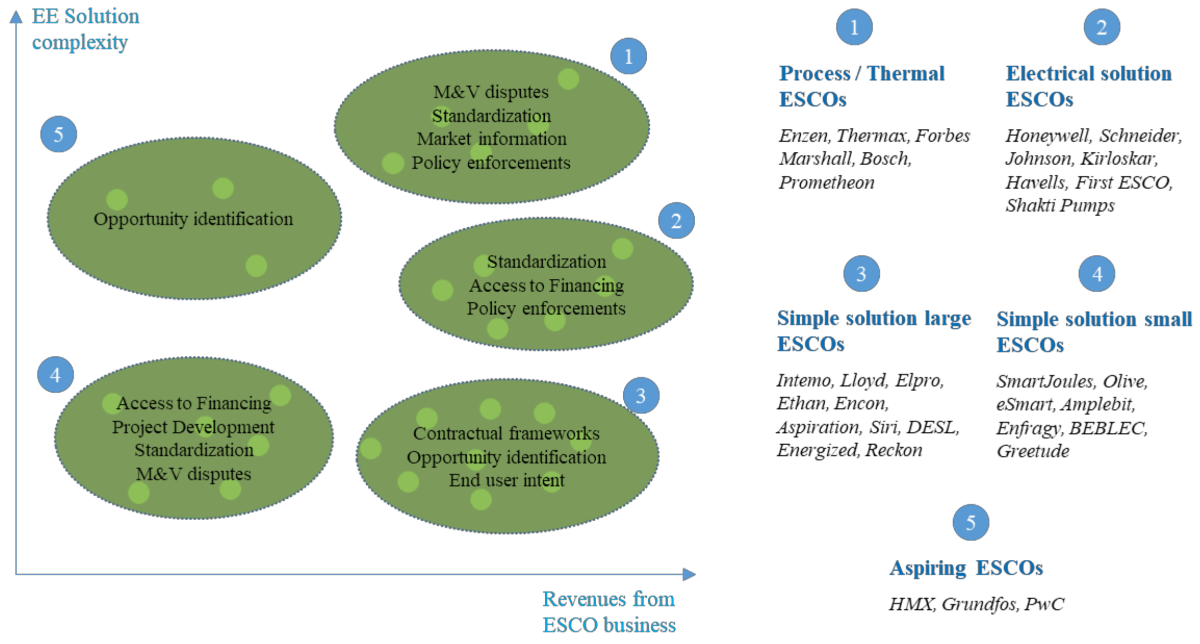

Figure 6: Challenges of ESCOs

Forbes Marshall, Bosch) talk about the inherent difficulty in measurement of saved energy as their primary challenge, for Electical solution ESCOs restricted to the Utilities (e.g. Honeywell, Schneider Electric, Kirloskar), Standardization of audits, solutions, contracts, project execution and savings validation becomes the primary challenge. For ESCOs dealing with Simple solutions such as Power, Lighting and HVAC optimization, the ones that are relatively large (e.g. Elpro, DESL, Reckon Green) feel lack of proper contractual frameworks as their primary challenge while the smaller ones (e.g. Amplebit, Greetude) feel access to financing is their biggest challenge. For the Aspiring ESCOs (e.g. HMX, Grundfos) who are reluctant to take financial risks, opportunity identification itself is a big challenge.

There are subtle differences in the way some of these challenges are articulated as well. For example, M&V disputes for complex solution ESCOs are about the challenge in measurement of saved energy while the same for Simple solution small ESCOs are about the fear of payment risks. Similarly, access to financing is not a huge challenge for million-dollar savings solutions since end users are comfortable doing that investment, while it is a challenge for ESCOs dealing with relatively smaller value of solutions.

Some common challenges also include working out contract mechanisms between Technology providers and ESCOs, and building & sustaining a high-quality team for energy services.

LEARNINGS FROM INTERNATIONAL AND INDIAN SUCCESS STORIES

ESCO market has globally succeeded through strong policy push, progressive financing mechanisms and standardization of solutions (Source: Ella Aglipay Delio et al., 2009)

US Mandatory adoption of energy efficiency in Government buildings led to large scale emergence of ESCOs in the US. Because of a credible market created by the Government, funding started flowing in, from Non-Banking Financial Companies (NBFCs) to begin with, followed by mainstream banks. Further impetus through building labelling and disclosures along with removal of utility disincentives through correct pricing mechanisms put the ESCO market under a catapult. Utilities brought in large capital that was then deployed to improve EE in Commercial and Industrial (C&I) establishments.

Europe Europe benefitted from stiff policy targets covering longer horizons (such as 20% reduction by 2020 and 30% by 2030). EE certificates for building sales and rentals along with strong standards and labelling mechanisms provided the necessary market stimulation. Further to this, standardization of solution approaches gave the scale needed to grow the market.

China World Bank / GEF aggressively funded three ESCOs that enabled shared savings model in a large way providing the necessary scale for ESCO projects. Government matched this progress by making energy efficiency part of successive 5-year plans with clear targets and incentives. Further, ESCO was made a priority industry and Energy Efficiency from Energy Performance Contracting (EPC) was listed as a major initiative for Energy Efficiency.

Bra il Utilities were mandated to invest a minimum percentage of their revenues in energy efficiency. Government and Private lending were supported with strong lines of credit. A strong ESCO association carried forward responsible Government lobbying along with awareness creation.

India The largest success in India has come through the EESL model that simplified and standardized the procurement, execution and M&V of appliance-oriented projects (lighting with great success, fans, pumping and air conditioning under roll out). Demand aggregation on the large-scale requirements greatly brought down the prices which created further impetus to the targeted ESCO segments.

This paper uses the best practices and tested models across the globe to arrive at methodologies and mechanisms to accelerate pace of EE adoption and ESCO projects in the country.

THE NEED FOR A NEUTRAL MARKET ENABLEMENT ENTITY

The interactions with Indian ESCO ecosystem point to the need for a neutral and a credible market marker. The role of such a market maker should be:

1. To create awareness on EE as a resource
2. To create standardized approach to solutions
3. To create an open marketplace for EE
4. To enable access to financing
5. To make organizational facilitation of contracts
6. To work with policy makers on enforcements

Awareness on EE as a resource While the importance of energy efficiency is understood, the cost of implementation versus the opportunity cost of non-implementation is not necessarily understood by the end users. A culture of energy management has to be created within the country with the benefits of data-driven decision making through energy measurement and management well understood by stakeholders.

Standardi ed approach to solutions EE solutions have to be standardized for audit approach, solution design, solution engineering, project execution, M&V and O&M. Frameworks and templates have to be created for audit reports, contracts and M&V reports for the standardized solutions. Globally accepted best practices must be leveraged. Many countries including China have embarked on this model and the authors believe that India needs focus in the short-term and the success of EESL has reinforced their views.

Open marketplace for EE The different stakeholders of the EE business ecosystem – ESCOs, Technology providers, Start-ups, Consultants, End users and Financial institutions must be brought on to the same platform. The platform should enable lead flow, solution discussion and discourse on success stories. The platform should act as a central repository of country-wide energy efficiency data. Once evolved, the platform should morph into a technology-driven app for businesses and consumers for data analytics, benchmarking of energy data and EE transactions.

Access to financing The ESCO process and contracts have to be streamlined to lower transaction costs for financial institutions. Post that, the financial community along with the ESCO community needs to work out financial models and instruments that will enable scale for the Indian market. The new entity should be in a trusted position for financiers for technical due diligence, solution certification, ESCO accreditation and M&V dispute resolution.

Organi ational facilitation of contracts Technical assistance for audits, solution engineering, project management, M&V and carbon credits has to be provided. Business facilitation for solution selling and contract making has to be enabled. Arbitration during M&V and payment conflicts has to be ensured.

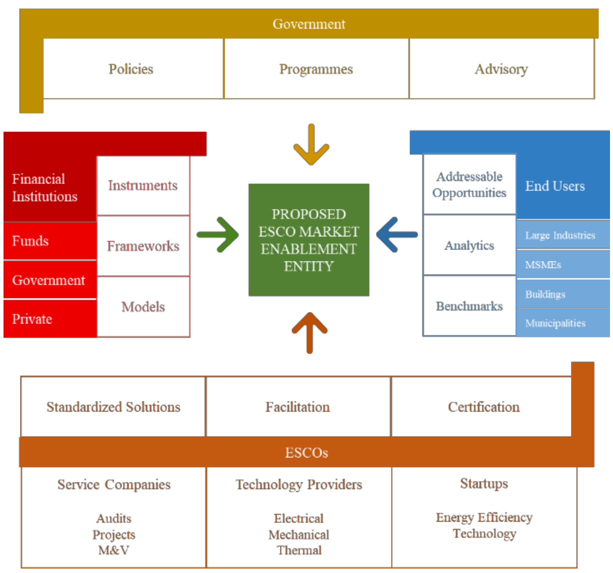

Figure 7: ESCO ecosystem positioning of the proposed market enablement entity

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Policy advocacy Existing EE programs (such as PAT, ECBC, Standards & Labelling) have to rolled out more effectively for continued sustenance. Growth programs such as Smart Cities, Power for All, Make in India and Startup India have to be leveraged to drive energy efficiency. EE Financing has to become a priority sector lending.

CREDENTIALS NEEDED FOR THE MARKET ENABLEMENT ENTITY

The market enablement entity should have the following strengths and credentials to ensure the industry transformation.

Neutral Body The entity should be an industry neutral body that is trusted by the ESCO ecosystem to transform the EE market in India. The entity cannot have affiliations with specific institutions including the Government, and to ensure independence, should be a not-for-profit entity.

Network The entity should have a strong network and working relationships with the different spokes of the ESCO wheel, viz. Policy makers, End users, ESCOs, Technology providers, Start-ups and Financial institutions.

Capability The entity should have the capabilities to work across the spectrum of the EE ecosystem, be it at the technical, business, financing or policy levels.

Policy Advocacy The entity should have credentials working with different levels at the policy for Buildings, Industries, MSMEs, Municipalities, Infrastructure and Agriculture.

Capacity Building The entity should have expertise in capacity building through training programs, workshops, seminars, webinars and courses.

Global Name The entity should be recognized globally so that not only the best practices can be leveraged but also the global ecosystem could be leveraged for technology, funding and recognitions.

MARKET ENABLEMENT STRATEGY

The ESCO market in India needs conjunctive actions on the policy and the business fronts. A composite approach of Awareness Building, Market Enablement and Business Facilitation has to be unleashed. Through a two-pronged strategy of Business-driven and Technology-driven catalysis, the Enablement entity should drive an industry transformation.

The Business-driven enablement will start with Facilitation activities that include Project assistance on the technological, business and financing fronts. This will be carried out alongside creation of technology specific Standardization approach for solutions, eventually maturing into a Certification process that includes accreditation / incubation of ESCOs and ESCO solutions.

The Technology-driven enablement will aim to create benchmarks through analytics of energy consumption data and audit reports, which will further enable the creation of a cloud-based benchmarking tool for end users and a report generation tool for auditors, culminating into the creation of a B2B and a B2C marketplace for energy efficiency in India.

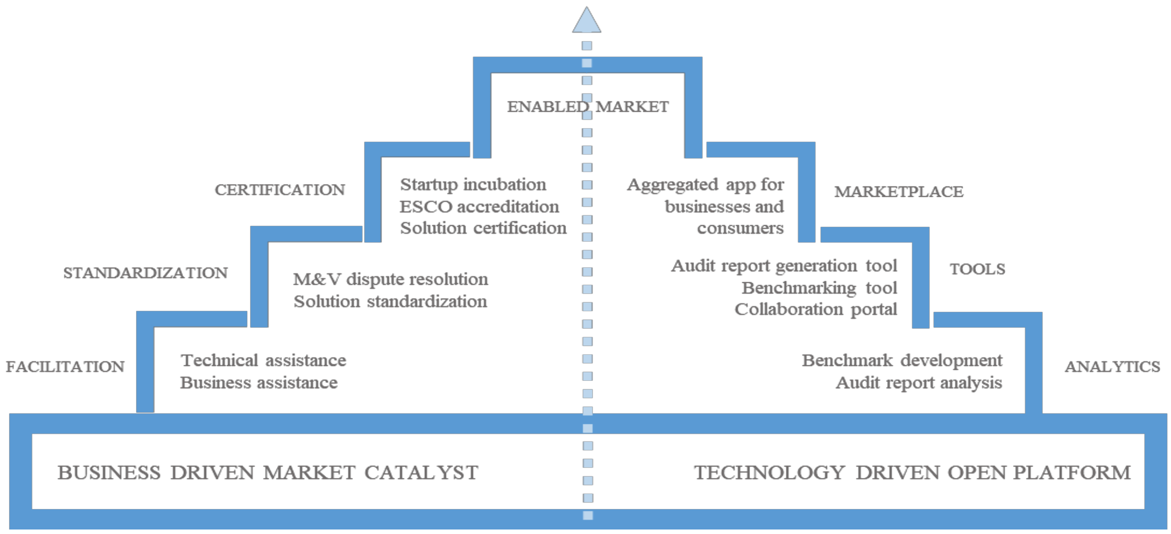

Figure : ESCO market enablement pyramid

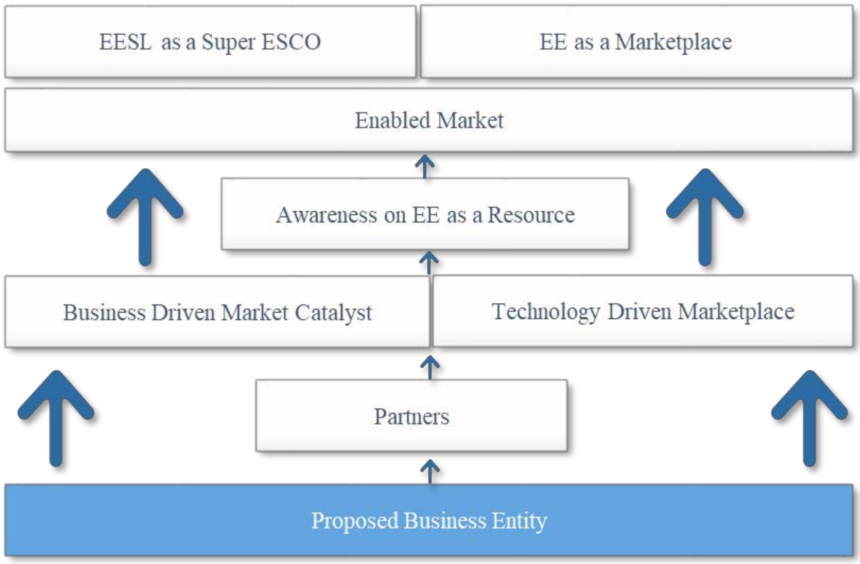

Figure : ESCO market enablement rollout model

A country-wide collaboration portal will also be created to bring the entire EE community on to a digital social media platform. The platform will enable discussions, announcements, lead flow mechanism and capacity building initiatives such as webinars. The platform will also host country-wide energy efficiency data with calculated benchmarks.

STRATEGY ROLLOUT MODEL

The Entity, along with Partners such as EESL, BEE, CII, etc. shall drive the two-pronged business and technology strategy for ESCO market enablement.

The strategy will look to steer Energy Efficiency Services Limited (EESL) into creating model successes for a larger replication of solution-oriented ESCO projects rather than appliance-oriented replacement projects. EESL's strengths of data aggregation and supply chain streamlining shall be leveraged to roll out this enablement strategy.

Partnership with Bureau of Energy Efficiency (BEE) shall improve the ESCO accreditation process along with financial rating agencies such as CRISIL and ICRA, incorporating both financial and technical aspects. The vast amount of energy and energy audit data with BEE, CII and Industry associations shall be utilized to create country-wide energy and energy efficiency data. The Entity will also work with technology and service providers to create technology-specific standardization approach and to create end use benchmarks of energy data. The data will further be kept updated through the cloud-based marketplace platform.

The enablement will result in EESL emerging as a Super ESCO and EE emerging as a marketplace in India.

CONCLUSION

The Indian ESCO industry has been a sleeping giant for a long time now. Unless policy, business, technology and financing aspects of the market are addressed together, the industry cannot be disrupted. Unless the global and local learnings, and success stories are leveraged effectively, this cannot become a billion-dollar market.

The proposed market enablement entity cannot have affiliations with any controlling institution including the Government. To operate neutrally and to gain the trust of the industry, it cannot have the pressure of revenues and hence must be a not-for-profit organization. It should have demonstrated capability for market enablement and needs to have global recognition.

It is time an existing entity or a new entity that fits the above criteria and has the capability to execute this transformation, adorned this market enablement role on a larger scale to create a multi-billion-dollar energy services market in India.

ACKNOWLEDGEMENT

Project on “ESCO Market Assessment, Identification of Energy Conservation Measures (ECMs) and Development of Financing Framework for Select ECMs” carried out by Alliance for an Energy Efficient Economy (AEEE) funded by Shakti Sustainable Energy Foundation, 2016-17

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ENERGY EFFICIENCY SERVICES: OPPORTUNITIES AND BUSINESS MODELS FOR THE PRIVATE SECTOR

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Keywords: Business models, private organizations, partnerships, financing, implementation

ABSTRACT

Governments and donor agencies have funded many energy efficiency projects to demonstrate the benefits of energy efficiency improvement. Many of these projects have been funded through grants. But there is a limit to the amount of grants or other financing options provided by governments and donors. For the long-term sustainable development of an energy services industry, the private sector must play a major role. This paper presents the rationale and opportunities for private sector-led energy efficiency services.

The paper first defines the Energy Services Value Chain and the range of products and services that may be offered by the private sector across this value chain. It identifies the various private sector organizations that can have a role in offering various types of energy services. These organizations include energy auditing companies; engineering firms; construction management companies; equipment manufacturers and suppliers; appliance retailers and dealers; banks, financial institutions and leasing companies, privately-owned electricity distribution companies; and partnerships among these organizations. The paper then defines different business models for energy efficiency services and lays out "pathways" for establishing energy services businesses. Finally, the paper identifies the barriers to private sector implementation, and provides a "road map" for overcoming the barriers and establishing energy services businesses.

INTRODUCTION

Global environmental concerns, particularly those related to climate change, have led to the recognition that energy efficiency is the most cost-effective near-term mitigation option. In addition to climate change mitigation, implementation of energy efficiency projects also contributes to reducing the supply-demand imbalance, enhancing energy security, and providing fiscal benefits to developing countries, without compromising economic development.

Most energy efficiency projects in developing countries have been sponsored and funded by donor agencies and governments. These projects have benefited from grants or subsidies and have served the purpose of demonstrating the feasibility and benefits of implementing energy efficiency (EE) projects. However, grants and subsidies are not sustainable and cannot assure the scaling up of EE project implementation (World Bank 2013). Multilateral and bilateral financing institutions are therefore facilitating and promoting a private sector energy services delivery market and leveraging private sector investments in energy efficiency (Wang et al 2013). The ongoing restructuring and deregulation of energy markets has also made the use of performance-based services more common.

These factors present unprecedented opportunities for the development and growth of energy service businesses that can provide performance based energy services to public, commercial, industrial and even residential energy users.

WHAT IS AN ENERGY SERVICES BUSINESS?

An energy services business is an organization that provides some or all of a wide range of services related to design and implementation of energy efficiency projects and related services to energy users. Generally, such a business provides services using the energy saving performance contracting (ESPC) approach (Limaye et al 2014).

While an energy service business is commonly referred to as an Energy Service Company or ESCO, a wide range of different types of organizations may operate as energy service businesses. Such organizations may include energy auditing firms, design and engineering firms, equipment suppliers, contractors and installers, construction management firms, utilities, NGOs, etc. We refer to these as Energy Service Providers (ESPs)

PRIVATE SECTOR ENERGY SERVICE PROVIDERS

Private sector ESPs can provide many advantages for energy services projects, such as (Limaye 2014):

- Mobilizing private innovation and entrepreneurship
- Accessing the latest energy efficiency technologies
- Reducing project risk through performance guarantees
- Mobilizing private financing from banks and financial institutions
- Offering a range of business models
- Providing high quality installation, operation and maintenance
- Reducing overall implementation costs due to more efficient implementation
- Providing training and capacity building for operations and maintenance.

THE ENERGY SERVICES VALUE CHAIN

The services provided by ESPs can include many activities that can be illustrated by the Energy Services Value Chain (Figure 1). These include:

- Project design and engineering
- Equipment procurement
- Project installation and commissioning
- Financing
- Operation and maintenance of energy equipment
- Facilities management
- Energy sales

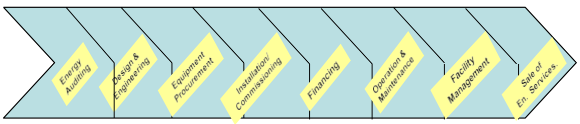

Figure 1: The Energy Services Value Chain

ESPs may offer a wide range of services spanning the various elements of the Value Chain, including:

- Energy efficiency services, including installation plus operations and maintenance
- Energy tracking and reporting services
- Cogeneration or combined heat and power (CHP)
- Standby generation
- Power quality services
- Outsourced energy management (also referred to as contract energy management or "chauffage").

The specific services offered by an ESP would depend on the ESP's capabilities and customer needs.

ESP BUSINESS MODELS

ESPs offer various business models, classified into four common types as shown in Figure 2.

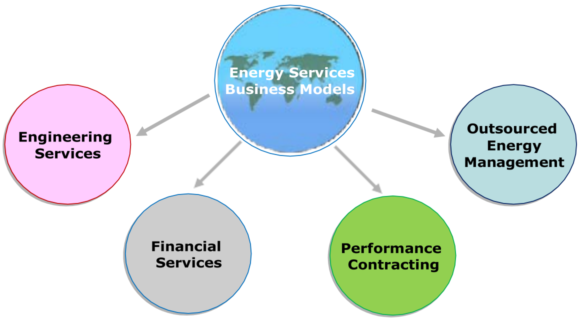

Figure 2: Energy Services Business Models

Engineering Services Business Model

The Engineering Services Business model (Figure 3) focuses primarily on energy audits, identification of EE options, project design and engineering, equipment procurement, and project installation.

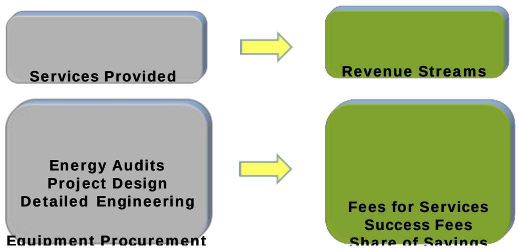

Figure 3: Engineering Services Business Model

Payments to the ESP include basic fees for services plus success fees or a share of the savings. The difference between traditional engineering, procurement, and construction services and this business model is that some of the payments (success fee and/or savings share) to the ESP are performance based.

Financial Services Business Model

In this model, the ESP provides financing for the EE project. The financing may be in the form of loans (debt), project equity, or equipment lease. The payments for the ESP services will be derived from the energy cost savings, to service debt, provide a return on equity investments, or make lease payments

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(Figure 4). ESPs offering such financial services include banks, financial institutions, equipment suppliers and leasing companies, and distribution utilities. Utilities may recover the payments though the energy bills. Equipment suppliers typically provide such financing through “supplier credit,” wherein the services include designing and implementing the EE project with deferred payments from the host.

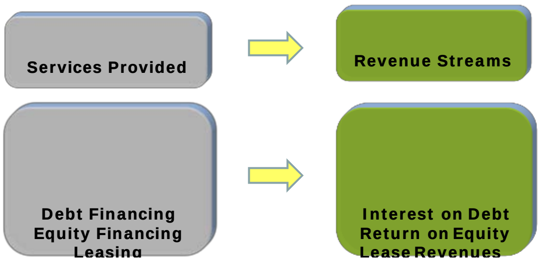


Figure 4: Financial Services Business Model

Performance Contracting Business Model

Energy Saving Performance Contracts (ESPCs) have been introduced in many countries to help address some of the more difficult issues associated with facilitating EE investments (Singh et al 2010). The concept of an ESPC involves an ESP offering a customer a range of services related to the implementation of an EE project. The ESP may also provide or arrange financing, so that the host facility invests little or no capital. Typically, at least part of the compensation from the host facility is contingent upon demonstrated project performance, and is structured such that the compensation for the ESP services is recovered from the energy cost savings (Figure 5).

The four major characteristics of ESPCs are as follows (SRC Global 2005):

- The ESP provides a full range of energy services for financing and implementation of EE projects.
- The payments for such services are made by the customer from the resulting cost savings.
- The payments are generally contingent upon satisfying certain performance guarantees provided by the ESP.
- The ESP assumes most of the technical, financial, and performance risks.

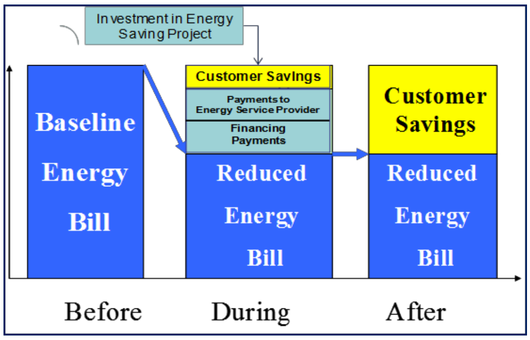


Figure 5: Performance Contracting Business Model

Two basic versions of the ESPC model are common in North America and other countries like China, Japan, Korea, and Thailand: Shared Savings and Guaranteed Savings.

Shared Savings. In the Shared Savings Model, the ESP generally provides or arranges for most or all of the financing needed for the implementation of the project. The ESPC specifies the sharing of the cost savings (which are measured and verified using a pre-specified protocol) between the ESP and the host facility over a specified time period. The host facility generally makes no investment in the project and gets a share of the savings during the contract period and 100 percent of the savings after the contract period, thus maintaining a positive cash flow throughout the life of the project.

Guaranteed Savings. In the Guaranteed Savings Model, the host facility generally takes the loan on its own balance sheet. The ESP guarantees certain performance parameters in the ESPC, and specifies the methods for measurement and verification (M&V). Payments are made once the project performance parameters have been confirmed.

Outsourced Energy Management Model

The Outsourced Energy Management model may also be referred to as an *energy performance management contract*, or simply *energy supply contracting*. In this model, the costs for all equipment upgrades, repairs, and so forth are borne by the ESP and the ESP sells the energy output (such as steam, heating and cooling, lighting, etc.) to the customer at an agreed price (Figure 6). Ownership of equipment may remain with the ESP (Build-Own-Operate or BOO model) or may be transferred to the customer (Build-Own-Operate-Transfer or BOOT model). This business model is common in EU countries, where contracts for this type of arrangement tend to be substantially longer than the other contract types, ranging from 10 to 30 years.

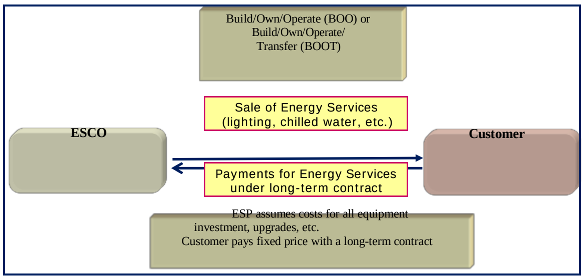
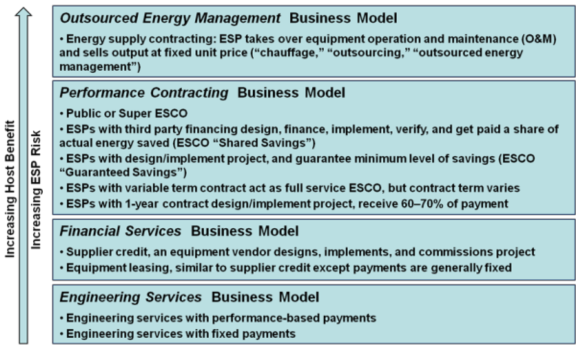


Figure 6: Outsourced Energy Management Model

Summary of Business Models

Figure 7 summarizes the four business models discussed above.



Source: Adapted by authors from World Bank 2006.

Figure 7: Summary of Energy Services Business Models

PATHWAYS TO ENERGY SERVICES BUSINESSES

Different business models can be adapted for use by different types of ESPs. Figure 8 shows the different "pathways" for ESPs to offer the business models.

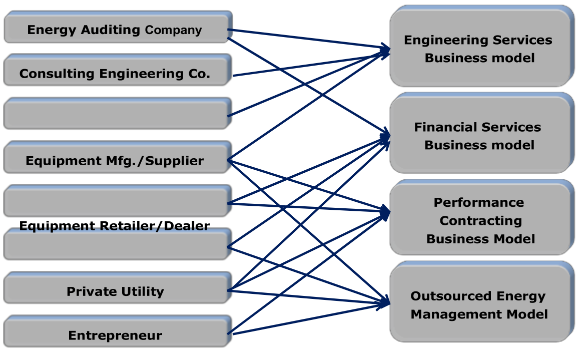


Figure 8: Pathways to Energy Services Businesses

As illustrated in Figure 8, a wide range of different types of organizations can participate in the energy services market by offering one or more of the four business models.

PARTNERSHIPS

The Performance Contracting and Outsourced Energy Management Model require a wide range of skills and capabilities that some of the ESPs may not possess. However, ESPs can enter into partnerships to expand their skills and capabilities to offer these models. Figure 9 provides a schematic illustration of partnerships.

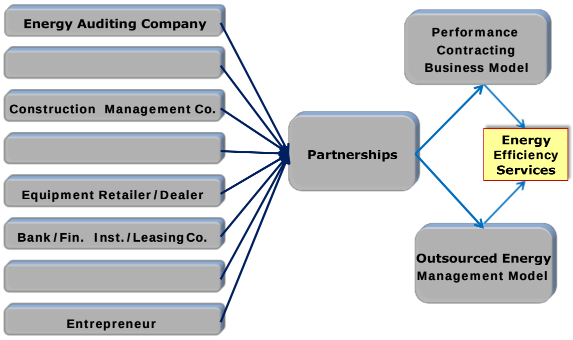


Figure 9: Illustration of Partnerships

HOW CAN ESPs ADDRESS THE BARRIERS TO EE IMPLEMENTATION?

The barriers to large-scale implementation of EE projects are well documented (Wang et al. 2013, Singh et al 2010, and Ryan et al 2012): (i) policy and regulatory barriers; (ii) barriers related to energy end users; (iii) barriers related to providers of energy equipment and energy services; (iv) institutional barriers, and (v) financing barriers. Private sector ESPs can address these barriers by:

- Developing standard contracts
- Providing best technical solutions
- Providing or arranging financing from commercial banks/FIs
- Providing project management services
- Entering into public-private partnerships
- Providing training to facility engineers/managers.
- Providing project installation, commissioning and measurement and verification (M&V)
- Developing case studies and demonstration projects
- Facilitating financing of EE projects
- Building capacity of banks/FIs
- Developing M&V protocols & building M&V capacity.

MARKET ENTRY BARRIERS FACED BY PRIVATE SECTOR ESPs

While there are many opportunities for private sector ESPs to play a major role in scaling up EE implementation, they face many hurdles that limit their ability to capture a significant share of the EE market. For example:

- Most ESPs are small and have limited technical, financial and human resources, making it difficult for them to scale up their EE activities.
- ESPs often have poor credibility with private sector businesses.
- ESPs face numerous challenges in working with public sector (these are well-documented in World Bank 2016)
- The limited capitalization and weak balance sheets hinder their ability to raise financing for ERE projects.
- Most banks and financial institutions do not understand the ESP business models
- ESPs face high project development costs, which result in less attractive project economics.
- In many countries, there is a lack of supportive legislative and regulatory framework that can facilitate the growth and development of ESPs
- Lack of demonstrated experience affects their credibility with potential customers.

WHAT ACTIONS CAN HELP THE DEVELOPMENT OF A PRIVATE SECTOR-LED EE INDUSTRY?

Governments can facilitate and promote the establishment and growth of ESPs by undertaking a set of legislative, regulatory, and policy initiatives targeted at (Limaye et al 2014):

- Creating a large and stable demand for energy services projects in the public sector;
- Removing barriers to public procurement of EE services and establish clear regulations, rules and procedures for public agencies to work with ESPs; and
- Facilitating adequate and affordable financing of ESP projects.

International experience indicates that the following specific actions have helped the development of an EE market with participation by a wide range of ESPs:

- Legislative and regulatory changes to remove some of the barriers to ESPs in working with the public sector.
- Enabling the establishment of public-private partnerships
- Formation of an Energy Service Providers Association
- Accreditation and licensing of ESPs by the government or an industry association
- Building technical and implementation capacity of ESPs
- Preparing templates of standard contracts and agreements for ESP services
- Facilitating collaborative relationships among banks and ESPs
- Increasing customer awareness of benefits of the services provided by ESPs.

EXAMPLES OF SUCCESSFUL ESP ACTIVITIES

International experience demonstrates that, despite the many barriers faced, an ESP industry can be developed. Some examples from developing countries include:

China

China has the largest ESP industry in the world today. Established in 1998 with assistance from the World Bank, the industry now has over 2,000 ESPs – called ESCOs or Energy Management companies (EMCs). The types of organizations offering EE services includes building and system control manufacturers, energy supply companies, equipment manufacturers, suppliers, or installers (IFC 2012).

The national government actively supports ESPs and has made legislative and regulatory changes to support performance contracting. The primary business model used by ESPs is “Guaranteed Savings.”

Thailand

In 1992 Thailand established a dedicated fund to finance energy efficiency projects. This fund, operating through commercial banks, provided soft loans for EE projects, including projects implemented by ESPs (CCAP 2012). The projects developed by ESPs were in the industrial and commercial sectors and utilized both the “Shared Savings” and “Guaranteed Savings” models.

More recently Thailand established a dedicated fund to provide equity investments in energy service companies. Currently there are over 45 ESPs operating in Thailand.

South Africa

In South Africa, the regulator ordered Eskom, the national electric utility, to establish a demand-side management (DSM) fund. In order to help ESPs access this fund, the Government of South Africa, under the advice of the World Bank, created the Standard Offer and Standard Product programs to acquire energy efficiency resources from projects identified and implemented by ESPs (ESMAP 2011)

These initiatives have led to the establishment of over 500 ESPs in South Africa and successful implementation of about 150 EE projects leading to savings of about 180 MW in the first few years of the program (Skinner 2013).

DEVELOPING AN ENERGY SERVICES BUSINESS

This paper has identified the opportunities for establishing private sector energy services businesses that can play a major role in scaling up implementation of EE projects. The key steps include:

- Identify the business opportunity
- Assess company strengths, weaknesses, opportunities and threats
- Identify critical success factors
- Identify key barriers and define measures to overcome them
- Develop the business plan
  - Define goals and objectives
  - Define target market
  - Specify products and services
  - Develop marketing and sales strategy
  - Establish organizational structure
- Obtain management approval

CONCLUDING REMARKS

The private sector can offer many advantages for implementing EE projects and is likely to have a major role in scaling up EE implementation. Many different types of organizations, such as energy auditing firms, design and engineering firms, equipment suppliers, contractors and installers, construction management firms, utilities, NGOs, can potentially become ESPs. By offering a wide range of business models, ESPs can match their services to customer needs.

ESPs face many barriers that may that limit their ability to capture a significant share of the EE markets. For the long-term scalability and sustainability of EE markets, it is important for governments, with the help of donors, to create an environment that will overcome many of these barriers and support the establishment and growth of ESPs.

ACKNOWLEDGEMENT

This paper is partly based on research sponsored by the World Bank and the U.S. Agency for International Development (Jordan), Energy Sector Capacity Building Program.

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FINANCING MODELS FOR SCALING UP ENERGY EFFICIENCY IMPLEMENTATION IN THE PUBLIC SECTOR

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Keywords: Public sector, financing, implementation, scaling-up

ABSTRACT

Public buildings and facilities include schools, hospitals and public buildings, and municipal infrastructure, such as water supply and district heating/cooling. Improving the energy efficiency (EE) of public facilities offers cost savings as well as a wide range of environmental and socioeconomic benefits, including reduction of the need for investments in future energy supply facilities. But, while many EE technologies, products and equipment are commercially available, deployment of these options in the public sector has been rather limited due to many challenges and barriers. This paper provides an overview of the key considerations in financing and implementation of energy efficiency (EE) options in cities and municipalities.

The paper lists the major barriers to deployment of EE technologies and discusses international best practices with innovative financing mechanisms to overcome these barriers, based on several World Bank studies of energy efficiency implementation in the public sector. An important element in this discussion is the concept of a "financing ladder" that illustrates the roles of the public and private sectors in scaling up financing for energy efficiency.

INTRODUCTION

Energy Efficiency is being increasingly recognized worldwide as the most cost-effective option in the short to medium term to meet the energy requirements of increased economic growth, while mitigating the impacts of global climate change (IEA 2015). To national governments, energy efficiency represents a win-win-win option by providing positive returns to the government, energy consumers, and the environment.

The public sector[1] is often the single largest energy user in a developing country and represents a large cost burden to the government (World Bank 2016a). It represents a large, homogeneous market that presents opportunities for packaging or bundling projects to achieve scale.

NEED FOR ENERGY EFFICIENCY IN THE PUBLIC SECTOR

Energy use in the public sector is generally very inefficient because of the use of old, outdated equipment, inadequate maintenance, limited budgets for purchasing efficient equipment, and lack of knowledge and awareness of energy efficiency options on the part of public agency managers and staff.

Due to its large size and potential for energy savings, the public sector represents a very attractive market for implementing energy efficiency services that lead to the following benefits (Singh et al 2010):

- Energy user benefits include reduced operating costs, improved productivity and work environment, and better comfort and convenience.
- Government benefits include reduced supply shortfalls, improved energy security, and reduced capital requirements for new capacity.
- Environmental benefits include reduced local pollution, conservation of natural resources, and mitigation of global climate change impacts.

BARRIERS TO ENERGY EFFICIENCY

Despite the large opportunities and many benefits of energy efficiency (EE), the implementation of EE projects in the public sector has been rather limited due to many important barriers. These barriers include policy and regulatory barriers; public sector end user barriers; barriers related to EE equipment suppliers and service providers; and financing barriers (World Bank 2013)

[1] The "public sector" refers to publicly owned institutions subject to public procurement rules and regulations, including federal/municipal buildings, universities, schools, hospitals/clinics, public lighting, water utilities, public transportation stations, community centers, fire stations, libraries, orphanages, etc.

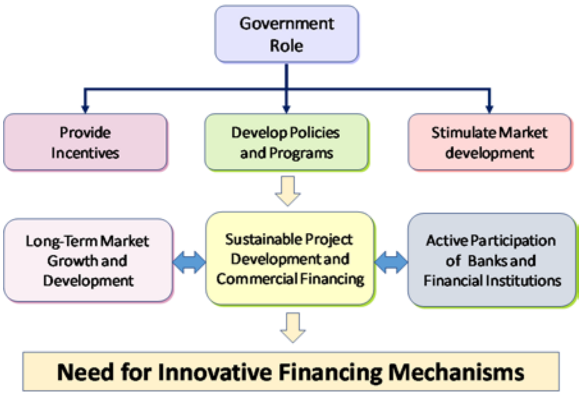
- **Policy and regulatory barriers** include low energy prices, rigid budgeting policies, procurement rules that prevent purchase of efficient equipment with higher first cost, limitations on public financing, ad hoc planning, and limited and poor data on energy use.
- **Public sector end user** barriers include limited incentives to save energy, no discretionary budgets for special projects or upgrades, unclear "ownership" of energy and cost savings, limited availability of financing, lack of awareness and technical expertise, and behavioral biases.
- For **energy efficiency equipment and service providers**, barriers include high project development and transaction costs, perceived risk of late payment or non-payment, limited technical, business and risk management skills, and limited access to commercial financing.
- **Financing barriers** include high perceived public credit risks, lack of customized financing mechanisms for EE, small project size and relatively high transaction costs, and lack of interest on the part of lenders in energy efficiency project financing.

OVERCOMING THE BARRIERS

Governments around the world have implemented a wide range of interventions to address these barriers. These interventions include: legislative and regulatory changes, policy measures, procedural changes, information programs, and incentive mechanisms (Wang, et al 2013). Many international financing institutions (IFIs), such as The World Bank, International Finance Corporation, European Bank for Reconstruction and Development, Asian Development Bank, and United Nations Development Program, have actively supported governments in developing countries with public sector energy efficiency programs. The experience from these programs points out that interventions that combine information and awareness programs with policies, incentives, and procedural changes can help address some of the barriers.

International experience also indicates that financing barriers are the most challenging for EE implementation in the public sector (World Bank 2014a). To address the financing barriers, many interventions have included grants and/or subsidies. However, while grants and subsidies can help implement pilot and demonstration programs that illustrate the benefits of EE, such financing is not sustainable in the long term.

As illustrated in Figure 1, the best roles of governments (and donors) are to develop policies and programs supportive of EE implementation, provide incentives, and stimulate market development for energy service providers. For the long-term development and growth of an energy services market, there is a need to have sustainable project development and commercial financing, which requires the active participation of banks and financial institutions. This in turn requires the development of innovative financing mechanisms for EE projects.



Source: Limaye 2011

Figure 1 – Need for Innovative Financing Mechanisms

FINANCING LADDER FOR PUBLIC SECTOR EE

Recognizing that grant financing is not sustainable, various governments, with the assistance of donors, have implemented a range of financing and implementation options. The ultimate objective is to enhance the financial leverage of public funds and to gain access to commercial funding for public sector EE projects. However, this objective cannot be easily achieved in the short term.

In research conducted by the World Bank, the following financing mechanisms have been identified (World Bank 2013):

- Budget financing with capital recovery, or "budget capture"
- Utility on-bill financing
- Establishment of an EE revolving fund
- Establishment of a public or super ESCO
- Establishment of an EE credit line through existing financial institutions, such as a development bank or commercial banks

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- Creation of a risk-sharing facility, such as a partial credit guarantee program, to cover commercial loans
- Commercial financing, bonds
- Vendor credit and leasing
- Leveraging commercial financing using energy service companies (ESCOs) under the energy saving performance contracting (ESPC) approach.

Figure 2 illustrates these options in the form of a "financing ladder" for public sector projects, moving from public (bottom) to commercial (top) financing.[2]

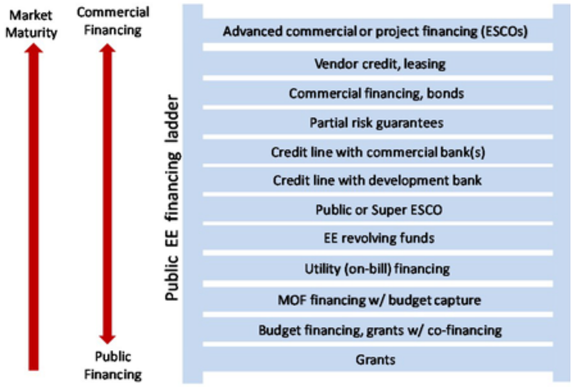

Figure 2: The Financing Ladder

Ideally, to achieve sustainable financing, commercial financing using performance contracting would be the most effective option. However, in most developing countries, due to the maturity of the financial markets and limited capacity and resources of ESCOs, it is not feasible to move to this financing option (Hofer et al 2016). Therefore, it may be desirable to implement one or more of the lower steps in the ladder.

A brief description of the steps in the ladder follows.

OVERVIEW OF THE FINANCING OPTIONS[3]

Budget Financing with Capital Recovery

Under this approach, financing is provided by a government agency, such as the Ministry of finance (MOF), using a combination of government budget allocations and IFI funds. This funding covers the investment costs of the EE projects in both central and municipal government buildings and facilities. The funding recipient agency "repays" the funds using the savings generated by the investment project in the form of reduced budgetary outlays for energy bills in future years ("budget financing"). The size of the reduced outlay is usually based on the amount of energy cost savings. Many municipal development banks that manage budgetary flows often rely on budget capture schemes.

The flow of funds to pay for EE improvements follows the same flow as the normal appropriations from the MOF. The repayment to MOF could be complete or partial; the partial approach encourages municipal utilities and public agencies to participate in the program because they retain a share of the savings achieved. An example of a financing facility using this approach is the Macedonia Municipal Services Improvement Project (World Bank 2012a).

Utility On-Bill Financing

Utility on-bill financing is a mechanism under which a utility provides financing for the implementation of EE projects. The funds are provided as a loan to the public sector entity for equipment purchase and installation, and loan repayments are recovered by the utility through the energy bill (ECO-Asia 2009). The cost of the EE measures is borne by the individual customers in whose facilities the EE measures have been installed (the direct beneficiaries of the energy savings and related cost reductions).

The utility on-bill financing approach is designed to overcome the first cost barrier (lack of availability of internal funds) for investment in EE. Under this approach, the utility provides or arranges for the financing needed for the project investment. The customer signs a loan agreement with the utility and the utility collects the loan repayments from the customer through the customer's utility bill by adding a line item on the bill. In most cases, the loan repayments are arranged such that the amount of the repayment is smaller than the customer's cost reduction from the energy savings created by the energy-efficient equipment. This allows the customer to be "cash flow positive" throughout the life of the EE project.

This approach has been successfully used by utilities in the U.S. (Heffner et al 2013).

Energy Efficiency Revolving Fund

An energy efficiency revolving fund (EERF) has been demonstrated to be a viable option for scaling

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[2] The concept of the Financing Ladder was initially developed in the World Bank's project on improving energy efficiency in the Western Balkans. It has since been applied in a number of projects in Eastern Europe and Central Asia to identify financing options for public sector projects.

[3] This discussion has been adapted from recent World Bank projects to define financing options for public sector EE projects in Kosovo, Georgia, Kazakhstan, Macedonia, Turkey, and Ukraine.

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up EE financing in the public sector. Under a typical EERF, created using public funds and donor loans, financing is provided to public agencies to cover the initial investment costs of EE projects; some of the resulting savings are then used to repay the EERF until the original investment is recovered, plus interest and administrative costs. The repayments can then be used to finance additional projects, thereby creating a sustainable financing mechanism (World Bank 2014b).

An EERF provides a more-efficient use of public funds than typical grant- of budget-funded approaches. Examples of EERF include the funds established with the financing and technical assistance from the World Bank in Bulgaria, Romania and Armenia (World Bank 2014b).

Public or Super ESCO

Several countries have taken a more active role in promoting EE projects using the performance contracting approach by creating either public or "super" ESCOs that are wholly or partly owned by the state. Often this was done to promote ESCOs in general, examples being China Poland and Croatia (World Bank 2014c). Such public ESCOs were typically formed when the local ESCO markets were immature and some public assistance was deemed necessary to catalyze them. The advantage of a public ESCO is that there is often no competitive process required for project development since a public agency is simply contracting with another public entity.

The super ESCO is a special type of public ESCO that has the dual functions of financing and implementing projects in the public sector and building the capacity of private sector ESCOs (Limaye and Limaye 2011). This is discussed in more detail later in this paper.

Public Sector Energy Efficiency Credit Line

A public sector EE credit line is a financing mechanism that makes funds available to local banks and financial institutions (FIs) to provide debt financing of EE projects in utilities and public buildings and facilities.[4] The major purpose of such a credit line is to increase the funding available from these lenders for debt financing of municipal EE project investments. These can be managed by a development bank, municipal bank, commercial bank(s), or other financial institutions. An example of a credit line for public facilities is the KfW municipal credit line in Serbia (KfW 2014).

Dedicated EE credit lines may be established by governments, multilateral or bilateral financial institutions, or governments in cooperation with international donor agencies. The funds provided by the donors or governments to lenders are often leveraged by additional funds provided by the participating banks and/or financial institutions to increase the total amounts available for debt financing (Limaye 2013).

Risk-Sharing Facility

A major barrier to commercial financing of public EE projects is commercial lenders' perception that EE projects are inherently riskier than their traditional investments. A risk-sharing facility is designed to address this by providing partial coverage of the risk involved in extending loans for EE projects. The facility - essentially a bilateral loss- sharing agreement - generally includes a subordinated recovery guarantee and might also have a "first loss reserve" to be used to absorb up to a specified amount of losses before the risk sharing occurs.

A partial risk-guarantee facility, provided by a government, donor agency, or other public agency, can assist municipal utilities and public agencies by:
(a) providing them access to finance, (b) reducing the cost of capital, and (c) expanding the loan tenor or grace periods to match project cash flows (Mostert 2010). Such a facility would also build commercial lenders' capacity to finance EE projects on a commercially sustainable basis.

Commercial Financing, Bonds

Under this option, municipalities take commercial bank loans (if they are creditworthy and have borrowing capacity) or issue bonds to finance EE investments (Bennett 2016). This option can mobilize commercial financing which can deliver scale and be sustainable. The elements of competition can help lower financing costs, address overcollateralization and short tenor issues, and allow public agencies to undertake own procurement/implementation.

This option can work if there are well-developed municipal credit and rating systems, financial institutions who are willing and able to lend to public sector for EE projects, and large municipalities with

[4] The European Bank for Reconstruction and Development (EBRD) has established a large number of EE credit lines in developing countries under their Sustainable Energy Financing Facilities (SEFF) program.

strong technical capacity willing and able to bundle many EE projects together.

Vendor Credit and Leasing

A lease is a contractual arrangement in which a leasing company (lessor) gives a customer (lessee) the right to use its equipment for a specified length of time (lease term) and specified payment (usually monthly). Depending on the lease structure, at the end of the lease term the customer can purchase, return, or continue to lease the equipment. Many different types of organizations, including proprietorships, partnerships, corporations, government agencies, religious and non-profit organizations, use leasing throughout the world. Suppliers of energy efficient equipment can provide such equipment under a leasing arrangement, usually with lease payments based on estimated energy savings (Amnuaisuk 2011).

Equipment leases are broadly classified into two types: operating lease and finance or capital lease (Lee 2003). In an operating lease, the lessor (or owner) transfers only the right to use the property to the lessee. At the end of the lease period, the lessee returns the property to the lessor. Since the lessee does not assume the risk of ownership, the lease expense is treated as an operating expense in the income statement and the lease does not affect the balance sheet.

Leveraging Commercial Financing with Private ESCOs

At the top of the "financing ladder" for public sector projects described earlier is the development of private sector energy service providers, such as ESCOs that specialize in EE project development and implementation. Private ESCOs can help overcome important barriers to scaling up implementation of public sector EE projects. They can (a) offer a range of services spanning the energy services value chain and (b) provide the technical skills and resources needed to identify and implement EE opportunities, perform services using performance based contracts (thereby reducing the risks to the municipal utilities and public agencies), facilitate access to financing from commercial lenders, and enable energy users to pay for services out of the cost savings achieved.

Performance contracting refers to EE implementation services offered by private ESCOs under ESPCs. These have the following key attributes (SRC Global 2005):

- ESCOs offer a complete range of implementation services, including design, engineering, construction, commissioning, and maintenance of EE measures, and monitoring and verification of the resulting energy and cost savings.
- ESCOs provide or arrange financing (often 100%) and undertake "shared savings" or "guaranteed savings" contracts, such that the payments to the ESCO are less than the cost savings resulting from the project implementation.
- Under the performance contract, ESCOs offer specific performance guarantees for the entire project (as opposed to individual equipment guarantees offered by equipment manufacturers or suppliers) and generally guarantee a level of energy cost savings.
- Payments to the ESCO are contingent upon demonstrated satisfaction of the performance guarantees.
- Most of the technical, financial, and maintenance risk is assumed by the ESCO, thereby substantially reducing the risks to the energy user.

SELECTING THE FINANCING OPTIONS FOR A DEVELOPING COUNTRY

Ideally, it is desirable to maximize the leveraging of commercial financing for EE using the performance contracting approach implemented by ESCOs. However, international experience indicates that attempts to replicate traditional performance contracting business models in developing countries have been mostly unsuccessful due to a number of significant challenges, including:

- These models are complex and require strong legal, financial, accounting, and business infrastructure - often lacking in developing countries.
- ESCOs in developing countries generally have limited assets and weak balance sheets, which makes it difficult to obtain and offer commercial financing.
- Commercial lenders are unfamiliar with the performance contracting business models and lack developed procedures for technical due diligence and project appraisal, which leads to their perception that such projects are highly risky. EE credit lines therefore are of limited value for the public sector.
- Private ESCOs often lack credibility with public sector energy users due to their limited track record and (perceived) limited technical capabilities.

- Performance contracting projects in the public sector face significant barriers related to budgetary procedures and procurement issues.

Recent projects by the World Bank have focused on three options that can be implemented in the near term. Together with regulatory and policy initiatives that remove some of the barriers to ESCO projects in public sector, these options can establish the basis for performance contracting and can facilitate the development of the market environment conducive to implementation of performance contracting in the longer term. These three options are summarized below.

Budget Financing with Capital Recovery.

This approach can work for central and municipal entities and, since there is almost no risk of non-payment, this can also be useful for municipalities without credit histories or borrowing capacity.

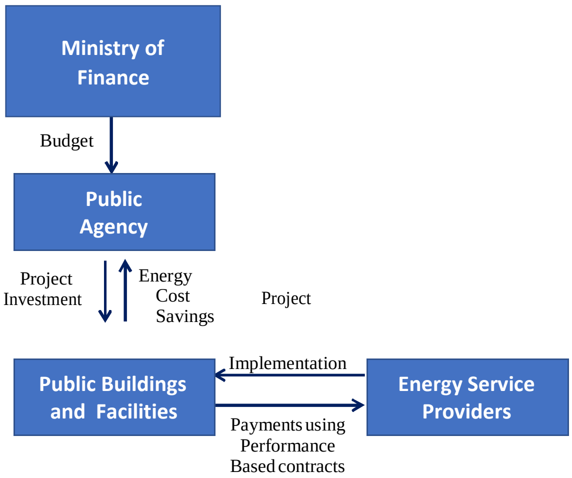

Figure 3: Illustration of Budget Capture

The implementation of the EE projects would be conducted by energy services providers using performance based contracts, thereby providing an experience base for future commercial financing by ESCOs.

Energy Efficiency Revolving Fund

The revolving nature of an EERF provides a sustainable financing mechanism for implementing EE projects in all types of public buildings and facilities. Also, an EERF can help demonstrate the commercial viability of EE investments and provide credit histories for public agencies, paving the way for future commercial financing.

A typical structure of an EERF is shown on Figure 4. municipalities that may have already reached their debt limits or otherwise have borrowing restrictions.

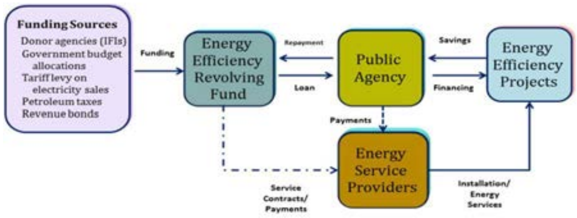

Figure 4: Typical structure of an Energy Efficiency Revolving Fund

The EERF may also offer, in additional to traditional loans, an energy service agreement (ESA), which can be very useful for public agencies that typically lack capacity to borrow funds and implement EE projects. Under an ESA, the EERF offers a full package of services to identify, finance, procure, implement and monitor EE projects. The public agency is only asked to pay what it is currently paying for energy, i.e., its *baseline energy costs*, which the EERF uses to make the new (lower) energy payments and recover its investment cost and associated fees until the contract period ends. Figure 5 provides a schematic illustration of an ESA.

For public clients, ESAs are generally not viewed as debt, but rather long-term service contracts, thereby allowing financing of central government entities that are typically not allowed to borrow, and

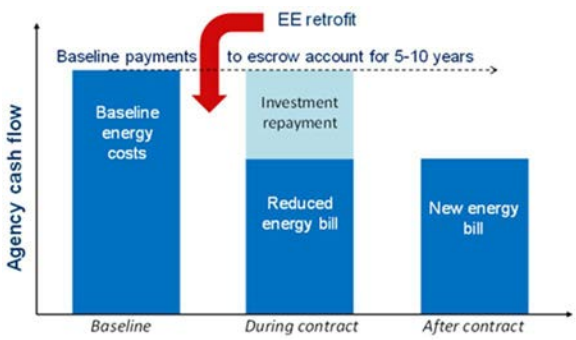

Figure 5: Illustration of Energy Services Agreement

An excellent example of the ESA implementation is in Armenia under the Renewable Resources and Energy Efficiency (R2E2) Fund (World Bank 2012b). During the period 2013 to 2016, this Fund completed 63 ESA projects with total investment of $9.6 million (World Bank 2016b).

Public or Super ESCO

Established by the government, a public (or super) ESCO functions as an ESCO for the public sector

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market, entering into energy performance contracts with public agencies to finance and implement EE projects. The public ESCO may also collaborate with local or international financial institutions to increase its financial resources. The public ESCO can provide credit or risk guarantees for EE projects, or act as a leasing or financing company to provide ESCOs and/or customers with EE equipment on lease or on benefit-sharing terms.

The *Super* ESCO is a special type of public ESCO. Established by the government, it functions as an ESCO for the public sector (hospitals, schools, municipal utilities, government buildings, and other public facilities) while also supporting the capacity development and project development activities of existing private sector ESCOs (see Figure 6). The government (possibly with help from IFIs) capitalizes the super ESCO with sufficient funds to undertake public sector ESPC projects and to leverage commercial financing.

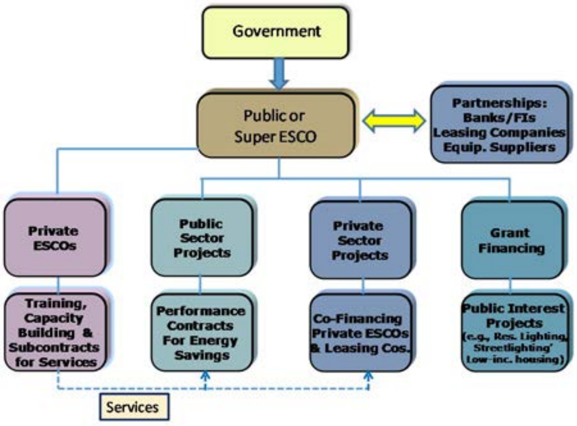

Figure 6: Typical Structure of a Super ESCO

Examples of Super ESCOs include Fedesco in Belgium, HEP ESCO in Croatia, Fakai SSC in Hebei, China and Energy Efficiency Services Limited (EESL) in India (Hofer et al 2016). EESL has successfully scaled up a range of public sector EE improvement programs (EESL 2016).

CONCLUDING REMARKS

The public sector represents a large untapped market for improving energy efficiency in developing countries. Public buildings and facilities are very inefficient in their energy use, and collectively they account for a large amount of energy consumption and a significant cost to the government. The public ownership and many common characteristics of many of the facilities, such as those with common functions (e.g., schools, hospitals), offer unique opportunities for bundling and scaling up EE projects, thereby facilitating financing at a large scale and attracting new firms in/to the EE market. But many important barriers, particularly those related to financing, have presented many challenges to large- scale implementation of EE projects.

This paper has identified a range of financing mechanisms that can be structured to overcome some of the challenges and move towards establishment of long-tern sustainable energy services markets. particularly in developing countries where public/ municipal credit markets are underdeveloped.

The selection of the specific mechanism depends on the existing legislative and regulatory framework, the characteristics of the public sector, the current status of the energy services market and the maturity of the financial sector (Figure 7).

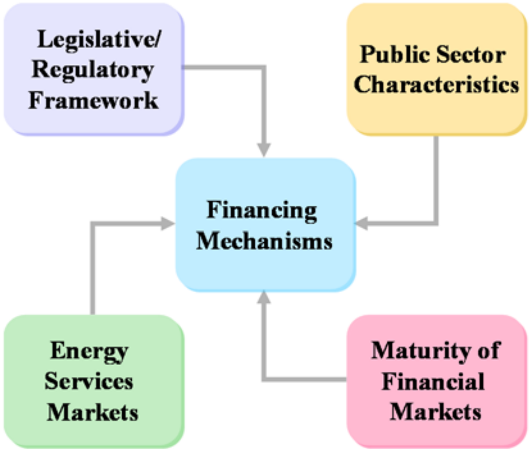

Figure 7: Selecting the Financing Mechanism

International experience can provide useful guidelines, but needs to be adapted to local conditions to select the most appropriate financial instrument(s).

ACKNOWLEDGEMENT

This paper draws upon several projects funded by the World Bank on development of financing mechanisms for the public sector in developing countries.

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ENERGY ACCOUNTING; A STATISTICAL MODEL TO IMPROVE OVERALL PLANT PERFORMANCE MONITORING

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Keywords: Energy Accounting, Multi variable Regression, Energy Intensity, SEC, Data-uncertainty

Objective: Use of Statistical Tools to understand Chlor-Alkali Process dynamic along with formulation of Energy Baseline, Standardization of Energy Management Program, and Prediction of Energy Use

ABSTRACT

The abstract is part of the "Energy Accounting" study carried out in a Chlor-Alkali Unit. The objective was to improve the present energy monitoring & reporting practices.

A "Whole plant" energy performance monitoring system, covering major electrolysis process area along with total utility load, is developed with an excel based tool.

As we know, SEC or Energy Intensity has its own limitation in terms of apple to apple comparison and energy saving/avoided energy quantification. So the alternative technique is to develop a "Mathematical Model" correlating energy with explanatory variables, i.e., monthly production and other drivers', i.e., key process parameters.

The purpose of Energy Accounting is to

1. Use energy performance Indicators (EnPIs) to measure, track, improve and compare energy efficiency.
2. Quantify potential increase or decrease in Energy Consumption for a given period.

In this study, base period (CY 2012-14) process data (key variables) with production and energy consumption is validated.

Statistical analysis is carried out with a simple Multivariable regression (MVR) in baseline period (CY 2012-14), considering data deviation, quality, relevance and time long enough to prove that load is likely constant. Data uncertainty and Model validation are carried out with statistical indicators like CV (RMSE), relative precision, etc."CUSUM" was made for the Performance period (CY 2015).

INTRODUCTION

Over the years, industries have developed equipment/components specific approach as opposed to "systems specific." A paradigm shift to look at systems can help industries immensely.

A strategic approach to energy management allows an organization to gain a better understanding of its energy usage. The Industrial Process Data is considered as a potential "productivity gold mine." The proper analysis of these data is critical in improving energy management.

Energy accounting with a statistical tool used to measure, analyze and report energy consumption for different activities on a regular basis correlating with the key variables and final production.

Energy accounting can help in budgeting, resource allocation for capital investment, and verify results of any energy management/effective operation and maintenance (O&M) activities. It is carried out to improve system reliability and to monitor the environmental impact due to energy consumption. It can be applied to any major system with a defined conditions/boundaries.

Energy Accounting Objectives

1. Use EnPIs related to process, operation, and production to measure, track, improve and compare energy efficiency.
2. Improve plant level Energy performance monitoring system with real-time decision-making. [Broadly into Planning, Scheduling, Optimization and decision support, Asset Management], etc.
3. Quantify potential increase or decrease in Energy consumption for a given period and verification of savings from energy efficiency retrofits.

4. Motivate staff to manage energy costs.
5. “Measurement & verification” to justify investment (budgeting & targeting).
6. Prioritize sites for energy retrofits.
7. Troubleshoot unprecedented increase in consumption.

By consistently tracking energy use, you can identify problems. A sudden unexplained increase in consumption, for instance, means it’s time to investigate the site for the cause.

STATISTICAL MODEL

Energy accounting exercise was carried out by using plant data historian (PDH) and monthly process parameters, for real-time data collection and analysis.

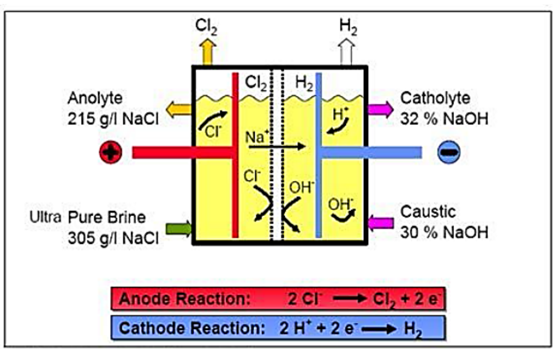
In this process around 90% of energy is consumed by electrolysis /rectiformers followed by total utility load (common for both M/c 1 & M/c 2).

In this process, the technology adopted is the most modern bipolar membrane-single cell type to produce caustic.

The reaction for the formation of Chlorine, Caustic Soda, and Hydrogen from a sodium chloride solution can be expressed as follows:

$NaCl + H_2O \longrightarrow NaOH + 1/2Cl_2 + 1/2\ H_2$ ---- (1)

This reaction is taking part as two separated cell electrode reactions: the anode and cathode reaction.



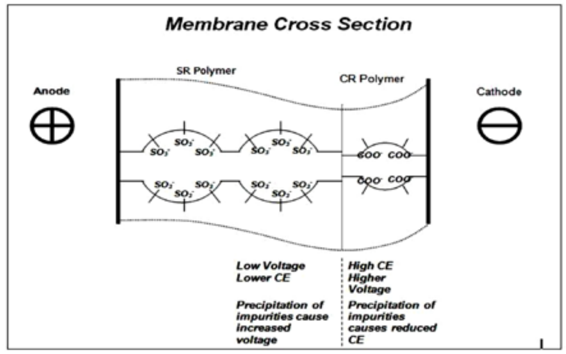


Figure 1: Schematic view of Chloro-Alkali process & Membrane Cross Section

It is found that the quantity of electricity which is needed to separate one gram equivalent of substance from an electrolytic conductor is 96,485 ampere seconds. The quantity of caustic soda solution liberated by 1 kA, theoretically is 1492.35 gNaoH.

The process parameters are closely monitored by the process engineer as per process need, which is decided based on the current density of the running load.

The voltage of each element is closely monitored for performance evaluation of membranes as well as element coating, as these are crucial factors in profit generation from production and lifespan of the electrolyzers.

The primary objectives of cell control are to:

- Reduce energy consumption by reducing the gap between anode and cathode
- Achieve an even current distribution over all anodes
- Increase production by increasing current and reducing cell voltage (electrical energy consumption remains constant)
- Reduce instances of cell shorting and associated production loss
- Reduce maintenance costs through reduced cycling of cell operation

Present Practices followed at the site in Energy Performance Monitoring and Reporting:

1. Dedicated Energy Monitoring System (EMS).
2. Mass flow meters used for recording of caustic production (MT). *(density accuracy $\pm$0.0005 g/cc and flow 0.10% of rate ISO 17025)*
3. Monitoring of specific energy consumption (kWh/MT of production); If the user is a designated

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consumer (DC), then it is on the basis of normalized production. (MToE/MT).
4. Main Meter and sub-meters *(sub-meters with 0.5s class and DC energy meter with Current output $\pm$0.1% of FS)*
5. Source of data: SAP/log book
6. Calibration in-house/NABL certified Lab.
7. Annual projection of energy saving separately for each Energy Efficiency projects with estimated running hrs.

Overall Breakdown Hrs. in last 4 years

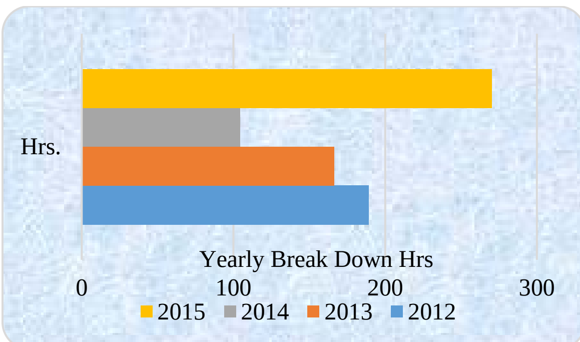

Figure 2: Break Down Hrs

Illustration of "Energy Accounting" (Whole plant Performance Monitoring) through statistical analysis

Data Collection Scheme: Selecting Relevant Independent Variables:

The independent variables are the forcing functions of the energy-using system. So for this project total Energy consumption (kWh) including utility, key process variables, and production data were considered as performance matrix.

The process performance/yield and variation in the major variables completely depend on following parameters:

- Caustic concentration & Temperature and feed brine concentration and temperature
- Life of membrane, anode, and cathode, cell efficiency.
- No. of tripping, Cell Voltage
- No. of cell elements v/s Current density (CD)
- Brine Impurities (ca & mg)
- Capacity Utilization, Rectifier efficiency
- Control system & Measuring instrument Precision and level of Uncertainty.

Data validation was carried of key process variables, i.e., monthly caustic production (NaOH), k-factor, CD, cell efficiency, byproducts, i.e., H_2 & CL_2, avg. running electrolyzer in baseline period [CY 2012 -14].

Calculations: A baseline model is developed to correlate actual baseline energy use with substantive fluctuating independent variables. This model is subsequently applied in an algorithm to determine saving, to derive energy consumption underperformance period.

The modeling method factors in the uncertainty, for determining saving. It also ensures that there is no net determination bias.

Statistical Analysis

EnPI Tool (Energy Performance Indicator): The EnPI based on Multivariable regression analysis is developed to establish a normalized baseline of energy consumption and to track the annual progress of intensity improvements. The EnPI tool is a standard executable Microsoft Excel, which uses Microsoft Office libraries.

Data uncertainty and Model validation are carried out with statistical indicators like CV (RMSE), relative precision, etc.

Following are the indicators used for data validation and derived model uncertainty/model validation.

- R-squared value: Coefficient of Determinations: Indicates the proportion of response variation. R^2 value tells us how much of the observed variation in energy consumption- appears to be accounted for by variation in the chosen driving factor.
- CV (RMSE): Coefficient of Variation of the Root Mean Squared Error (should be <5%). It Indicates the uncertainty in the model. It is not affected by the-degree of dependence between the independent and dependent variables, making it more informative.
- Net Determination Bias**:** The necessary assumptions and the unavoidable errors in metering of energy use and demand introduce random error and bias into the computed savings. The algorithm for savings determination used in whole building and retrofit isolation approaches shall be tested for net

determination bias. Net determination bias shall be no more than 0.005%.

Energy Model

Base period (CY 2012-14) process data (key variables) with energy consumption was validated, and the statistical analysis is carried out, considering data variation, quality, and relevance long enough to prove that load is likely constant.

Precision value of key variables, which is the measure of the absolute and relative range within which the true value is expected to occur with some specified level of confidence is derived. Detail is tabulated below.

Table 2: Considered variables Uncertainty and Relative precision in CY 2012-14

FY	Caustic Production (TPM)	Vm2/kA (K factor)	Cell Eff.	Avg. Current density CD (kA/m2)	Input Electrical Power
Average	22107.51	0.14	94.72	3.93	51859415.38
STDEV	1516.342	0.005	0.578	0.153	3527622.390
Stand Err.	223.572	0.001	0.085	0.023	520119.546
AP	449.380	0.001	0.171	0.045	1045440.287
RP	2.033%	0.931%	0.181%	1.151%	2.016%

Based on above table, there is 95% confidence that true mean production, CD, k factor and energy consumption lies in the range ± 2.033%, ±1.15%, ±0.931% and ±2.016% (RP value) respectively.

Based on above data analysis with EnPI tool, 40 number of valid energy models were computed. Only one model with highest R^2 value mentioned below is considered for our further analysis.

Table 3: Energy Model derived from Base year data (CY 2012-14)

Model Number	Model is Appropriate for SEP	Variables	Variable p-Values	R2	Adjusted R2	Model p-Value	Formula
18	TRUE	Caustic Production (TPM)	0.000	0.9874	0.9862	0.0000	Base line Equation *
		Vm2/kA	0.118				
		Cell eff%	0.0001				

The best fit equation (baseline eqn.*)/ (derived base Model) from multi-variable regression analysis based on last 36 months data (CY 2012-14), is

Calculated Energy Consumption (kWh) =

(2405.46 x A + (30457686.18 x B) + (-506569.59 x C + 42327251.87 (2)

Extrapolations: Coefficients are: A is "production value" and B is the sensitivity factor i.e. "k" value and C is "cell efficiency" and 42327251 is the constant value.

The model was further validated with CV and net determination, and it was found below the prescribed limit. The values are shown below.

CV RMSE	*0.63%*
CV STD	*5.43%*
R Square	*0.987*
Normalized Mean Bias Error	*0.0000%*

The variation in Current density (CD) and "k factor" in last four years is shown in *figure 3*. CD is purely dependent upon the targeted production with no. of cell in operation. "k" value purely depends upon cell voltage and no. of cell elements in operation.

Cell voltage is comprised of decomposition voltage (independent of CD), anode over potential, cathode over potential, structural contact, electrolyte and gas voltage drop and Membrane voltage drop.

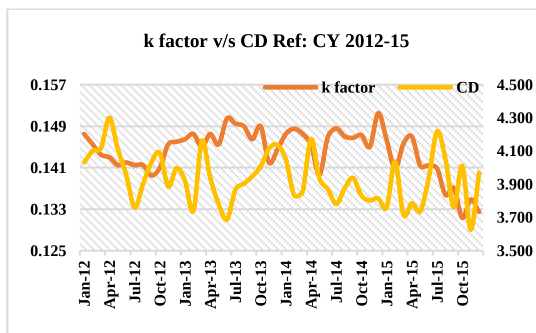

Figure 3: Variation in the major process indicators

Performance/Reporting Period

To evaluate result w.r.t overall any energy efficiency, best O&M practices applied in the performance period 2015; reporting-period energy saving/avoided energy savings, are calculated by "cusum" method is as shown in next page.

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CUSUM for the Performance Period 2015.

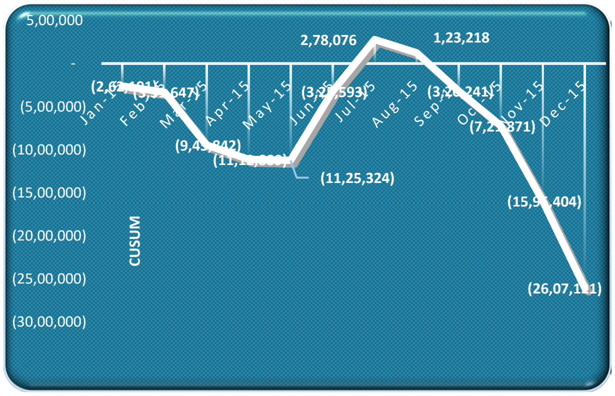


Figure 4: *Cusum graph*

"CUSUM' was made for the Performance period (CY 2015).

Table 4: Tabular representation of the performance period (CY2015):

Month	Caustic Production (TPM)	Vm^2/kA (K factor)	Cell eff%	Actual Energy (kWh)	Modeled Energy (kWh) Consumption	(Eact – Ecalc)	CUSUM
Jan-15	21207.85	0.1463	94.51	49662674.0	49924865.5	(262,191)	(262,191
Feb-15	21828.67	0.1408	94.97	50945835.0	51015290.9	(69,456)	(331,647
Mar-15	19844.90	0.1456	93.68	46432041.0	47046235.6	(614,195)	(945,842
Apr-15	20260.65	0.1470	92.85	48340226.0	48507273.4	(167,047)	(1,112,889
May-15	18529.27	0.1414	93.85	43650829.0	43663263.3	(12,434)	(1,125,324
Jun-15	17397.04	0.1415	94.00	41668504.0	40868773.0	799,731	(325,593
Jul-15	21778.98	0.1408	94.67	51654572.0	51050903.3	603,669	278,076
Aug-15	23347.55	0.1358	94.26	54719306.0	54874163.8	(154,858)	123,218
Sep-15	21246.82	0.1370	94.76	49161675.0	49605134.6	(443,460)	(320,241
Oct-15	22709.01	0.1313	94.95	52452558.0	52854187.9	(401,630)	(721,871
Nov-15	20435.95	0.1349	94.64	46775045.0	47648577.9	(873,533)	(1,595,404
Dec-15	23941.76	0.1325	94.84	54901348.0	55913064.5	(1,011,716)	(2,607,121
						Total	-260712
			Total	590364613.0	592971734		(13,035,603

Energy Development Index

Energy Development Index (EDI) as shown in *figure 5*, is an indicator towards efficient use of Energy. In this case, it is at +0.44%. It means that in the performance period, overall electrical energy has been utilized in an efficient way, compared to Model/baseline period.

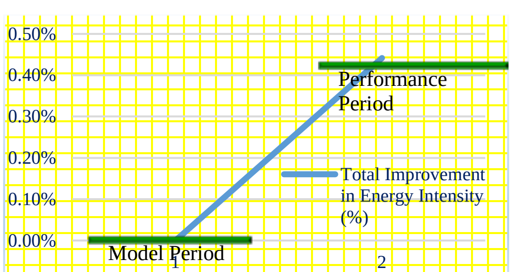


Figure 5: Improvement in energy intensity, Model year (CY2012-14) v/s performance period (CY 2015)

DISCUSSION & RESULT ANALYSIS

1. As shown in the above-derived model (refer table: 4), production has been reduced in the month of May-15 & June -15. It indicates that lower production has a higher impact on energy productivity. Lower production was because of scheduled replacement of old membrane. (Based on available information, avg. no of electrolyzer running in M/c 2 in May & June was 4.19 compared to 5.63 in preceding months)
2. There is an overall reduction **of 2607.12 MWH** in **energy consumption** in CY 2015. It is demonstrated in the cusum curve (*figure 4*) with the downward trend from July-15. It shows that "k factor" from Oct-15 has been reduced to avg. 0.135 compared to avg. 0.143 in preceding months, along with improved "cell efficiency." But with the isolated/conventional calculation, annual projected **energy saving was DOUBLE (only replacement of electrolyzer)**. It shows that energy saving calculation in isolation to production will give an unreliable figure.
3. All passive energy efficiency (EE) improvement measures & active EE (monitoring & strategic analysis) and capacity utilization (TPD) with minimum turnaround time, play the key role reducing energy and projecting the accurate figure of reduction in energy consumption.
4. It is recommended to link the model with routine plant monitoring system/ (RTM) and control the performance deviation from targeted value. In this whole plant performance modeling, the major role (deteriorated or improved performance) is played by electrolysis process parameters followed by critical equipment testing (PdM) parameters. So it is equally important to monitor the efficiency of all utility equipment. A performance matrix has been shared with Unit, to develop key performance indicators/parameters to be tested for all energy intensive utility load. Depending upon the no. of variables, statistical model (MVR) can also be developed for any of this specific utility equipment.
5. Energy productivity improvement can be further explored through *advanced process control* techniques with focused monitoring/squeezing the amplitude of deviation of "key process variables" to reap additional benefits in terms of increasing yield and reduction in energy consumption.

CONCLUSION

1. Model-based energy monitoring and targeting should be the basis for effective energy accounting. It reflects the true benefits realized based on activities w.r.t energy efficiency (EE) project implementation and/or efficient operation & maintenance, carried out in a given period. It has overcome possible deficiencies in the traditional performance indices or specific energy consumption (SEC) based monitoring.
2. In the conventional approach, there is no proper measurement and verification (M&V) carried out in any of the EE project implementation to realize actual benefits of energy saving.
3. The statistical approach starts with data validation will always justify the investment towards upgrading instrumentation (w.r.t desired accuracy, resolution and uncertainty) for measurement, monitoring, and reliable plant operation.
4. Multivariable regression (MVR) with "cusum" has the potential to pinpoint the specific reason for performance deterioration or improvement on a real-time basis. It also helps in better resource utilization, proper planning for any activities towards efficiency improvement, reduce breakdown, lower turnaround time (TAT).
5. The Scientific Way of data monitoring, analysis, and trending, will help in a) pinpoint incipient failures of equipment b) optimize the maintenance interval c) Provide a proper estimate of remaining equipment life d) improving the financial efficiency.
6. Energy Accounting helps in improving standardization and automated Plant Performance assessment, transparent reporting, increased communication and collaboration between teams. The real benefit is beyond energy saving covering: *Real-time decision, system reliability, Improving operational efficiencies and Enhancing field force productivity.*

NOMENCLAUTURE

A = [Caustic Production (TPM)]

B = [Vm2/kA(K factor)]

C = [Cell Eff.]

DC = Direct current

FS = Full Scale

EAM = Enterprise Asset management

AP = Absolute precision

RP = Relative precision

CUSUM = Cumulative Sum of differences

Current density (CD) = (operating current (kAs)/effective electrolyzer area (m^2))

K-factor = (Avg. Element voltage-Decomposition voltage /CD).

TPD = Tons per day

Designated Consumers (DC): A section of energy-intensive industries have identified as "designated consumers" and the account for a major share of about 45% of commercial energy use in India and contribute 25% to the national gross domestic product (GDP).

Decomposition potential or Decomposition voltage = It refers to the minimum voltage (difference in electrode potential) between anode and cathode of an electrolytic cell that is needed for electrolysis to occur.

Cell efficiency = Ratio of the real amount of Caustic produced in the cell to the theoretical amount which should be produced according to Faraday's Law.

MToE = Metric Ton of Oil Equivalent

CV (RMSE) = Coefficient of Variation of the Root Mean Squared Error.

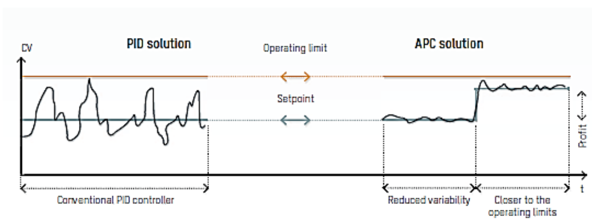
RTM = Real-time Monitoring

PdM = Predictive Maintenance

"CUSUM" Analysis: A statistical analysis technique that demonstrates the ongoing changes between actual and predicted values during the performance period. CUSUM, which is an acronym for cumulative sum deviation method. Deviation refers to differences between the actual consumption and the consumption you expect on the basis of established pattern-what we have called the base energy Performance Model derived from baseline period (2012-14).

It is a measure of the progressive deviation from a standard consumption pattern. It is simple to calculate and involves the cumulative summation of the differences between actual energy consumption and target, or baseline, energy consumption. Baseline values should be computed from a standard performance equation which should be derived from analysis of data collected during the monitoring period (CY 2012- 2014) before any interventions are made. The baseline should always be a horizontal line through zero. This is because by definition it is a best-fit straight line for the data samples occurring during the baseline period. The actual samples during this period may deviate from the predicted baseline figures, but the CUSUM plot will always fluctuate about zero. The greater the slope downwards of the CUSUM line, the more energy efficient the process.

Advanced Process Control (APC) = It is the intelligent, well-managed use of process control technology, systems, and tools, based on sound process knowledge, to enable and to benefit from operations improvements in the most cost and time-effective way.



Expectation from APC: Squeezing the variance allows moving the mean value closer to constraint/operating limit.

Passive energy efficiency: Energy efficiency/process performance improvement through integration project identification and implementation.

Active energy efficiency: Stringent procedure for real-time data monitoring, analyzing and reporting.

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SMART MANUFACTURING COMPONENTS, COLLABORATIONS, AND CASE STUDIES

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Keywords: Smart Manufacturing, Supply Chains, Intelligent Efficiency, ICT

ABSTRACT

When fully implemented, Smart Manufacturing integrates all facets of manufacturing using information and communications technologies (ICT). It enables the sharing of information between all components of a manufacturing process, regardless of level of automation, and all the individual units of an organization in order to achieve superior control and productivity. It can give everyone in the organization the information needed, when needed, and in actionable form. Each person is empowered to contribute to the optimal operation of the enterprise through informed, data-driven decision-making.

The networking of devices, systems, facilities and business units creates new energy savings opportunities. Starting at the device level, replacing an inefficient device such as a motor with a more efficient one will save energy. However, additional energy can be saved when the motor becomes a connected device within a network. The motor, the motor-driven system and the process can be run more efficiently. Ultimately, the entire manufacturing facility operates more efficiently, and the entire manufacturing supply chain produces only the particular items requested by customers. This paper will explain and give examples of how smart manufacturing saves energy at each of these levels. It will provide a basic understanding of the layers of smart manufacturing and how they all contribute to a superior ability to manage energy use and document energy savings. It will describe collaborative efforts in North America and Europe to create common software platforms, communication standards, and promote smart manufacturing and supply chain innovation.

INTRODUCTION

Smart manufacturing is often considered the fourth industrial revolution. The first was mechanical production using animals or water power and later steam power to drive processes. Grist mills and mechanical looms are examples. The introduction of electricity brought about the second revolution. It gave us electric motors, resistance heaters, electric lighting, and arc welding. The microprocessor brought about the third industrial revolution that resulted in the use of information technologies (IT) to improve the automation of manufacturing. Computers, robots, and early supervisory control and data acquisition (SCADA) further automated production lines. The fourth revolution, smart manufacturing, uses the Internet of Things (IoT), cyber-physical systems such as Cloud computing, use of Big Data, and machine learning. All of these technologies enable the integration of a company and its supply chain.

Smart manufacturing comprises a broad suite of emerging technologies and practices. It affects almost all functions of a company and can manifest itself in many decision making processes. It integrates all facets of manufacturing through the use of information and communication technologies (ICT). It has the potential to affect every aspect of the manufacturing process and all the individual units of an organization. It provides everyone in the organization the actionable information they need, when they need it, so that each person can contribute to the optimal operation of the enterprise through informed, data-driven decision making (Rogers 2014). Smart manufacturing is enabled by sensors, connected devices, smart devices, networks, wireless connectivity, data analytics, and remote computing. New, low-cost sensors often have wireless connectivity and are powered by ambient light or vibration. Devices of all types from the simplest light fixture to the most complex manufacturing process can be connected to a network. The term “smart devices” has come to encompass many new technologies that improve and expand the performance of a device over that of a contemporary devices. Improvements include convenience, value, and energy efficiency (Schlautmann et al. 2011). Devices, systems, and facilities are considered to be “smart” if they have the ability to make logical choices

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about future actions. It may be useful to think of a dumb device as having no embedded logic, a smart device as having embedded logic, and an intelligent device as one that is networked and has adaptive and anticipatory capabilities.

The Internet is fundamental to smart manufacturing. Devices connected to the Internet can be accessed from anywhere in the world. There are now more devices connected to the Internet than people (Ericsson 2011). The integration of devices through the Internet in the industrial sector is called the "Industrial Internet" or the "Industrial Internet of Things." It enables manufacturing to move from simple device integration and connectivity to the higher-level challenges of connecting people and devices throughout an organization and allowing them to communicate with each other. Machine-to-machine (M2M) communication is further empowered by the ubiquity of local wireless networks and international mobile Internet access. Sometimes referred to as the "pervasive Internet" (Harbor Research 2011), it makes connectivity and networking available independent of location.

Smart manufacturing is changing the nature of existing jobs in manufacturing and how people use technology. It marries information, technology and human ingenuity to bring about a rapid revolution in the development and application of manufacturing intelligence to every aspect of business. It changes how products are invented, manufactured, shipped and sold. It even has the potential to improve worker safety and protect the environment by making zero- emissions, zero-incident manufacturing possible. (Warren 2011)

SAVING ENERGY WITH SMART MANUFACTURING

Energy savings manifests in three fundamentally different ways: a device is made more efficient; a process is operated more efficiently; or innovation brings about a new way to accomplish a task with less energy. The first type is considered device-level efficiency, the second produces system efficiency and the third is substitution. Smart manufacturing produces system efficiencies and involves some substitution. In this paper, we focus on how smart manufacturing enables system efficiency.

System Level Energy Savings

A pumping system that pulls water from the city water supply and moves it to a water tank several hundred feet away can be used as an example of how process- level efficiency can be achieved with smart manufacturing. In this example from Rogers 2014, the water tank supplies various processes through the factory, so water is drawn out of the tank at varying rates throughout the day. The goal of the manufacturer is to use as little electricity to supply water to the plant as is needed to keep up with the pace of customer demand for product.

To achieve this goal, the manufacturer has many control technology options. Table 1 organizes them in a hierarchy of sophistication. The levels connote complexity rather than additional energy savings, although energy savings generally increase as we move toward Level 4. [1]

Table Hierarchy of control technologies

Level	Technology
Level 0	Manual on/off
Level 1	Reactive on/off
Level 2	Programmable on/off
Level 3	Variable response
Level 4	Intelligent controls

To start, the pump in the water system is driven by an electric motor that has the most basic method of control, a simple manual on/off switch. We call this Level 0 because there is no automation at this level. The amount of time that the pump is turned on has an obvious impact on the energy use of the system, but other components—the pump, valves, and piping— also contribute to the pumping system's energy use. The amount of energy consumed by the motor is related to the efficiency of the pump and friction within the piping and valves.

The next level (1) is a reactive control, such as is possible with a water level sensor that turns the pump motor on and off automatically. In a common setup; the pump fills the tank until it is full, at which time a float trips the off switch and the pump is turned off. When the tank gets too low, another sensor and mechanical device turn the pump on. This process

[1] This hierarchy is not the same as the International Society of Automation's ISA95 (https://www.isa.org/isa95/) international standard for developing an automated interface between enterprise and control systems.

continues without human intervention day in and out. It is a rudimentary example of a closed-loop system.

Level 2 has a modest amount of programmability. Instructions in the water pump's programming determine the conditions (e.g., time, tank level, production scheduling) under which the pump is turned on or off.

Considerable energy savings are achieved with Level 1 and Level 2 controls, so they may be efficient enough for many companies. However, in both scenarios, the pump operates at full speed each time it runs. Running the pump at a lower speed can save energy. Cutting the speed in half reduces energy consumption for a given amount of time by seven- eighths, so even though it will take twice as long to fill the tank, it will take a fourth as much energy. The challenge though is that if the pump runs too slowly, it may not be able to keep up with demand from production for water.

Level 3 addresses this challenge by incorporating variable response. The pump motor is connected to a variable-speed drive (VSD) that speeds up or slows down the pump in response to an instruction from a sensor or some software program. For example, the pump might speed up the lower the tank gets and slow down the closer to full it gets. The VSD adjusts the speed of the pump, and with each second that the pump operates at less than full speed, saves energy.

There is still a small amount of additional energy savings that can be achieved. The difference between what this automated system uses to fill the water tank and the least amount needed to satisfy production. Smart devices can provide a central control information on how much water it needs now and will need five, fifteen, and sixty minutes from now. The control system can direct the pump to fill the water tank to the exact level needed to ensure it maintains pressure and volume for the production line.

Smart manufacturing, Level 4, is the full integration of manufacturing processes with analytical software system that analyses past performance and adjusts system outputs in anticipation of future performance. At this level, full optimization of a system is possible because the process control is proactive and not just reactive.

It is important to note that the higher levels of complexity do not automatically translate into greater energy savings. For example, a reactive control for warehouse lighting might save as much or even more energy than a programmable system. However, the more sophisticated systems enable a greater level of control and reporting of performance which more readily leads to optimization of an entire enterprise.

Machine learning

Data analytics is the science of examining raw data with the goal of drawing conclusions about that information. Very often, data analytics will identify patterns. Machine learning is a subfield of computer science that evolved from the study of pattern recognition and includes computational learning theory in artificial intelligence (Rogers et al. 2015). Rapid advances in sensors, smart devices, energy management systems, and smart grid infrastructure have led to a massive increase in energy data production. New data analytical software programs are mining these data to identify patterns and some of them employ machine learning to make predictions about future. Manufacturers are beginning to use data analytics and machine learning to turn data into information, and information into knowledge that can be acted upon. ICT has already improved the ability to identify opportunities to save energy. Now organizations are deploying ICT systems to calculate, track, and document energy savings, provide near- real-time performance feedback, and predict future energy savings (Grueneich and Jacot 2014).

Networked enterprise

Enterprise Resource Planning (ERP) systems have been the business-operating backbone of many corporations for decades. However organizational resource planning and manufacturing execution systems (MES) are often hindered by a lack of integration with control systems on the factory floor (Koc and Lee 2002). Without the information coming from and flowing to the plant floor, important details, such as maintenance schedules, unpredicted downtime, and product variability are not factored into the information these systems provide to high-level decision makers.

In most facilities, production information flows between production and management, and ERP systems share information between business operations and supply chain. They cannot use production information to influence interactions with the supply chain or have supply-chain information influence production decision making (Koc and Lee 2002).

A smart manufacturing software platform will handle information only once, enabling the optimization of assets, synchronization of enterprise assets with supply-chain resources, and automation of business processes in response to customer demands (Koc et al. 2005).

A fully integrated ERP will be an enterprise-level resource and asset-management system that can reach down into the day-to-day operations and collect data, to enable more informed decision making. This can extend beyond collecting production and energy information. The ultimate goal is the integration of all methods of monitoring, reporting, and managing organizational tasks: environmental monitoring and compliance systems, customer relationship software systems, purchasing, financial, payroll, and even worker training. Software platforms will provide tracking of products throughout a production process, benchmarking and tracking of performance at every step of the process, and traceability of all input and output materials (SMLC 2011).

The time and locational value of energy can even be incorporated into the day-to-day operation of a facility if provided by an energy supplier. Demonstrations involving smart grids to relay pricing signals provide a clue to what might be possible (PNNL 2015).

Smart manufacturing platforms enable performance oriented enterprises to minimize energy and material usage while simultaneously maximizing environmental sustainability, health and safety and economic competitiveness. SM platforms enable corporate management real time global performance metrics that merge actionable business and operations information with the ability to anticipate, plan, and manage risk across suppliers. (Davis et al. 2012).

Smart Design

Energy use in designing new products is negligible compared to the energy used in production processes. However, as the saying goes, "time is money" and so time is also energy use. The longer the design process takes, the more energy consumed by the design staff and their facilities. Products designed digitally through computer-aided design eliminate the expensive and energy-intensive physical modelling step. This accelerates time to market and reduces the likelihood of making a product that will not perform as intended.

For example, Nissan uses product life cycle management software in its three U.S. production plants. By integrating its design practice, it was able to reduce its development cycle from 20 months to 10.5 months and decrease design changes by 60–90%. It is now experiencing 80% fewer problems after vehicle release (IndustryWeek 2013).

Designing a product also includes developing the manufacturing process. There are many opportunities to reduce production costs including energy. A common rule of thumb is that 75% of the costs of manufacturing are determined during product design stage (Warren 2011).

Smart design includes designing for the environment (DfE), a holistic approach to the treatment of raw materials, product life cycle, and user experience. It is the process of thinking through future energy use and production by-products and developing product designs and production processes that minimize both. It will also take into consideration wastes that customers will generate using the product and the ability of the product to be recycled at end-of-life. Product design informed by production process realities and sustainability performance metrics has the potential to reduce overall costs and improve profitability.

New IT capabilities, smart manufacturing software platforms, now make computer simulation of production processes possible. Design processes can integrate feedback from actual production operations so that material flow can be optimized during the ramp-up to full production (Siemens 2014). Companies are achieving shorter production ramp up times, faster production cycles, and greater production-floor flexibility as a result of these smart manufacturing technologies (IndustryWeek 2013).

Calculating Energy Savings from Smart Manufacturing

Smart manufacturing can produce efficiency gains at all levels of an enterprise. It can enable companies to operate each component of a system and every collection of systems more efficiently. However, the leading motivation for most manufacturing concerns to invest in automation is to improve productivity. The benefits of energy savings are secondary to that of other higher-priority performance metrics such as increased throughput and lower unit production costs. Additionally, automation and integration projections can seldom be justified on energy savings alone (Forrester 2012). Therefore, when considering the impact of smart manufacturing on energy consumption, it is important to think of energy costs as just one of many production costs that are also being addressed.

If productivity is the ratio of throughput to the value of capital equipment and operating costs, then improvements in productivity can come from greater output, lower value of equipment, or lower operating costs. Since energy is one of the variable costs of production, an investment or change in practice that lowers per unit energy consumption will increase productivity.

Treating energy use as a variable cost of production is often captured in an “energy intensity” metric. At the most basic level, energy intensity is the amount of energy used by a manufacturer divided by production volume. It is a useful metric for companies to track the collective impacts of their investments on energy consumption. The amount of total energy consumed by a facility may go up even as efficiency improves because expansions, changes in product mix, or processes changes required more energy. An energy intensity metric will give decision makers context for understanding their energy use.

Some investments in smart manufacturing will yield significant energy savings, while others will produce only marginal and inconsistent savings. It is the collective impact of improvements made by smart manufacturing that is important to consider. In aggregate, all of the small improvements in operation will have a profound effect on energy consumption.

Since energy savings is incremental and additive, the determination of total savings requires multiple equations. Table 2 lists the equations that can be used to calculate savings from each level and in total.

Table Calculations for determining energy savings from smart manufacturing savings baseline technology energy use - smart technology energy use

ENERG SAVINGS	SMART TECHNOLOG	BASELINE TECHNOLOG
Device-level	Efficient device	Inefficient device
Device-level	Device operating only as needed	Device operating in on/off mode
Process-level	Process operating only as needed	Process operating in on/off mode
Facility-level	Connected processes	Isolated processes
Enterprise-level	Networked business units	Isolated business units
Machine learning	Past performance informing current operation settings	Best guess at optimal operation settings
Design savings	Smart design process	Conventional design process

Source: Rogers 2014.

Each source of energy savings has a direct impact on the bottom line of a company and the competitiveness of individual facilities. Furthermore, such investments introduce a new level of flexibility and responsiveness to manufacturing processes that will help companies make additional investments in productivity and efficiency.

Case Studies

The manifestation of smart manufacturing can be difficult to visualize. Case studies can help make the features and benefits more tangible.

Case Study Use of RFI at Ford Motor Company, BMW, and Vau hall

Smart manufacturing also includes building connectivity into products to aid the manufacturing process. Ford uses RFID technology in its engine production lines: as the engine starts down the line, the entire work sequence is loaded onto the RFID tag and each station interrogates the tag to determine what task it should complete. Quality control test results are written directly onto the tag.

Both BMW and Vauxhall use RFID tags to accurately customize their products. A read/write smart tag is programmed with a customer’s order, and the tag is attached to and travels with the car throughout the production process ensuring that the car is manufactured with the correct colour, model, interior, and any other options the customer specifies (Zhekun, Gadh, and Prabhu 2004; Sharp 1999; Brewer et al. 1997). Energy is saved by producing only cars customers want and using only as much material as needed.

Case Study: Huntsman Petrochemical’s use of Process control and ata Historian

Huntsman Petrochemical upgraded its process control system at one of its ethylene manufacturing facilities in Europe. The plant is one of the largest of its type in Europe, with 17 cracking furnaces that turn various hydrocarbon feedstocks into intermediate products that are shipped to other locations and to a number of downstream users. A high-fidelity process historian that saves past production settings and performance information was added to the existing process control system. It allowed Huntsman to compare current and past conditions. This new capability yielded increased production and plant reliability, and it reduced out-of-specification production and energy consumption, allowing Huntsman to make additional capital investment in a new Distributed Control System (DCS). The new control system enabled the plant to produce the maximum amount of ethylene and propylene, reduce production disruptions and upsets, decrease furnace energy consumption, and reduce flaring by 75% (Singh et al 2007).

Case Study Faribault Foods

Faribault, a Minnesota-based food processing company, installed a new heat and energy recovery system along with new automation controls and monitors. The new system collects and presents water, air, gas, electric, and steam (WAGES) consumption information through dashboards, visual displays that put production information into context. The software system also leverages access to individual motor control and monitoring provided by the production process control system. The investment resulted in a reduction of natural gas consumption by more than 38%, CO2 emissions reductions by over 3,000 metric tons annually, and savings of more than 100 million gallons of water each year. At the same time, throughput at the plant was increased by 90% and production waste was reduced (Rockwell 2011).

Each of these three examples demonstrates how energy waste is reduced through superior control of one or more manufacturing processes. The case studies also highlight the power of historical information to provide benchmarking, facilitate performance monitoring, give context to current performance data, and enable wiser, more-informed decision making.

COLLABORATIONS

To facilitate the development of smart manufacturing technologies and practices, several collaborative efforts have evolved around the world. Each of these initiatives has a different set of goals but they all seek to accelerate the adoption of smart manufacturing technologies.

Smart Manufacturing Leadership Coalition SMLC

The purpose of SMLC is to lower the cost of applying advanced analytics to manufacturing, build pre-competitive software infrastructure, establish an industry-shared, community-source smart manufacturing (SM) platform and create test beds for SM concepts (SMLC 2014).

SMLC was foundational in the creation of the Clean Energy Smart Manufacturing Innovation Institute (CESMII), a newly formed partnership with the U.S. Department of Energy, several universities and manufacturers, and technology vendors. CESMII brings over $140 million in public-private investment to “radically improve the precision, performance and efficiency of U.S. advanced manufacturing”. CESMII is the 9th Institute of the Manufacturing USA initiative established by the Obama administration to spur U.S. innovation, sustainability and competitiveness (CESMII 2017).

Digital Manufacturing and Design Innovation Institute DMDII

DMDII is another one of the centres created by the Obama administration. It is intended to establish a state-of-the-art proving ground for digital manufacturing and design that links IT tools, standards, models, sensors, controls, practices and skills, and transitions these tools to the U.S. design & manufacturing industrial base for full-scale application (DMDII 2017).

It has brought together over 190 companies, universities and laboratories in a precompetitive collaboration focused on what it refers to as the “digital thread” that ties together all aspects of product design, development, manufacture, and distribution (DMDII 2017). This initiative focuses on developing a common method of using ICT to incorporate smart design and DfE throughout a product’s lifecycle

Volttron Open Source Platform

The Grid Modernization Laboratory Consortium is comprising of representatives from several of the US DOE programs and national laboratories. One research and development project by Pacific Northwest National Laboratory (PNNL) is the open- source[2] reference platform called Volttron. It can be loaded onto a very small computer and yet is powerful enough to interact with utility distribution system sensors and controllers (PNNL 2015) Volttron is an execution platform designed to facilitate implementation software agents - computer programs coded to perform certain tasks with autonomy - that perform electric power system sensing and control tasks (Akyoul et al. 2012). Volttron’s true potential can be easily understood with a smartphone app analogy: just as apps are developed to perform a

[2] An open-source reference platform is a software program developed in a public and collaborative fashion and the use of which is not restricted by proprietary code or licensing requirements.

particular task on a smartphone, software agents can be developed by third parties to control and sense various electric power system parameters and use that information towards a particular task (Srinivas Katipamula, staff scientist, PNNL, pers. comm., July 13, 2015). Advance Metering Infrastructure (AMI) infrastructure (also known as smart grid) execution platforms such as Volttron, and applications that can perform measurement and verification of energy savings can work together to create an electric grid that is as interactive and dynamic as our telecommunications network is today (Rogers et al. 2015).

NIST Cyber Security for SM systems

The vulnerabilities of sensors, wireless communications, networks, and control systems makes manufacturers hesitant to adopt many smart manufacturing technologies. In response to this market barrier, the U.S. Department of Commerce, National Institute of Science and Technology (NIST) launched the Cybersecurity for Smart Manufacturing Systems research initiative. It aims to develop a risk management framework with supporting guidelines, methods, metrics, and tools to enable manufacturers, technology providers, and solution providers to assess and assure cybersecurity for smart manufacturing systems. The goal of this initiative is the successful development of a framework and methodology that will stimulate the adoption and use of new security technologies and development of smart manufacturing systems that offer the security, reliability, resiliency, and protection against disruption that manufacturers want (NIST 2014, Stouffer 2016).

Europe Commission Single Digital Market

The European Commission (EC) launched an initiative in 2008 to create a single digital market for all of Europe. This effort is addressing IT and communications issues affecting all businesses. The Single Digital Market initiative is carried out by the Directorate General for Communications Networks, Content and Technology (DG CONNECT). It develops and carries out the Commission's policies on digital economy, research and innovation, business and industry, culture and media. Within the larger Single Digital Market initiative are programs to accelerate smart manufacturing (EC 2017d).

The Factories of the Future

The EC launched the Factories of the Future Public-Private Partnership (PPP) in November 2008 as part of its European Economic Recovery Plan to the global economic crisis. The goal is to exploit advances in ICT across the entire manufacturing process chain and facilitate the modernization of manufacturing in Europe. Key industrial partners in this PPP are large manufacturers in automotive, aerospace, engineering, suppliers, electronics manufacturers and software as a service (SaaS) providers. The initiative is supported by a large number of Europe's academic and research institutes. It has funded more than 150 research development and innovation (RD&I) projects that have improved processing of raw materials and movement of materials within a facility, supply chain configurations, virtual factories, and upgrading existing machines and technologies with ICT (EC 2017e).

Factories of the Future is supported by the European Factories of the Future Research Association (EFFRA), an industry-driven association promoting the development of new and innovative production technologies. EFFRA’s objective is to promote pre-competitive research on production technologies within the European Research Area by engaging in a public-private partnerships (EFFRA 2017).

Another smart manufacturing focused initiative is the DIGITAL Factory which has the goal of “First time right”. The DIGITAL Factory provides technical assistance and convenes stakeholders to address the early stages of manufacturing and engineering. It assists in the development of interoperable models, engineering platforms, computer-assisted product and process development, virtual prototyping, and testing environments to reduce the need for physical mock- ups (EC 2017a).

Other projects include the Smart Factory and the Virtual Factory. The first is focused on the production automation landscape and how it will be transformed into smart entities that provide interoperability. Production machines have become smart enough to adapt and react flexibly to any kind of digital input or event. The Virtual Factory is focused on managerial control in manufacturing through the Cloud (EC 2017c, EC 2017f).

The Factories of the Future will continue in the research programme Horizon 2020, a large EU program focused on driving research and innovation related to advanced manufacturing. In addition to the private investments from partners, Horizon 2020 is a financial instrument for implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe’s global competiveness. The initiative emphasizes science, industrial leadership and taking on societal challenges (EC 2017f).

Horizon

Horizon 2020 is stimulating innovation through awareness and convening activities. Its aim is cross-fertilisation of knowledge to reinforce international cross-border and cross-sector collaboration in research and innovation. Key activities include organising events and support of exchanges of R&I staff among a partnership of universities, research institutions, research infrastructures, businesses, SMEs and other socio-economic groups (EC 2017g).

An example of an event is the International Conference on Sustainable Smart Manufacturing which was held in Lisbon in October of 2016. It featured research in the fields of manufacturing, design, architecture and construction, eco-design, and sustainable manufacturing (EC 2017h).

An example of convening is Working Group 2. These stakeholders are working on development of the next-generation digital platforms and considering how existing and planned EU-wide, national, and/or regional platform development activities can contribute (EC 2017b).

Industry .

Germany is particularly focused on leading the fourth industrial revolution. "Industrie 4.0 is a strategic initiative to keep Germany in a pioneering role in industrial IT. It is focused on cyber-physical systems (Cloud-based data analytics) and how they can improve resource productivity and efficiency while also enabling more flexibility in the organization and operation of facilities. Industrie 4.0 is managed by Germany Trade and Investment (GTAI). Industrie 4.0 has been exploring the move from centralized to decentralized manufacturing and the move from mass production to mass customization (GTAI 2014).

An example of the type of issue GTAI is researching is the future of ERPs. Some industry experts expect ERP software will ultimately be directly linked to process control systems (PCS) at the production level, thereby eliminating the need for individual software systems. Conversely, others consider manufacturing execution systems (MES) software to be excellently situated for the implementation of Industrie 4.0. The resolution of this issue is not as important as the organized deliberation of it.

In 2012, the German government passed the High- Tech Strategy Action Plan to further implementation Industrie 4.0. New funding comes with a focus on embedded systems, simulated reality for grid applications and infrastructure, virtual and augmented reality, ambient intelligence, human to machine interaction, and bioanalogous information processing (GTAI 2014).

All of these initiatives and collaborative efforts are helping to advance smart manufacturing. Each of them demonstrates the important roles government agencies can play in fostering economic development through an emerging suite of technologies. Some agencies, like the U.S. DOE, EU, and GTAI provide financial assistance. Others convene stakeholders and facilitate the development of common protocols and platforms. Research and innovation are common roles for governments to fill and fund. All will contribute to expanded use of smart manufacturing.

SUMMARY

Smart manufacturing technologies enable the sharing of information throughout the organization and its supply chain in an actionable format that facilitates decision making and superior management of the entire manufacturing process. The ubiquity of performance data and the ability to analyse them is enabling enable companies to compete on energy efficiency, environmental, safety, and sustainability performance metrics.

The elimination of barriers to interconnectivity and the falling prices of networks and data analytical capabilities are making smart manufacturing more practical to a greater number of manufacturers. This will enable them to offer new products and services that will improve their productivity and reduce their energy intensity.

The implementation of smart manufacturing includes collaboration of all units within an organization. It includes development of new performance metrics and real-time decision making. It breaks down horizontal and vertical silos and connects all the components of a supply chain.

Its focus is improving organizational performance but also results in minimizing energy and material usage while also maximizing environmental sustainability, worker health and safety, and overall competitiveness. It enables management to anticipate, plan, and manage risk across suppliers. It provides new degrees of freedom for performance, efficiency and productivity. "Smart Manufacturing enables all information about the manufacturing process to be available when it is needed, where it is needed, and in the form that it is needed across entire manufacturing supply chains, complete product lifecycles, multiple industries, and

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small, medium and large enterprises” (Davis et al. 2012).

CONCLUSIONS

Smart manufacturing is transforming the manufacturing environment and enabling companies to address waste, energy, water, and material optimization more effectively than before. The potential of smart manufacturing technologies and practices to reduce operating costs and improve competitiveness will drive adoption by greater segments of the industrial sector.

Countries and manufacturers benefit from forming and working with voluntary collaborative efforts such as the EFFRA, Industrie 4.0, SMLC, and DMDII. These initiatives support precompetitive research, innovation, and development of intelligent efficiency and smart manufacturing platforms that will result in improved market dynamics.

Smart manufacturing has become an economic engine of growth in the industrial sector. Companies can more readily respond to customer demand and develop better and more-targeted products. Design, development, and delivery to market is getting quicker and costing less.

Aided by government involvement and technical resources, precompetitive collaboration within the vendor and manufacturing communities is bringing about common protocols and standards. The interoperability of systems will continue to grow the market to the benefit of all customers and vendors. Government agencies and private sector should continue their collaborations and support the development and demonstration of new technologies. They will all contribute to the continued health, growth, and decreasing energy intensity of the manufacturing sector.

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STRATEGIC ENERGY MANAGEMENT: MOVING FROM A TRANSACTIONAL MODEL TO AN ENTERPRISE-WIDE APPROACH TO ENERGY EFFICIENCY

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Keywords: strategic, customer-centric, integrated, deep savings

ABSTRACT

Large commercial customers represent opportunities for significant energy savings. Very often these opportunities entail longer project timelines, interactivity of multiple and complex systems, and the need for customized solutions. Strategic energy management (or SEM) proposes a multi-year and enterprise-wide approach to planning long-term and deep energy savings goals for such customers, in a way that:

- It creates a cultural shift in the way energy is viewed and managed in an organization;
- It maps more closely to the organizational goals and budgeting process;
- It creates an opportunity to go deeper into the operations and reach to the technical and achievable potential that comes from planning and execution over a multi-year process; and
- It integrates energy efficiency with broader organizational aspirations such as, emissions reduction, environmental stewardship, Climate Action Plans, etc.

SEM as a delivery model to bring energy efficiency to large complex customers is gaining momentum in the US. This paper will present the key aspects of a SEM approach – organized as WHAT, HOW and WHY of SEM – and discuss its applicability in India.

- WHAT: understanding the meaning and features of strategic energy management.
- HOW: discussion of the SEM process under a framework that can be broadly applied to any organization and industry.
- WHY: potential benefits of SEM will be discussed, and highlighted utilizing some examples from the United States (US) and a detailed case-study from India. Finally, the paper will discuss the relevance and applicability of the SEM approach in the Indian context.

WHAT: INTRODUCTION TO SEM

Strategic Energy Management is a holistic approach to energy efficiency that enables businesses to achieve long-term and persistent savings. The US Department of Energy (DOE) defines SEM as an organization-wide approach to efficiency that sets long-term energy savings goals and uses rigorous tracking and reporting systems to drive greater savings that reach across entire portfolios (SEE Action, 2012). National Grid defines strategic energy management as a collaborative approach that:

- Achieves comprehensive energy saving goals, plus benefits beyond energy efficiency, ranging across the triple bottom line spectrum of people, planet and profitability.
- Leverages an organizational shift in how energy management decisions are made within the organization.
- Changes focus from isolated measures to integrated system-wide efficiencies in the built portfolio.
- Establishes an organization-wide roadmap to achieve persistent energy savings, and efficient operations through a cycle of continuous improvement.

SEM is essentially a shift away from the traditional transactional model for energy efficiency that uses external motivators such as rebates to make one-time capital improvements. Instead, it aims to embed long-term energy-management practices within organizations. The idea is to institutionalize practices that will enable organizations to independently achieve on-going savings from conservation, streamlined operations, focused capital investments, and behavioural modifications. The underlying idea behind SEM is: "Give a man a fish and you feed him for a day. Teach a man to fish and you feed him for a lifetime" (ESource, 2013).

The SEM approach is best suited for large commercial, institutional and industrial entities that typically have significant energy consumption and large built portfolios, often coupled with multiple and complex physical systems. Rather than addressing each facility or site as a separate entity, SEM promotes an organization-wide approach (also referred to as enterprise-wide or portfolio-wide) to emphasize energy management as a business priority (versus a facility management issue), to streamline processes, to drive consistency across locations, and

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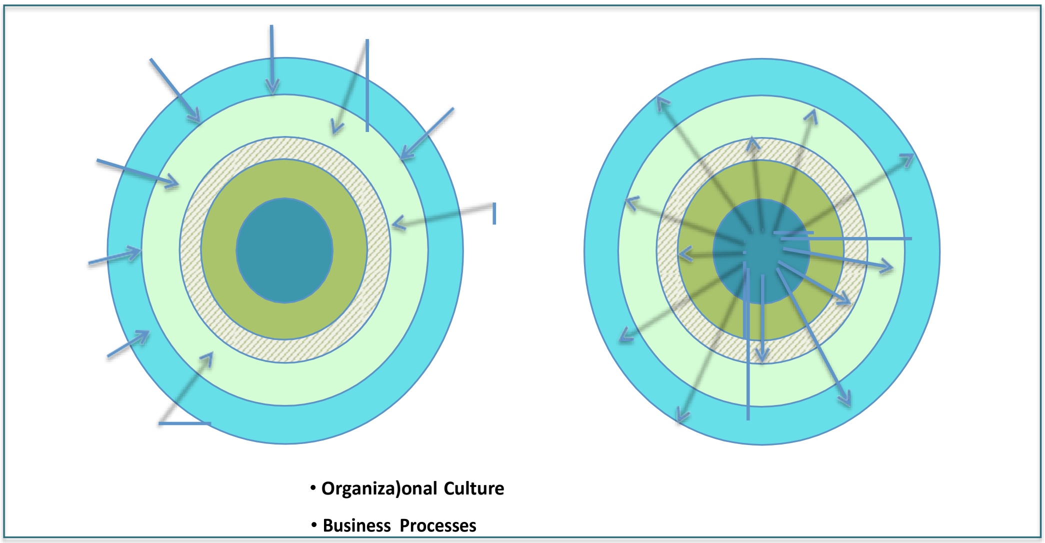

Figure 1: The Concept Of Energy Efficiency From The Inside-Out

to benefit from economies of scale as well as transference of best practices across the organization.

The best way to understand SEM is: quite simply put, it is the concept of energy efficiency (EE) from the inside out!

Energy Efficiency From The Inside Out

Traditionally, EE retrofits are approached from the outside-in, most commonly addressing fixtures, appliances and equipment, occasionally touching physical systems and controls, and rarely, if ever, going beyond that towards the building features. This approach has its place and may serve well in the 'homogenous' buildings category – that is, typically large volume of customers with simplistic and similar energy systems, and moderate consumption per customer. For example: small/medium offices, small/medium retail, bank outlets, etc. However, this approach essentially catches the so-called low hanging fruit, as is commonly referred to in the industry. The same approach applied to large complex customers limits the depth of energy savings achieved and leaves a lot at the table.

The concept of EE from the inside-out (Figure 1), on the other hand, mines the full potential of energy efficiency and then some! Foundational to this concept is the notion of energy conservation being intrinsic to an organization's value system and value chain. EE starts at the very core of the organization, and permeates throughout into the organizational processes, built environment, energy systems and operational protocols, and the equipment and fixtures. (And not necessarily in that order, but the idea is that there is top-down buy-in and support to enable energy conservation throughout the organization). An important aspect of EE from the inside-out is that it reinforces a cultural shift in how energy is viewed and used within an organization. Energy is no longer an after-thought in response to high utility bills, but rather a controllable business lever, impacting cost-competitiveness, shareholder value, environmental footprint, and user comfort.

Philosophical speaking then, this approach truly enables adoption of the triple bottom line construct in business practices, positioning energy as integral to the people-profitability-planet equation. And practically speaking, this approach truly mines the depth of energy savings possible across the organization's operational and built footprint, bringing persistent savings and a culture of continuous improvement.

SEM History And Proof-Of-Concept

Energy efficiency program administrators started exploring the idea of SEM in North America, a little over a decade ago. Northeast Energy Efficiency Alliance (NEEA) was the first organization to design and test a holistic SEM program approach when it launched a four-year pilot called Continuous Energy Improvement (CEI) in 2005, as a component of its Industrial Initiative Program (NEEA, *https://neea.org/docs/default-source/food-processing-documents/neea_cei_lessons_learned.pdf?sfvrsn=4*). The CEI pilot targeted the region's largest food-processing firms and sought to demonstrate that embedding SEM throughout an organization could achieve significant and persistent savings from capital and non-capital improvements. The highlights summarizing the CEI initiative are:

- NEEA's original goal was to enrol 13% of target companies, but by 2009, 20% were on board.
- NEEA demonstrated through an evaluation that 3% of the pilot's energy savings came from non-capital improvements.
- In 2010, NEEA surpassed its 1.6 average megawatt (MW) savings goal by achieving a total of 2.23 average MW.
- In 2011, 36% of target food-processing companies were enrolled and practising SEM.
- In 2013 NEEA completed program implementation for its target facilities and in 2014 transitioned to a continuous monitoring initiative.

Through a series of follow-up surveys with past participants, NEEA found that most companies continue to practice SEM by revisiting their energy goals, dedicating additional resources to manage energy, and tracking energy usage.

The NEEA Industrial CEI program was a major industry influence by testing and proving out the efficacy and persistence of a comprehensive management systems approach to energy efficiency.

Other noteworthy early-proponents of SEM are BC Hydro and Energy Trust of Oregon (ETO), two energy efficiency program administrators in North America (ESource, 2013).

ETO launched an Industrial Energy Improvement (IEI) pilot in 2008, to tap into savings from non-capital projects. Now a mature program, IEI is a component of ETO's broader Production Efficiency Program. The early pilot tested the efficacy of strategic energy management on a diverse segment of mid-sized industrial customers and found that on an average, participants achieved energy savings of 7.9% per customer in the first year. The second phase of the pilot achieved similar outcomes, with an average of 9% savings achieved per customer.

While the ETO pilot was focusing on non-capital improvements, the noteworthy contribution of their pilot lies in validating the persistence of the approach. Post-surveys of participants in both phases of the pilot suggest that savings persist after engagement with the program. Some survey responses suggested a resulting increase in employee engagement and attributed ongoing savings to that.

BC Hydro explored aspects of SEM approach as early as 2002. They identified three broad elements that are key in creating lasting changes in the way an organization manages energy:

- Energy management resources – availability of dedicated and skilled energy professionals;
- Energy assessment – the means to accurately and consistently measure and benchmark energy use, that informs an action plan with tangible targets;
- Energy awareness – employee/user training and conservation awareness events within the workplace that drive behaviour changes.

These elements planted the seed for what has evolved into a structured SEM framework over the past decade.

HOW: SEM FRAMEWORKS

At a simplistic level, SEM programs follow a traditional framework of: plan, implement, evaluate and modify. At a more evolved level is the ISO 50001 standard that provides organizations with an internationally recognized framework for implementing an energy management system. The ISO 50001 standard addresses the following:

- Energy use and consumption
- Measurement, documentation, and reporting of energy use and consumption
- Design and procurement practices for energy-using equipment, systems, and processes
- All variables affecting energy performance that can be monitored and influenced

Key Steps to ISO 50001

- Set an Energy Policy
- Have management commitment
- Empower an energy team
- Iden7fy where energy is used
- Create plans to improve energy use
- Management approval of plans
- Track progress and reassess energy ac7on plans

Figure 2: Key Steps To ISO 50001 *(Source: U.S. Department of Energy: energy.gov/eere/amo)*

While the ISO 50001standard may or may not be the ultimate goal of an organization, but its key steps (Figure 2) provide a logical and generally applicable framework, and many program administrators and consultants have used a process that is very similar. SEM implementation process typically includes the following sequential steps as core elements of a SEM framework:

1.Commit

Commitment from top leadership is key in setting a strong foundation for SEM within an organization. At a basic level, this commitment has to manifest in the form of at least:

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- Establishing overarching objectives for the organization, and framing the energy conservation drive within those broader goals;
- Allocating appropriate resources for SEM implementation, including setting up a team and determining accountability and governance.
- Initiating appropriate communication plans to bring awareness and culture shift within the organization.

Leadership commitment ultimately is instrumental in establishing both an organizational structure and the necessary processes to achieve results through a systematic energy management approach.

A **best practise** is a having a dedicated ‘champion’ at a leadership level in the organization, who drives the SEM progress and provides due governance.

Typically, at this stage, the organization will also establish (or firm up if already existing) an overarching set of guidelines and goals which could be in the form of either an energy strategy, or sustainability policy, or climate action plan.

2.Measure And Assess

Taking stock of the energy use and development of organizational baselines is the next important step in the SEM implementation process. The principle of “what we cannot measure, we cannot improve” sums up the importance of this step.

Judiciously installed meters and sub-meters are an important component at this step, giving visibility into the energy consumption and the operational schedules of different buildings and systems at the desired level of granularity. This enables establishing baselines, assessing savings potential, and mapping where the organization stands with respect to its goals. Additionally, accurate metering can give a jumpstart to the SEM effort by identifying some quick and no-cost improvements, through standardization of operational schedules for different locations, and improvement in operational sequencing for equipment.

3.Prioritize And Plan

Once the energy consumption and savings potential in different facilities/buildings is visible, the next step entails prioritization of projects and development of an implementation roadmap, taking into account the organizational parameters. These parameters would be unique to each organization and may include budgeting process and spending appetite, operational cycles, and deferred maintenance plans.

A **best practise** at this step is to commit to a reinvestment cycle, such that the cost savings gained from operational and energy efficiency are reinvested into the next set of energy efficiency projects.

4.Deploy

This step involves implementation of identified projects, including capital investments, operations and maintenance (O&M) improvements and behavioural initiatives.

5.Evaluate

The importance of measuring and verifying results, and communicating progress to employees and management cannot be stressed enough. Tracking improvements and communicating successes is important in order to keep the momentum strong, validate the benefits of energy conservation, and reinforce a drive for continuous improvement.

A **best practise**, and in fact an important component for this step is a robust energy management system (EnMS). Ideally this should be established during the early steps of SEM implementation.

An EnMS allows accuracy and consistency in measuring improvements, provides analytics for deeper assessment of systems and processes, and enables data driven decision-making. It also drives consistency and ease in reporting, and helps define and track key performance indicators. Depending on its sophistication, an EnMS can increase the energy performance visibility within the organization through the use of public dashboards.

6.Recalibrate

Recalibration is an opportunity to review and adjust SEM implementation efforts to achieve continual improvement. Depending on the effectiveness of an organization’s SEM implementation, recalibration may take many forms, such as: adjusting project priorities, ensuring use of energy data in long-term planning and decision-making, and ensuring integration of energy management into existing processes.

The takeaway here is that various SEM frameworks - from the simplistic to the highly structured - essentially offer a similar process: a logical series of steps with some essential components, and a feedback mechanism to enable continuous improvement. EPA’s Energy Star Energy Management Framework (Figure 3) is a good graphical representation summarizing this process (U.S. EPA, 2016). Within this framework, each organization has the flexibility to tailor the details of their SEM plan per their unique organizational parameters and goals.

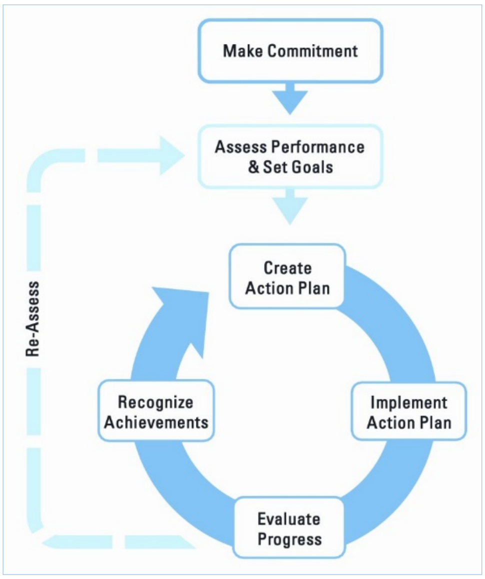

Figure 3: U.S. EPA's Energy Management Process

WHY: THE BENEFITS OF SEM

The potential benefits of strategic energy management go far beyond energy savings, and translate to business benefits, user benefits, and environmental benefits. These wide-ranging benefits are summarized in the following Table 1, and exemplified in the section on "Case Study and Examples".

Table 1: Benefits of Strategic Energy Management

BUSINESS BENEFITS
Improved profits and cost-competitiveness
Reduced operational costs, efficient operations
Reduced risk to energy price fluctuations
Improved processes, consistency across the organization
Efficient resource utilization through economies of scale
Embedded systems for continuous improvement
Enhanced shareholder value
Improved employee engagement, and retention
Positive brand visibility as an environmental steward
PEOPLE BENEFITS
Enhanced user comfort and wellbeing
Increased awareness and adoption of sustainable behaviors
Better work environment and thus enhanced productivity
SOCIETAL AND ENVIRONMENTAL BENEFITS
Reduced strain on the energy infrastructure
Reduced emissions
Judicious use of natural resources
Lighter ecological footprint

Organizations' level of SEM implementation can fall on a continuum depending on the breadth and depth of adoption of the core elements, and/or maturity of their SEM initiative. Correspondingly, the benefits achieved may also vary in their depth and range.

CASE STUDY AND EXAMPLES

For the new adopters, it is sometimes natural to wonder: is SEM a neat management concept or will it really work; are the benefits theoretical or actually achievable? Fortunately there is ample body of work out there to prove the latter. Per the U.S. DOE, a strategic energy management framework such as the voluntary ISO 50001 standard, if widely adopted, could influence up to 60% of the world's energy use across many economic sectors (*https://www.energy.gov/ISO50001*).

Some examples from the US, highlighting outcomes and benefits of strategic energy management, and a detailed case-study from India, discussing successful strategic energy management implementation are presented below.

Highlights From The US

In the US, organizations implement SEM either on a self-directed basis – where ISO 50001 is the commonly used framework – or driven by utility-supported programs. In the latter case, the utilities provide varying levels of support for SEM implementation ranging from financial incentives, technical consultations, cost sharing for energy management staff, metering and energy management systems, to project financing. Because this model is not immediately transferrable to India, the paper will not get into details of the utility-supported SEM programs. Instead the SEM examples from the US will focus predominantly on the self-directed efforts of organizations at their US and global sites.

Schneider Electric's Schneider Energy Action (SEA). SEA is Schneider Electric's global internal energy management program that uses ISO 50001 as the blueprint for continued energy savings across their widespread portfolio. Schneider Electric has benefited from persistent energy savings through the establishment of a "culture" of managing energy.

Between 2012 and 2016, Schneider Electric's enterprise-wide approach to energy management across 19 ISO 50001 certified sites in North America - 13 sites in the US, 5 in Mexico, and 1 in Canada - saved 22 million kWh of electricity and 57 billion Btu of natural gas resulting in $1.8 million of annual

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energy cost reductions (U.S. DOE, 2017). Aside from cost and energy savings, the company also noted other significant benefits, such as efficient resource utilization and consistency across locations:

- Reduced implementation labour by 75%, and implementation period from 13 to 3-7 months.
- Leveraged centralized expertise, and consistent communication to promote continued EE.
- Gained operational consistency and performance improvements across their widespread locations.

It would be remiss not to highlight Schneider Electric India's (SEI) success with the enterprise-wide energy management approach. SEA program was launched in India in 2012. Since then SEI has attained ISO 50001 certification at 13 sites, reducing the energy consumption at these energy-intensive sites by approximately 37%. Between 2012 and 2016, SEI has saved 12.6 million kWh of electricity, and avoided over 12,900 tonnes of CO2 emissions and more than INR 77 million of energy costs as compared to the 2011 baseline.

3M. The multinational manufacturer saved $3.6 million by using an enterprise-wide approach to certifying six sites to ISO 50001 standard. Operational changes with little capital expenditure accounted for 67% of the energy cost savings at five of those sites. Using the enterprise-wide strategy, 3M also reduced its implementation timeline by six months (compared to an individual-site approach). Based on this proven success, 3M has incorporated strategic energy management through the ISO framework as a key strategy to meet its next set of corporate energy goals.

Both Schneider Electric and 3M have worked with the U.S. DOE to assess the impact of ISO 50001 on their facilities and to compare those savings to their other facilities. The results showed that sites using an enterprise-wide energy management approach such as ISO 50001 showed greater energy savings that increase over the years, and outperformed other sites by up to 65% *(https://www.energy.gov/ISO50001)*.

Detroit Diesel. Detroit Diesel's engine manufacturing plant used ISO 50001 to improve its bottom line and meet corporate goals. The energy team established a rigorous energy management system and, obtained third-party verification of its energy performance improvements through DOE's Superior Energy Performance program. Auditors confirmed that even as production at the facility increased by 93%, its cumulative energy performance improved 32%, saving $37 million over 10 years *(www.energy.gov/eere/amo/articles/sep-success-story-detroit-diesel)*.

Aflac Insurance Company. Between 2007 and 2016, Aflac reduced energy use by over 50% across its two campuses in Columbus, Georgia. ISO 50001 is credited with helping the Aflac team optimize its energy review process, better understand weather impacts on energy use, set savings targets, and measure progress toward meeting them.

J. W. Marriott Group of Hotels. At Marriott, ISO 50001 has saved over one million kWh of electricity and improve guest satisfaction—Marriott's top priority. Aside from enhancing guest comfort, the ISO 50001 framework has been instrumental in fostering employee engagement on energy efficiency.

Infosys (India) Success Story: A Case Study In Strategic Energy Management

Utilizing an enterprise-wide approach to sustainability, and a process very similar to the SEM framework, Infosys has achieved incredible results in the last nine years towards saving costs and energy, improving operational efficiencies, enhancing human comfort and reducing the environmental footprint of their building portfolio. The key outcomes (Infosys, 2017), using 2008 as the baseline year, are:

- 51% reduction in the average per capita energy consumption across their campuses; this is well over $100 Million savings in electricity bills.
- While the number of employees has increased by 143% since 2007, the total electricity consumption has increased by just 19%.

It all started with a commitment! In fiscal year (FY) 2008, Infosys took up some aggressive internal goals to reduce energy intensity by 50% by FY 2018. This was also followed by a voluntary commitment at the United Nations (UN) in 2011. The organization established some bold and specific targets - such as, LEED Platinum certification as a minimum standard for all new buildings, 50% reduced energy consumption, 100% electricity from renewable energy by 2018 - with the CEO committing to monitor progress every quarter.

The leadership took a position that energy profligacy is unreasonable, and catalysed some bold steps for transformation. In the words of Mr. Ramadas Kamath, Executive Vice President and Head - Administration, Facilities, Infrastructure and Security

& Sustainability, Infosys's method was a "disruptive design" approach where the results are "an extreme conversion process" involving "design first, education second" *(http://www.eeb-toolkit.com/index.php/modal-case-study-infosys-modal)*. With such an approach, corporate commitment and establishing the right level of resources and systems become all the more critical for achieving success. And Infosys pulled it off very successfully by all standards!

Infosys's methodical approach to bring about a cultural shift in the management of energy closely mirrors the SEM framework, as discussed below.

Commit. In FY 2008, Infosys took up aggressive internal goals to reduce energy intensity, followed by a voluntary commitment at the UN in 2011. A Green Initiatives team was specifically established to test and develop progressive energy efficiency measures, and drive Infosys towards the organizational targets. The Green team members brought the appropriate technical skills such as HVAC system design, energy audits, lighting design, and long-term planning.

In 2009, a sustainability policy for Infosys was developed which acts as a guide for all sustainability actions. Strong corporate governance is a cornerstone to Infosys's sustainability policy — focused on providing business value while enhancing the long-term competitive advantage of the company and ensuring results on the triple-bottom line.

Measure and assess. The first and the most important step of the Green team was to meter the energy consumption in buildings across all the campuses. This was the only way to know the consumption levels, to establish organizational baselines, and to assess the potential for savings.

- Energy meters were installed in every building and every chiller plant and the energy team were able to monitor building wise energy consumption.
- Metrics such as per capita energy consumption, and energy use per sqm. area were calculated.
- A central energy dashboard was created to accurately consolidate energy and employee data for all locations.
- These numbers in 2007-08 were the first calculation of normalized energy data for Infosys buildings, and therefore became the baseline for comparison:
  - 2007-08: The per capita energy consumption of Infosys was 297 kWh/employee/month and office building energy consumption was an average of 200 kWh/sqm/year.
  - 2016-17: The per capita energy consumption improved to 145 kWh/employee/month and the new office buildings energy consumption was an average of 75 kWh/sqm/year.

Prioritize and plan. Accurate metering informed the prioritization process by identifying buildings with highest energy consumption and highest potential for energy savings. Buildings were identified for detailed audits to uncover greater potential for improvement by changing system design, and equipment replacement.

The Infosys team planned the overall energy efficiency storyline in stages:

- Stage I – No-cost measures: These interventions did not require any capital investment, and included measures such as standardizing of operational schedules for different locations, improvement in operational sequencing for equipment particularly in air conditioning systems.
- Stage II - Low cost measures: This was the second step, which included replacing small equipment like pumps, installing thermostats and timers for electrical panels (to schedule the major equipment on/off). This gave the second level of energy savings in the buildings.
- Stage III – The major retrofits and capital-intensive projects were planned as the third stage.

The idea behind this graduated approach was to harvest the 'easy' savings first, in order to deliver results, gain management confidence, and pave the way for investments in further efficiency measures.

Deploy and Evaluate. For each stage, the achieved savings were duly measured and verified and results were presented to the management. Stage I achieved energy savings in the range of 15-20%. The savings were clearly visible; they got all the stakeholders excited about energy savings and helped gain greater confidence with the senior management.

Stage II brought the next level of granularity for energy efficiency measures, such as: pump replacement, VFDs, replacing deteriorated equipment, LED lighting and granular energy monitoring. At the end of Stage II a presentation was made to the management showing measured savings and payback for each project. Every time the numbers prove the impact, the Green teams's interventions and strategies gained more credibility.

For Stage III, a 5-year plan was developed and associated cost and savings details presented to the management. The benefits realized till date and the projected benefits were so attractive that the CFO accelerated this to a 2-year plan and granted budgets accordingly. The stage III projects involved major retrofits: redesigning the air conditioning plant, replacing redundant Un-interruptible Power Supplies from buildings with high efficiency modular UPS systems. These retrofits have helped reduce the electrical connected load by over 30 MW across campuses in 6 years, often with a payback of less than 3 years.

Recalibrate. Infosys effectively applied lessons learned from their existing building retrofit projects to make their new construction more energy efficient. They also explored innovative technologies and solutions; for instance radiant cooling. Through a study conducted in two identical buildings on their Hyderabad campus Infosys discovered that the radiant cooling system was 33% lower in energy consumption compared to the conventional air- conditioning system designed per ASHRAE standards, and at a lower cost per sq. ft. To overcome the limitations of a slab-based radiant cooling system, Infosys team also developed a panel based cooling solution that uses chilled water for cooling.

As next steps, the Infosys team is focused on increasing adoption of renewable energy, as well as implementing more efficient water treatment systems that not only uses less energy use but also reduce water wastage.

The Green team that started as a 5-person team has grown to 30, with expanded skill-sets that include smart building systems, water efficiency, waste management, and biodiversity, to develop a holistic approach to sustainable development. Infosys is gaining momentum towards its long-term goal to becoming water sustainable and carbon neutral.

The results and benefits thus far. Infosys's organizational transformation and a culture shift in energy management has brought not only impressive energy and cost savings over the past 9 years, but also several non-energy benefits.

- Infosys has drastically reduced peak load and per capita energy consumption, and avoided about 1400 Million kWh.
- The retrofits of existing buildings have resulted in 30% reduction in energy, 45% reduction in equipment, and 25% reduction in space.
- All new construction post-2007 is rated LEED Platinum or equivalent. Infosys has a total of about 11.3 million sq.ft. of built up area with highest level of green certification (LEED Platinum and GRIHA 5-star).
    - The average energy consumption in these super-efficient new buildings is 75 kWh/sq. m./year (compared to 200 kWh/sq. m./year in baseline year 2007-08).
    - The new buildings have seen around 43% reduction in maximum electrical load (kW) compared to conventional buildings.
    - It is noteworthy that this increase in efficiency has been achieved without increase in the first cost.

Other benefits include:

- Reduced maintenance issues, smoother operations, and enhanced cost-competitiveness.
- Business predictability and de-risking.
- Improved indoor environment and enhanced comfort and well being of users.
- Greater employee awareness on energy efficiency as well as greater employee engagement.
    - Infosys has policies and systems in place for positive engagement with employees.
    - Infosys organizes awareness programs and camps to help the Infosys family become proactive about their wellbeing and reduce their ecological footprint.
- Greater social impact through encouraging sustainable practices among vendors and contractual partners.
- Infosys has reinforced its brand equity as a global leader in sustainability.

By integrating sustainable practices into all aspects of their business, Infosys is enhancing shareholder value as well as making positive contributions towards global ecological challenges.

RELEVANCE FOR INDIA

India has committed to reduce the emissions intensity of its GDP by 33 to 35 percent by 2030 from 2005 level as part of its Nationally Determined Contributions. Energy efficiency is positioned at 51% *(Bureau of Energy efficiency, 2016; based on WEO 2010)* of the share of India's cumulative emissions abatement between 2010 and 2035. Given these ambitious targets the full technical and achievable potential of EE needs to be leveraged, making a program like SEM highly relevant.

Some immediately visible areas where SEM can be beneficially leveraged are:

PAT Program, And Overall Industrial EE

Within the context of India's NDC targets, the Perform, Achieve and Trade (PAT) scheme was announced by the Indian Government in 2008 under its National Mission on Enhanced Energy Efficiency (NMEEE) in National Action Plan on Climate Change (NAPCC). PAT is a regulatory instrument to enhance cost effectiveness of improvements in energy efficiency in energy-intensive large industries and facilities, and imposes mandatory specific energy consumption targets on the covered facilities.

PAT is currently in its second Cycle of implementation, with national savings target of 8.869 MTOE (approximately 103 million MWh) at the end of Cycle, by 2018-19. This roughly translates to an aggregate reduction of approximately 4% in the total energy consumption of the 621 participants (referred to as Designated Customers or DCs) in Cycle II.

While the PAT scheme has been a significant boost to the energy efficiency drive in India, industry stakeholders and participating DCs highlight several gaps that if addressed could help improve the efficacy of the program. A knowledge paper on the PAT Scheme, prepared by the Tata Strategic Energy Management Group uncovers challenges faced by the DCs with regards to PAT compliance. Many of these challenges, such as below, can be addressed well and mitigated with an SEM approach:

- Decision-making in India is still based on 'first-cost and payback' and not on cost over the operational life, leading to sub-optimal decisions and less efficient equipment.
- Most of the EE projects are perceived as high risk as returns are dependent on proper implementation and maintenance by DCs.
- O&M practices are not refined. Lack of skilled personnel often leads to inefficient operations and thereby poor energy performance
- Lack of project based funding at low interest rates for energy efficiency projects, and competing financial priorities within the organization, give a back-seat to EE projects.
- State of energy monitoring in industrial plants in India needs a lot of improvement. Accurate measurement system is not only critical for energy optimization, but will also lead to improvements in maintenance practices.
- Lack of proper and consistent baselining practices is an untapped lever for energy management.

In fact, some DCs have adopted the ISO 50001 framework to increase awareness and methodologically gear up all stakeholders towards energy efficiency.

With SEM bringing a change in culture around the management of energy, skilled resources for energy conservation projects, rigorous O&M guidelines, energy monitoring systems, measurement and verification practices, and opportunity to reinvest savings into EE projects, several of the barriers to energy conservation efforts, experienced by the DCs, can be effectively addressed. SEM can be significantly instrumental in maximizing the INR 34,000 crore market opportunity (AEEE and SSEF, 2016) in industrial energy efficiency.

Enhancing Efficiency In The Healthcare Sector

AEEE's research in the Healthcare sector highlights that a typical private hospital has more than 50% energy and cost savings potential.

Hospitals account for approximately 10% of the energy use of commercial building sector. The energy use intensity of private hospitals (which are about 75% of the total healthcare sector) ranges from 200 to 300 kWh/m2 or 10,000-20,000/bed. This translates to a monthly expense of INR 16/sq. ft. or INR 12,000/bed. In comparison, the monthly energy costs for a BEE 5-Star rated hospital is INR 8/sq. ft. or INR 4,500/bed, suggesting significant saving opportunity through energy efficiency (AEEE, 2017).

AEEE also found that equipment procurement and O&M guidelines are almost non-existent for the healthcare sector, pointing to a huge opportunity for improvement.

Incorporating a SEM approach to energy efficiency in this sector will bring multiple benefits:

- Manifest "easy" savings, that could be reinvested into EE projects. *Organization Name's* work in this sector shows that, using thorough retro-commissioning, up to 10-12% savings are easily achieved with no-cost/low-cost measures alone.
- Establish systems for operational efficiencies resulting in on-going savings, ease of maintenance, and cost-competitiveness.
- Enhance indoor environment for the users.

- Achieve the full technical and achievable potential of energy efficiency strategies.

SEM's applicability really transfers to multiple sectors: commercial and industrial organizations, institutional campuses, manufacturers and their suppliers, central, state, and local government, major chains in hospitality, health care, and more. This approach can be a significant contributor in mining the energy efficiency potential of India's built environment. The resulting energy and carbon reductions are increasingly valuable as a means to support India's emissions reduction commitment.

CONCLUSION

Strategic energy management has proven its efficacy as a framework to achieve the full technical and achievable potential of energy efficiency. Using EE as the starting point SEM paves the way for richer benefits to an organization. Beyond being merely a comprehensive suite of energy-management activities, SEM defines a holistic approach in which elements interact with, support and reinforce each other (Lancaster et. al., 2015). The result is a whole that is greater than the sum of its parts.

The time is ripe for widespread adoption of SEM in the commercial and industrial sectors in India. With deep energy savings, significant business benefits, and increasingly valuable emissions reduction, SEM promises multiple societal and environmental benefits, and can play a key role in advancing India towards an energy efficient economy and supporting its climate change commitments.

ACKNOWLEDGEMENTS

I'd like to express heartfelt thanks to: Mr. Guruprakash Sastry at Infosys for the consent to showcase Infosys energy management success story as a case-study in this paper, and for sharing relevant details; Mr. Aalok A. Deshmukh and Mr. Rohit Chashta at Schneider Electric for sharing information on SEI's energy management accomplishments.

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EFFICIENT COOLING THROUGH DECOUPLED SYSTEM DESIGN

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Keywords: Energy Efficiency, Building, HVAC Plant, Savings, Design

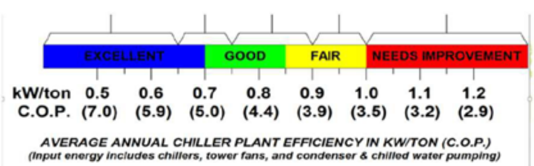
ABSTRACT

Review of system design concepts by considering latent heat load and sensible heat load independently, then practical system measures for functional building systems. A case study from one of the world's most challenging cooling requirements, Singapore, where the latent load requirement is significant all year. An operating and active site in the Singapore market is delivering performance of 0.53 kW/TR average plant efficiency (cooling tower, condenser pumps, chiller, and chilled water pumps) while maintaining target temperature and relative humidity levels within the conditioned space.

INTRODUCTION

Building air-conditioning designer are being challenged with ever increasing demand of energy efficient building thru MEP (Minimum Energy

Figure 1 : Plant Room Efficiency



Performance) and Green Building initiatives. A conventionally designed plant room efficiency is considered good, between 0.7 to to 0.85 KW/TR (refer Figure 1) and excellent efficiency level close to 0.60 KW/TR for hot and dry climate and 0.65KW/TR for a tropical hot and humid climate. Focus of the designers is to use more and more efficient chillers, pumps and cooling towers. The ever increasing energy cost, demand to reduce carbon foot print for sustainability and stringent building energy standards calls for looking at the design in an unconventional way to surpass existing system efficiency levels. Plant room efficiency target of 0.55KW/TR for a building in tropical climate having no respite from high wet bulb temperature seems unachievable with efficient equipment selection alone. This efficiency target can be achieved by addressing building load and system design in unconventional way. Chilled water plant energy gets decided on work done by compressor & pump and if we can reduce this work done, energy consumption will reduce. To reduce work done by plant room equipment we have to look at the building load in two components, sensible and latent load. Latent load drives leaving chilled water temperature set point and thereby work done by compressor. High latent load is inherent to tropical climate like Singapore city. Addressing latent load with lower chilled water temperature and using higher chilled water temperature to address sensible load can help reduce power consumption. Other design aspects which can help achieve target efficiency of 0.55KW/TR are higher delta T in chilled water system to reduce pump energy, arranging chillers in series counter system to reduce compressor head and selecting a cooling tower with lowest possible approach. Increasing the chilled water temperature and reducing flow raises concern of achieving desired ADP in AHU cooling coil, if not it may lead to higher RH in conditioned space thereby space humidity going outside the comfort zone. Further initial cost impact on airside equipment need to factor in.

CHALLENGE STATEMENT:

Designing a cooling system to meet Green Mark platinum energy efficiency requirement of 0.55KW/TR plant room energy consumption. A 15% lower energy consumption over other green buildings and 30% lower than a good plant room efficiency for tropical climate of Singapore.

DESIGN MODELS:

1. **Conventional Design Baseline**: Conventional energy efficient system design by designers, focusing on efficient HVAC equipment like chillers , pumps , AHUs and proven system design of variable chilled water systems ,VAV based air distribution system.

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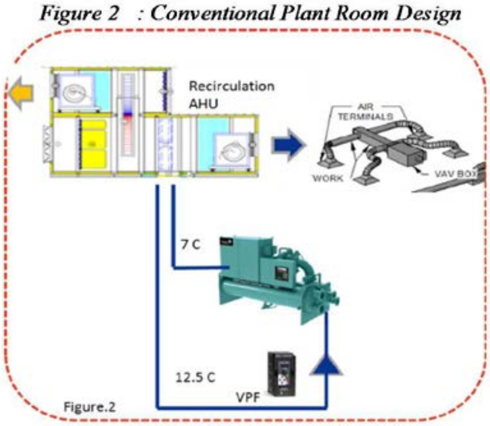
2. **Non-Conventional Design Alternate**: "Decouple" the chilled water system to address latent and sensible loads separately for energy savings and exploring different design aspects in chiller configuration as well as pumping system.

In a conventional cooling system design the building

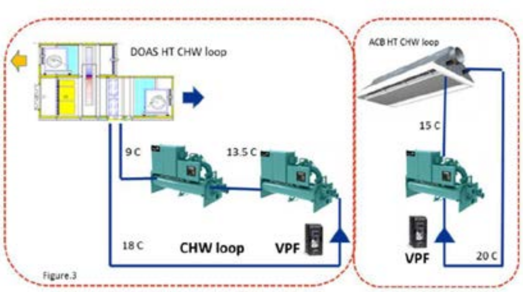
Figure 2 : Conventional Plant Room Design



load is addressed by common chilled water system for sensible and latent load, with design CHW supply temperature of 7°C supply temperature and 5.5°C delta T across cooler. Cooling tower designed of 4°C wet bulb approach (Refer Figure 2). To achieve energy savings design focus is on having highly efficient chillers with variable speed drives, a primary variable CHW system and a variable air volume system. The most energy efficient systems available with this system design can help achieve plant room efficiency level of 0.65 to 0.70KW/TR.

A decoupled system (Refer Figure 3) in same job with leaving CHW temperature of 9°C, delta T of 9° C, a cooling tower WBT approach of 2°C, high efficiency chiller in series counter arrangement

Figure 3 : Decoupled latent and sensible load



water loop addresses latent load with a DOAS (dedicated outdoor air system) and 15°C leaving CHW temperature having delta T of 5°C in VPF loop with chilled beams addresses sensible load. Typical source of sensible and latent loads ina building are as depicted in Figure 4.

Figure 4 : Source of Latent and Sensible Load

Cooling Load Component	Latent	Sensible
Conduction Thru walls, roof etc		→
Solar radiation		→
Lights		→
People	→	→
Equipments(some..most sensible)	→	→
Infiltration	→	→
Ventilation	→	→
System heat gain		→

BUILDING DESIGN REQUIREMENT:

Selected Singapore site is mixed use commercial property with retail and office having gross area of 108,169 sqm and air-conditioned

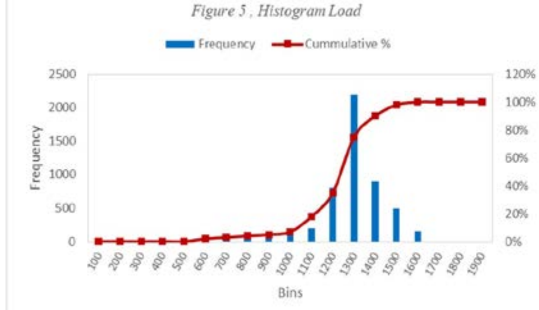


Figure 5 . Histogram Load

area of 94,786 sqm. With normal operating hours of 0900-2200 for retail and 0700-1800 for office space. The total design building load was estimated to be approx. 5500TR. The load variation with hours bin and cumulative % load line was as per the Histogram in Figure 5.

Load profile reflects variation in building load from 10% to 100% due to different operating hours of mixed use application. This load was divided into latent and sensible load and these decoupled loads were catered by two separate chilled water loops operating at different leaving chilled water temperature of 9°C and 15°C respectively.

To meet the building load profile chiller configuration

Figure 6 : Chiller Configuration and Operating Conditions

ID	Description	T ype	Motor KW	Cooling Capacity (RT)	Chilled Water LWT (°C)	Chilled Water Delta T (°C)	Rated Efficiency KW/RT	Year Installed
LTCH 1/2	Series Counter	Centrifugal	886	2000	9	9	0.443	2013
LTCH 3/4	Series Counter	Centrifugal	886	2000	9	9	0.443	2013
HTCH 1	Parallel Flow	Centrifugal	365	1000	15	5	0.365	2013
HTCH 2	Parallel Flow	Centrifugal	180	500	15	5	0.36	2013

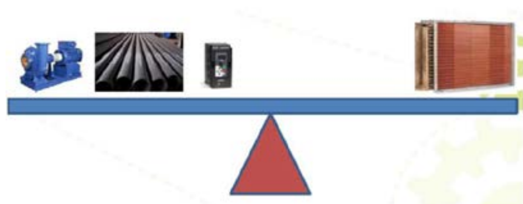
given in *Figure 6* was selected. Leaving CHW temperature of 9°C with delta T of 9°C chillers in series counter arrangement were selected to meet latent load requirement of the building, whereas 15°C leaving CHW temperature with delta T of 5°C parallel flow chillers were selected to meet sensible load requirement. Both the system were designed with variable primary flow to match the building load. High leaving CHW temperatures of 9°C and 15°C for latent and sensible loads respectively helped reduce the working head/lift of compressor which is reflected in rated efficiency of 0.443KW/TR and 0.365 KW/TR in *Figure 6*.

The segregation of sensible and latent load was done by addressing the latent load at DOAS unit with heat recovery wheel.(Figure 3). Removing latent load helped achieve desired dew point temperature requirement in space for a chilled beam applied to meet the space sensible load requirement. There are multiple ways to address the space sensible load i.e. using a chilled beam system or a VAV system. VAV system is not sensitive to the space dew point temperature but in chilled beam application it's critical to address the space dew point temperature to avoid water condensation on the beams. Building construction should avoid uncontrolled leakage of outside air into the conditioned space as it not only increases the energy consumption but also poses a threat of condensation.

CHW temperature of 9°C to DOAS unit makes it imperative to look at the coil selection which meets condensate removal requirement from fresh air. The way to ensure that desired ADP of the coil is achieved even with higher CHW temp and delta T , is to design the coils with low face velocity i.e. 1.5m/s instead of standard 2.5m/s and increasing the number of rows in the coil. This increases the size of the coil and thereby the cost. The cost aspect need to be looked at holistically instead of just coil/AHU and a right balance need to be arrived to make it commercially viable.

Though there is an increase in cost of coils there is saving in CHW pumps, piping, valves and plant room electrical. These savings helps overcome coil cost increase to a great extent *(Refer Figure 7)* and merit of energy savings by over 15% more than overcomes the small delta in cost with a payback of less than year. Further there were incentives by government on

Figure 7 : Cost trade off in airside and pumping



on meeting the energy eff levels of a green building which makes it an irresistible design alternative.

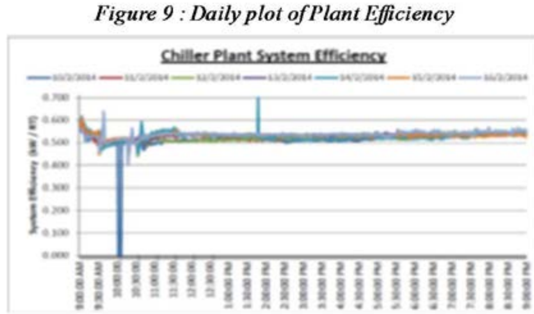
In selected Singapore project decouple system design philosophy and technology helped achieve and

Figure 8 : Summary of Plant Performance

Equipment	IKW/TR
Chiller(s) Efficiency	0.424
CHW Pump(s) Efficiency	0.032
CND Pump(s) Efficiency	0.049
Cooling Tower Efficiency	0.022
Overall Chiller Plant Efficiency	**0.527**

overcome 0.55 KW/TR energy target as per Green-Mark Platinum v 4.0. The actual measured efficiencies are as given in *Figure 8* and screenshot of Building Management System in *Figure 9.*

Figure 9 : Daily plot of Plant Efficiency



CONCLUSION:

With decoupled system, DOAS with heat recovery, high CHW temperature, high delta T, variable primary flow, series counter arrangement and cooling tower

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with 2°C WBT approach, cumulative plant room power consumption actually measured at site against design target of 0.55KW/TR was 0.527KW/TR for a climate which is hot and humid.

This design philosophy is more suitable for new building design considering the piping system and layout of decouple system. However with due consideration to the above it's feasible to retrofit this system design in an existing building and reap the benefits of major energy saving.

With a decoupled system – addressing latent and sensible load separately and looking at ways to reduce compressor lift helps overcome the energy barrier and set new benchmark in the industry.

NOMENCLATURE

CHW = Chilled Water Temperature CND
= Condenser Water
LTCH = Low Temperature Chiller
HTCH = High Temperature Chiller
CT = Cooling Tower
DOAS = Dedicated Outdoor Air System
VAV = Variable air volume
RT = Refrigerantion Ton
COP = Coefficient of performance

DATA ANALYTICS UNLOCKS SUBSTANTIAL ENERGY SAVINGS FOR WASTE ENERGY RECOVERY BASED CAPTIVE POWER PLANTS

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Keywords: Energy Analytics, Dynamic Benchmarking, Opportunity Costs

ABSTRACT

Several process industries are operating Waste Energy recovery based Captive Power Plants (CPPs) as a cost saving/additional revenue initiative. Though CPPs are promoted as an energy saving measure, the operational efficiency of the CPP itself is always in question as the performance is dependent on dynamic process conditions. As a result, several process based industries such as chemicals, pulp & paper, sugar, iron & steel and carbon black cannot accurately assess whether the CPP is operating at its optimum. Energy losses due to operational inefficiency continue to be high for such waste energy based CPPs.

The project involved developing an Advanced Analytics software solution for a leading Carbon Black manufacturing unit. Efficiency of CPP for different process conditions (product grades, waste gas availability, calorific value, etc.) were analyzed. Optimized benchmarks were developed by applying advanced statistical tools to 5-year old historic data. The unique Energy Analytics Dashboard provided precise clarity on the CPP performance, irrespective of varying process conditions. The visualisation enabled easy root-cause analysis for the plant staff to take quick corrective actions. The dashboard helped achieve around 8% additional revenue (through sale of power) by operating CPP closer to the optimum efficiency levels. Project payback was less than 6 months. An appropriate mix of analytics, IT programming and energy expertise helped convert complex industrial datasets into meaningful and quick actionable decisions. The above solution can be offered across process industry sectors.

INTRODUCTION

In the recent years, Captive Power Plants for medium/large Indian industries have become ubiquitous to ensure reliable power supply, extract waste energy where available, generate additional revenue by sale of power to grid and minimise expensive grid purchase. As per Central Electricity Authority (CEA, 2016), the total installed capacity of grid interactive CPPs - 1MW and above, in India was 47200 MW as on March 2016. However, unlike Independent Power Producers (IPPs) where factors influencing generation is relatively more stable and predictable, steam based CPPs (including Cogeneration Plants) using waste energy (heat, gas, biomass, pressure), face numerous challenges due to random variations on supply side (fuel availability, characteristics), demand side (grid conditions, steam demand) and operational problems (irregular soot deposition, boiler tube failures, poor turbine vacuum).

As a result, even though the industries set-up waste energy based CPPs with capital upwards of INR 35 Million/ MW and exhibit them as an exceptional energy efficiency and green initiative, the operational and financial effectiveness of CPPs always remains a question.

A major hurdle for achieving consistent high performance is the vast amount of disaggregated data handled in waste energy based CPP operations. The various existing Control Systems/ Enterprise Resource Planning (ERP) applications and legacy IT systems focus only on smoother operations but are not designed to compute on real-time basis, efficiency at a plant, system or equipment level. Consequently, most plants continue to use simplified metrics such as heat rate (kCal/kWh) or specific power generation (kWh/ Nm^3 waste gas) averaged over a shift or day basis, which neither gives an accurate picture, nor captures the dynamic nature of operations. Meanwhile, the plant personnel continue to give obscure technical reasons for underperformance and hence efficiencies remain poor. A need therefore arises for developing Dynamic Benchmarking model with appropriate real-time dashboard software that is customized for each plant's configuration and dynamic conditions. Such Data Analytics tool will give quick and precise visibility of efficiency performance against optimum levels, which will help take immediate corrective actions for achieving high efficiency.

The paper discusses the case of implementation Data Analytics for improving Energy Efficiency of a Waste Gas based CPP in Carbon Black Industry in the year 2015-16 and benefits derived thereof.

BACKGROUND

The company is a leading global Carbon Black multi-national player with a manufacturing facility in Northern part of India. Carbon Black is an engineered carbon that is primarily used as reinforcing filler in rubber compounding. The input for manufacturing carbon black through the oil furnace route is coal tar and fuel oil (both called as feedstock). The end product - carbon black powder is largely consumed for making vehicle tires, V-belts, foot-wear, printing inks, paints, etc.

The capacity of the plant was 85000 Metric Tonnes (MT)/ annum (2015). While around 58% feedstock is converted to end product, the remaining mass comes out in the form of tail-gas. Depending on the product grade and process conditions, waste tail-gas generated is in the range of 3500 - 6500 Nm^3/ MT product, with Net Calorific Value (NCV) varying in the range of 650 to 815 kCal/Nm^3.

A 15 MW Rankine Cycle based Power Plant was installed in 2008 to extract waste gas energy. Around 4 MW load is used for in-house power consumption and the remaining was sold to grid. In most process industries, selling waste such energy power has high operating profit margin, i.e. Earnings Before, Interest, Tax, Depreciation and Amortisation or EBITDA (see Table 1)

Table 1: Profitability of Waste Energy Power in Carbon Black Industry

SEGMENT	OPERATING PROFIT MARGIN, EBITDA
Carbon Black (Main Product)	9% to 12%
Waste Energy Power	50% to 75%

Source: CRISIL Analyst Report, 2012

The carbon black manufacturing unit was experiencing a modest growth in sales. However, increased market competition necessitated reining in of costs to protect profit margins. Energy sources, comprising mainly fuel oil, accounted for a significant 15 percent of total costs. The management strongly believed that its eight-year old power plant could generate and sell more power thus reducing overall plant energy costs. However, varying production grades to meet customer demand (see Table 2) and other process conditions, obscure technical reasons of line staff and disaggregated data meant that the underperformance of the old CPP continued over time.

SPECIFIC CHALLENGES

The challenges faced by the plant management in obtaining real-time visibility of Power Plant efficiency can be categorised as follows:

Dynamic Nature of Main Production Plant:

The plant produced 17 grades of Carbon Black to meet the market demand. Each grade has a different NCV (see Table 2 below), which affected the power plant performance. As in many such industries, the NCV of fuel is not a part of DCS system and is obtained separately from the plant Chemistry laboratory.

Table 2: Tail Gas CV variation with Product Grade

GRADE OF CARBON BLACK	TAIL GAS NCV (kCal/Nm^3)
N-110	650
N-134	651
N-220	652
N-234	670
N-326	700
N-330	696
N-339	705
N-347	710
N-351	715
N-375	718
P-330	720
N-550	790
N-650	792
N-660	800
N-762	805
N-765	810
N-774	815

Source: Company Database (2015)

The variation of capacity utilisation of the main plant also affected waste gas volume (Nm^3/ hour), hence the loading of the CPP boiler. The capacity utilisation varied from 40% to 100% in different shifts.

Legacy IT Systems:

At the 15 MW Power Plant, the standard Distributed Control System (DCS) aided only in automation/control for smoother operations, whereas the ERP and other IT system addressed purchase and inventory issues. The Power Plant DCS had 81 tags (pressure, temperature, flow, etc.), where instantaneous data was captured. There was no intelligent system to indicate the real-time energy efficiency using standard equations and compare with ideal performance for any given variable conditions. Tons of data was being collected, but only superficially being monitored on a daily/monthly basis, and with no precise accountability. The plant personnel were busy engaged in 24/7 running of the unit and efficiency evaluation was regarded as technically complex and laborious, and hence sidelined (see Figure 1).

System Challenges:

- Existing IT applications were not modified to suit latest MIS needs on energy efficiency analysis.
- Conventional spreadsheet (Excel) based analysis had limitations such as being non-interactive and considerable time and effort was required each time to generate prompt reports for different functional heads

Other Challenges:

The management also realized that Detailed Instrumented Energy Audit is a one-time effort, as process conditions keep changing for different carbon black grades. The Energy Audits are not dynamic enough to identify losses on a running plant basis

As each manufacturing plant is slightly unique in configuration and the raw material types used, benchmarking against external competitors was also found as an incorrect yardstick. The business challenges were as follows:

- Plant efficiency optimization
- Maximizing asset performance
- Real-time financial implication of energy losses
- Energy flow tracking
- Identifying underperforming areas for quick action
- Better maintenance and spares planning

PROJECT IMPLEMENTED

The Data Analytics solution provides data-driven intelligent analysis and visualization of energy use productivity through a Dashboard on a real-time basis. The method adopts Dynamic Benchmarking approach using historical data (Warren et al, 1999). This is because retrofits/modifications undertaken in the Power Plant over the eight-year period may help exceed the design/performance guarantee parameters. The following steps were involved in the implementation of the project.

Data Preparation:

The historic shift-wise data of past five years was taken from DCS. The plant personnel had stored monthly extracts of shift-wise data for years and this helped as a starting point for analysis. In case of plants, where historic data is unavailable, DCS data storage can be kick-started to extract data for at least two to three months. The DCS sheet had total of 81 parameter tags (pressure, temperature, flow, power generation, etc.) of the entire power plant operations.

Out of these 81 tags, only 17 parameters were relevant for assessing energy efficiency by direct method. The key parameter outside of DCS was NCV of waste gas being fired. This was obtained by correlating with the grades of Carbon Black produced during those shifts. Tariff rate of power sold to grid was included for the period. Other two parameters as required by the plant management to compute customised key performance indicators (KPIs) were also added. The total shift-wise data sets collected were 5482 from the five year data.

The simple energy efficiency for the Power Plant was computed using the direct method (Bureau of Energy Efficiency, 2005) for all the data sets. On computation, data sets with errors (primarily instrumentation errors) were eliminated leaving behind 4831 data sets.

Data Modelling:

A key variable, or constraint, affecting power plant efficiency was identified was waste gas (fuel) availability. This had a high correlation with overall power plant efficiency. The gas availability in percentage terms was broken from 30% to 100% in intervals of 5% (14 windows). For each of the fuel availability window, the efficiency value was correspondingly recorded. Post discussion with plant management, it was decided that the benchmark (optimised level) to be considered was the 95th percentile value under each respective window. This is because highest performance values (eg. average of 10 best values, etc.) may be prone to instrument errors, and may not always be achievable. Hence, the optimum efficiency band when gas availability is, say between the 95% to 100% window, was 26.22%, which was the 35th highest value in descending order, and not the absolute best.

$$\eta_{optimum\ (95\text{-}100)} = 95^{th}\ \text{Percentile}\ (N_1, N_2 \ldots Nn) \quad (1)$$

Where:

$N_1, N_2, \ldots N_n$ are the efficiencies of power plant in the respective gas availability window (eg. 95% to 100%)

A total of 14 optimum efficiency bands was computed. As the optimum benchmarks are arrived from the historic data of the same plant itself and is dynamic, the management convinced the Power Plant Department staff to consider this approach going forward for analysing efficiency performance.

It was surprisingly found from the analysis that the power plant efficiency was relatively high and steady between waste gas availability of 60% to 100% (see Table 3). Whereas the poor power plant efficiency was always blamed by plant personnel on waste gas fluctuations from the main process plant, this dynamic benchmark approach brought great clarity to plant heads on the performance pattern. It is to be noted that this information was not available earlier to the management as they only relied on a single fixed metric (Nm^3/kWh) to assess performance across all grades and capacity utilisation range.

Table 3: Dynamic Benchmark results for Gas Availability

Waste Gas Availability bands	Reference Optimum		
	Power Plant Efficiency	Boiler Efficiency	Turbine Efficiency
> 95 and≤ 100	26.62%	81.9%	26.20%
> 90 and ≤ 95	27.31%	83.9%	25.69%
> 85 and ≤ 90	27.52%	84.5%	26.44%
> 80 and ≤ 85	27.15%	84.2%	25.26%
>75 and ≤ 80	27.00%	84.3%	24.81%
>70 and ≤ 75	26.74%	84.4%	24.77%
> 65 and ≤70	26.73%	84.6%	24.42%
> 60 and ≤65	26.29%	83.9%	23.87%
> 55 and ≤60	23.25%	81.1%	23.04%
> 50 and ≤55	18.74%	80.1%	21.54%
> 45 and ≤50	18.17%	77.6%	21.65%
>40 and ≤45	16.11%	72.9%	20.83%
> 35 and ≤40	16.40%	68.9%	19.45%
> 30 and ≤35	14.70%	63.2%	19.00%

Source: Computed by author

Performance Analysis, KPIs and Financial Metrics:

Once the power plant efficiency mapping is completed, the actual performance at any point of time is then understood by simply comparing with the relevant Optimised Efficiency Band. The energy losses, or the Shortfall KPI, is calculated as the difference between the actual and optimised levels.

$$\text{Shortfall} = \eta_{optimum} - \eta_{actual} \qquad (2)$$

A distinct feature of Data Analytics is to provide easily understandable financial metrics or Business Analytics, as against the commonly used complex technical metrics (heat rate, Nm^3/kWh) which are not comprehended by many functions (finance, costing, purchase, etc.) across the company. The financial metric for inefficiency enables users to easily visualize losses across units and lines, seek control and target high performance consistently. The losses in the Power Plant here were converted to the Opportunity Cost financial metric (KPI) by translating the shortfall into equivalent monetary revenue foregone i.e. the selling of power to grid (tariff rate INR 4.10/kWh in 2015).

Similar drill-down analytics was done for individual major equipments of Boiler Efficiency and Turbine Efficiency to identify which major equipment may be affecting the overall power plant performance at any given point of time. Two KPIs of Boiler efficiency and Steam Turbine Efficiency were thus included.

DASHBOARD DEVELOPMENT

Web-based software applications help numerous plant personnel - right from DCS operator to plant head to top management (Managing Director, Finance Head, Maintenance Head, etc.) to simultaneously check the power plant performance on their desktop/laptop and undertake individual analysis suiting their roles. Upto 200 users can access the tool at the same time for performance analysis, without any problems.

Thus, a web-based Software Dashboard was developed using the Microsoft .NET application. The user interface (UI), trend analysis charts/ graphs (infographics) and web-administration configuration were finalised along with plant management. All the energy efficiency and costing algorithms were coded into a program and rigorous software testing was done to check for any defects and rectified.

A data upload window was provided, where Power Plant Control Room operators can upload 21 relevant parameters into the Dashboard application, immediately after the completion of a shift.

The preliminary Dashboard screens was shown to plant personnel and relevant changes requested were incorporated. The final Dashboard Software Application with the five-year database was eventually installed in the plant local server for use by the plant personnel.

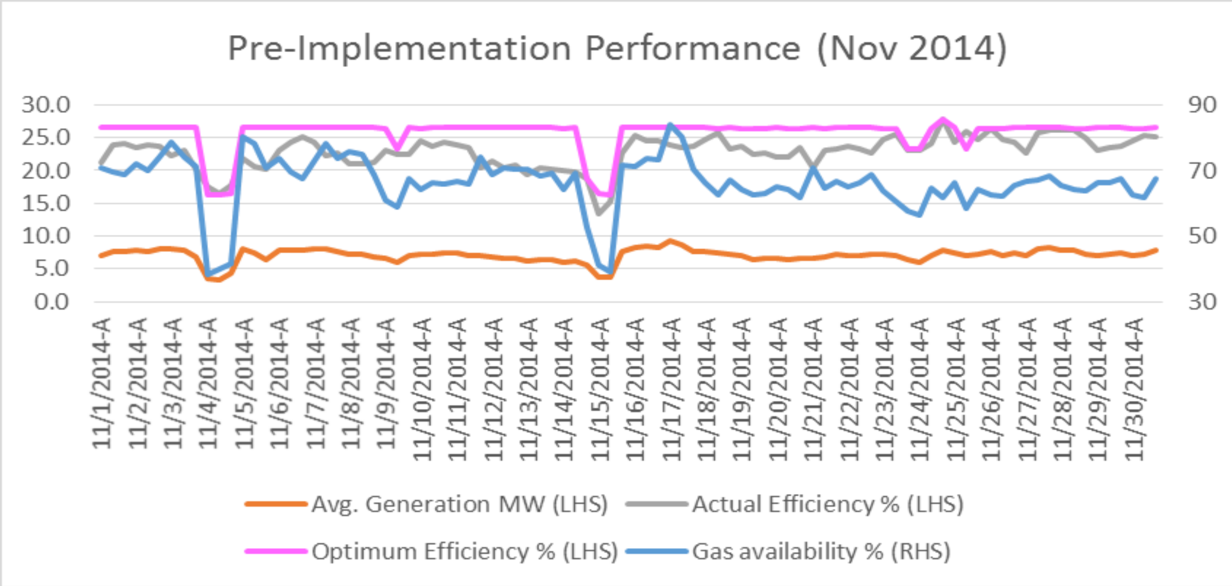

Figure 1 Pre-Implementation Performance (Opportunity Cost for Nov 2014 month Rs. 25.3 Lakhs/month)

RESULTS

Post implementation of the Energy Analytics intelligence tool, shift-wise data is uploaded instantly after every shift is completed. The plant personnel are able to quickly gauge the precise efficiency performance from the visual tools (infographics) by comparing with the optimum efficiency bands.

Armed with this interactive analytics tool, the management was able to continuously supervise operations closely, find where the problems could lie by doing root cause analysis, greatly improvise maintenance practices and even easily decide for retrofits/upgrades.

Major savings identified through this initiative were poor turbine condenser vacuum and cooling tower performance, fluctuating excess air levels in boiler, intermittent gas (fuel) flaring and lower economizer performance. Special attention was paid to these areas subsequently.

These measures helped in arresting the deteriorating plant performance - all with minimum/ no capex investment (see Figure 2).

The company was able to achieve 8% cost savings by improving efficiency performance and selling the additional power to grid. The payback for the project was less than 6 months. Carbon emissions reductions

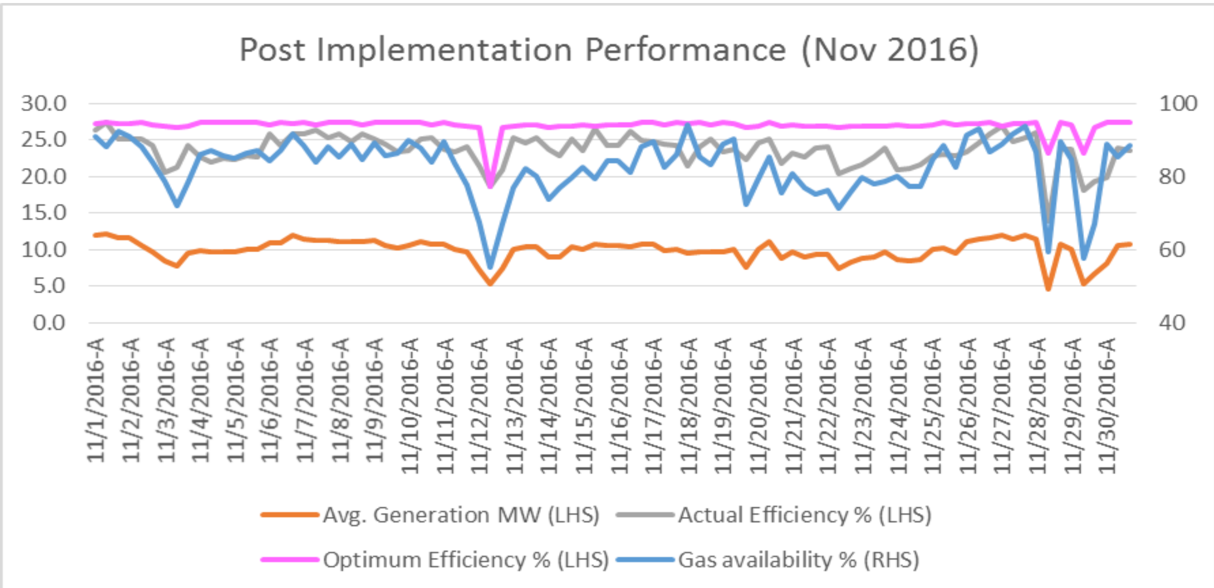

Figure 2: Post Implementation Performance (Opportunity Cost for the Nov 2016 month Rs. 16.5 Lakhs/Month)

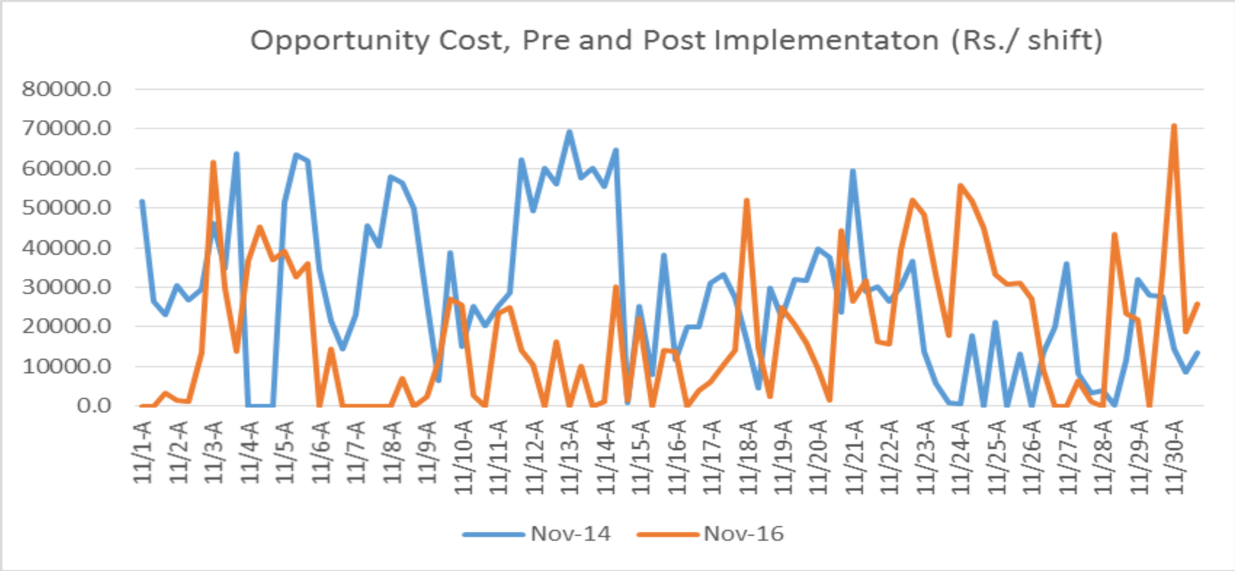

Figure 3: Shift-wise Opportunity Cost trend, Pre and Post Implementation

of around 3000 tons of CO_2 equivalent/year were achieved with the help of the initiative.

CONCLUSION

Data Analytics can help process industries with waste energy based CPPs to gain quick visibility and insights of the energy efficiency of the plant. With data connectivity using the Industrial Internet of Things (IIOT) technologies, trends can be made available even for every 15 or 30 minutes for quick insights and corrective actions. The following are the benefits that can be derived from Data analytics for CPPs:

- Around 5-15% savings in energy costs by adopting real-time Energy Analytics IT Solutions.
- Most efficiency improvement measures can be undertaken with minimum/ no capital investment. Hence, high ROI with typical payback < 1 year.
- Losses are translated to simple financial metrics (i.e. opportunity costs) – enables prompt awareness of top management and line functions (costing, maintenance, purchase etc.). Better accountability of energy use across the organization.
- Precise clarity on performance, irrespective of varying process conditions. Enables easy root-cause analysis of deviations. The tool is similar to getting an Energy Audit result every shift
- A major reason for underperformance is poor maintenance practices. The Dashboards help in improving plant maintenance and have better spares inventory management, as the opportunity cost of poor maintenance is immediately reflected in the financial metrics.
- Further, it enables use of Six Sigma and other Lean tools such as Pareto Analysis for narrowing the energy efficiency performance gap.
- Staff can be held more accountable for operational performance resulting in better equipment maintenance, instrumentation and spares inventory management.
- Single Dashboard platform across production lines and geographies.

The above solution can be offered across energy-intensive sectors with CPPs such as chemicals, sugar, pulp & paper, iron & steel, cement, etc. As each manufacturing plant's configuration is unique with its own distinctive mass and energy flows, customized Energy Analytics Dashboard solutions can help these industries gain quick insights conveniently, take corrective actions without delay and thus aim for consistent high performance.

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ENGAGING CUSTOMERS TO ADOPT DISTRIBUTED ENERGY RESOURCES

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Keywords: Behavioural EE, DER adoption, data analytics

ABSTRACT

Building a resilient grid of the future, managing aging infrastructure and integrating increasing penetration of distributed energy resources (DER) and other new technologies, are all driving the need for reconsideration of the utility business model and the ways in which energy is generated, transmitted, and distributed. New York State in the United States is leading the way in addressing these challenges through its Reforming the Energy Vision (REV) initiative. Through demonstration projects, REV will show how utilities can promote energy efficiency (EE) and speed the adoption of renewable energy, demand response, and new technologies, all while exploring new sources of revenue and empowering consumers with more choice and control. This paper describes the design, metrics, and initial results for one such project aimed at helping drive adoption of DERs, including energy efficiency, through sophisticated analytics and a multi-channel customer engagement platform. This Consolidated Edison (Con Edison) and Oracle partnership demonstrates show how utilities can match ~275,000 customers in the Brooklyn and Westchester areas of New York with products and services that meet their needs. These products and services include rooftop solar installations, home energy audits and retrofits, smart thermostats, and energy efficient lighting and appliances sold in a digital Marketplace. Using Oracle's technology platform, Con Edison will deliver personalized outbound communications, including paper and email home energy reports, as well as high usage alert notifications that feature energy insights and tailored recommendations for products and services. Con Edison will generate revenue through advertising, retail sales, and lead and conversion fees.

INTRODUCTION

In April 2014, the New York Public Service Commission (PSC) initiated the Reforming the Energy Vision (REV) proceeding as part of a broader state-wide initiative aimed at achieving deeper penetration of renewable and distributed energy sources, such as energy efficiency, demand response, rooftop solar, micro-grids, energy storage, combined heat and power.

An important part of realizing the PSC's new energy vision for the New York electricity sector is to test and learn through a series of demonstration projects (NY PSC M-14-0101 December 12, 2014). The intent of the early REV projects is to advance the development of new utility and third party service or business models and to gain experience with adoption and integration of distributed energy resources, including energy efficiency.

Con Edison and Oracle teamed up to deliver the Connected Homes Platform demonstration project (demonstration project) from June 2016 and running through July 2018.

EXPERIMENT

The Connected Homes Platform demonstration project is aimed at addressing two barriers to the REV goal of increasing customer adoption of DERs. The first barrier is a lack of understanding by residential customers of which DER products and services will help them effectively manage their energy usage, energy costs, and comfort in their homes. The second barrier is the high customer acquisition cost for many DER providers. The demonstration project does not address other market barriers.

To address the first barrier, the demonstration project is evaluating the effectiveness of various personalized paper and digital communications aimed at driving behavioral energy efficiency, and that include offers of DER products including rooftop solar and home energy services including energy audits and retrofits. What makes these offers unique as compared to traditional DER marketing offers is 1) they are being communicated within a personalized communication that is branded Con Edison – the trusted local utility, and 2) they are contextually relevant by being embedded within a broader set of analytics-driven information that is educating customers on their own household energy consumption and using personalized insights to drive behavior change.

Independent evaluations have consistently demonstrated the ability of Oracle Home Energy Reports (HER) programs to both consistently drive behavior-based energy savings and boost participation lift in energy efficiency and other utility programs on average by 11 percent. Program lift analysis and results are documented in multiple independent evaluations, covering 44 participant waves at 12 utilities, several of which are included in the References section at the end of this paper (Gunn 2012; KEMA 2013, NMR 2013, Opinion Dynamics 2013, Cadmus 2014, Navigant 2014, DNV GL 2014). The participation lift effect can be further increased through the targeted promotion of portfolio programs through the HER, with expected median participation lift increases of 30 percent based on past program performance.

To address the second barrier, the demonstration project will evaluate third party DER providers' willingness to pay Con Edison for qualified new customer leads and conversions, and whether this can generate a sustainable revenue stream for Con Edison by allowing it to monetize utility and customer data without exposing it to third parties due to privacy reasons. Revenues earned by Con Edison will be applied toward revenue requirement, therefore having a direct benefit to customers by helping to reduce overall rate impacts. Payments for lead generation and conversions are defined in bilateral agreements between Con Edison and the third party DER providers participating in the demonstration and offering rooftop solar and home services including audits and efficiency retrofit services.

The demonstration project will test four main hypotheses:

1. A Con Edison sponsored platform that matches specific DER solutions to eligible customers will drive greater DER adoption
2. Presenting third-party DER offers in the context of energy usage insights can drive greater DER adoption
3. Con Edison will be able to generate revenue from third-party DER providers through a combination of strategies including lead generation.
4. The Connected Homes Platform will provide customers with a positive customer experience and improve customers' access to their energy data.[1]

Communications Channels for Connected Homes Demonstration Project

The demonstration project will deploy a comprehensive customer engagement effort through outbound communications and a web-based channel. The channels provide an opportunity to reach customers during different times when they are thinking about their energy.

Outbound communications are important because they can reach customers at a large scale, particularly those who might not otherwise proactively seek information. The goal of each of these communication channels is to educate and engage customers on their energy consumption patterns and include contextually relevant recommendations to address that household's energy situation.

Direct-mailed HERs will deliver easy-to-understand, personalized, and actionable energy data, insights, and recommendations designed to capture the attention of customers and drive behavior-based energy savings. Direct-mailed HER include normative comparison of customer' energy use to that of similar homes, putting energy consumption in context; usage analysis that provides customer-specific insights based on usage, size of home, demographic information; and promotions that can drive customer interest in featured energy products and services. Oracle HERs are core to nearly 100 utility efficiency portfolios and have been independently evaluated over 100 times. In addition, Oracle's Customer Engagement Tracker, an ongoing survey conducted with over 100,000 utility customers at dozens of utilities has consistently shown that more than 8 in 10 HER recipients read and recall the reports (Puget Sound Energy DNV KEMA 2012, AEP Ohio Navigant 2012, Wickman and Van Atta September 2014).

Email eHER contain energy insights and analysis similar to direct-mailed HER, provide a cost-effective channel to remind customers about their usage behavior, and include direct links to promotions on utility and vendor partner landing pages.

[1] All Con Edison customers have access to their energy data via Green Button but only participants in the demonstration project will have access to the full Connected Homes platform.

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High Usage Alerts are intra-billing cycle notifications for customers who are trending toward a higher than normal bill. These communications raise awareness among customers of their energy usage and provide contextual actions to help them better manage their usage and eventual bill amount. The High Usage Alerts provide an opportunity to market relevant programs and services in a highly segmented fashion, taking advantage of when customers are particularly motivated to explore options for lowering their bills.

The online Marketplace is a website with a selection of over 2,900 energy-related products paired with customer educational tools such as energy ratings and customer reviews, and linking customers directly to retailers where they can purchase the products. The Marketplace also includes an online Storefront which provides customers with a way to purchase low cost and easy to fulfil products directly from Con Edison, including smart thermostats and LED bulbs for which instant rebates will be available. Where Con Edison offers rebates on other efficient products as part of its broader portfolio of energy efficiency programs, those will be indicated with each product marketed on the Marketplace. In addition to being promoted in the HERs, eHERs and HUAs, the Marketplace will also be promoted through a separate marketing campaign aimed at reaching all Con Edison customers.

Program Design

The initial phase of the demonstration project targets a limited set of DERs to customers through six different tracks as described in Table 1. Oracle's platform improves personalization based on customer interactions over time such as logging into the Con Edison website to view customer energy data, completing an online home energy audit, clicking on links in digital communications, making purchases of efficient products through the Marketplace, or participating in other utility offered programs. Therefore, the customer experience and offers will become more dynamic as the demonstration project progresses and as more DER providers gain interest in participating in the Connected Home demonstration to target customers.

Table 1. Program Design for Targeted Offerings

TRACKS	TARGETED OFFERINGS	CHARACTERISTICS	TARGETED HOMES[2]	NOTES
1 and 2	Rooftop Solar & Home Services	Single Family Owner Occupied High users	Track 1: 53,400 Track 2: 43,400	Households which have registered their emails with Con Edison receive a mixed paper and digital experience (Track 1), while homes that have not receive a paper-only experience (Track 2)
3 and 4	Smart T-Stat & Home Services	Single Family Owner Occupied Moderate Users	Track 3: 18,100 Track 4: 20,700	Households who have registered their emails with Con Edison receive a mixed paper and digital experience (Track 3), while homes that have not receive a paper-only experience (Track 4)
5 and 6	Smart T-stat	Multifamily (2-4 Unit) Owner Occupied Moderate Usage	Track 5: 30,200 Track 6: 33,300	Households which have registered their emails with Con Edison receive a mixed paper and digital experience (Track 5) while homes that have not received a paper-only experience (Track 6)

[2] Total number of homes targeted during the duration of the pilot from 2016-2018.

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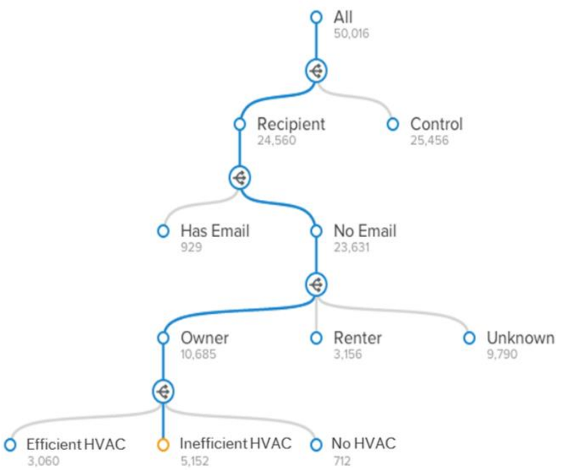
Segmentation

Targeting the right offers to the right customers will rely heavily on smart segmentation. The Oracle platform combines a wide variety of attributes from Con Edison and publicly available external data sources including energy, demographic, behavioral, and psychographic into segmentation profiles. The demonstration project will use customer segmentation to pair households to the right DER products and services, using criteria such as energy usage rankings, housing stock type, and home ownership data.

Using the results of segmentation, promotions for energy products and services can be carefully targeted and paired with timely advice to create an experience designed to motivate customers to take action and follow-up on featured promotions.

For example, a customer may receive a Home Energy Report in spring showing how their energy use compares to neighbors and providing tips for getting ready for the cooling season, including a targeted promotion for a smart thermostat. A few months later, after a summer month when the customer had higher than average usage, the customer may see a breakdown of how much cooling contributes to usage in their home and include a reminder about the same smart thermostat. Figure 1 illustrates an example of customer segmentation approach.

Figure 1. Sample customer segmentation tree



Metrics

Con Edison has identified specific metrics of success that will be measured across four categories: 1) market animation – measuring the effectiveness of targeted, personalized communications to drive adoption of DER products / services, 2) stakeholder sentiment – measuring the impact on key stakeholders and viability to apply the model outside of Con Edison, 3) new revenue – viability of the business model outside of a demonstration pilot, and 4) co-benefits – such as driving measureable behavior based energy savings. Randomized control trial (RCT) will be used to measure most of the demonstration project results (see Stewart and Todd 2015). The demonstration project began in June 2016 and final results will be reported in late 2018.

In addition to the above listed metrics, the demonstration project will provide key data and insights to help answer the following questions central to understanding customer roles and willingness to participate in the REV vision.

1. How effective can the Connected Homes Platform be as a tool for promoting the adoption of DERs in NY?
2. What messages and channels are most effective for engaging customers with information about energy products and services?
3. Which energy products and services are best suited for which groups of customers?
4. What is the revenue generation potential (to offset revenue requirement) for Con Edison from conversion and referral fees associated with targeted offers?

The project will provide insights and experience that can inform the design of future utility programs and revenue generating activities at Con Edison, and other utilities in New York and other jurisdictions.

Table 2. Metrics to be Measured from Connected Home Platform Demonstration Project

CATEGORY	GOAL	METRIC	DEFINITION	REPORTING CADENCE
Market Animation	Awareness and Engagement	Customers aware of DER partners	Response to customer survey questions about awareness of DER offerings in Con Edison's territory	Annually
		Total number of impressions	Total number of paper and digital communications sent to customers, cut by DER	Quarterly
		Open rates (eHERs)	Percent of customers who open eHERs with targeted offerings, cut by DER	Quarterly
		Open rates (HUAs)	Percent of customers who open HUAs with targeted offerings, cut by DER	Quarterly
		Click through rates (eHERs)	Percent of customers who click on the link/s included in eHERs with targeted offerings, cut by DER	Quarterly
		Click through rates (HUAs)	Percent of customers who click on the link/s included in HUAs with targeted offerings, cut by DER	Quarterly
		Unique web visits	Number of unique customers who visit the web portal	Quarterly
		Customers who recall HERs	Percent of homes that receive HERs who recall receiving HERs	Annually
	Leads and Acquisition	Qualified solar leads generated	Number of qualified leads from the targeted offerings	Quarterly
		Solar installations reported	Number of installations	Quarterly
		Thermostats sold	Number of thermostats sold through the targeted offerings	Quarterly
		Home Energy Audits completed	Number of home energy audits completed	Quarterly
		Home Energy Efficiency Retrofits	Number of completed energy efficiency projects following a home energy audit	Quarterly
		Recipients and controls	Number of leads and acquisitions among recipient customers and control customers	Quarterly
Stakeholders	Partners	DER partners retained	Percent of DER partners who choose to continue with the targeted offerings	Annually
	Customers	Positive customer experience	Percent of customers who respond positively to survey questions on their satisfaction with targeted offerings	Annually
Revenue Realization	Total Revenue	Total revenue to Con Edison	Revenue earned through the targeted offerings	Annually
Customer Co-Benefits	Energy / Demand / Benefits	Energy efficiency savings	Behavioral energy savings generated by customers as a result of participating in the program	Monthly
		Demand savings (MW)	Demand savings generated by customers as a result of participating in the program	Monthly

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		Indirect energy savings	Total kWh savings from product sales from the Marketplace/Storefront	Quarterly
Digital Marketplace		Reduction in greenhouse gas emissions	Greenhouse gas emissions reduction from product sales from Marketplace/Storefront	Quarterly
	Sales and Rebates on Marketplace/ Storefront	Number of sales on the Marketplace Storefront	Products sold (total and by product category) via the Marketplace Storefront by month	Quarterly
		Revenue per sale on Marketplace Storefront	Revenue earned by Con Edison by product category for sales in the Marketplace/ Storefront by month	Quarterly
		Revenue from reportable sales on third party retail sites	Revenue from products sold on third party retail sites within the retailer referral period to customers referred via Marketplace	Quarterly
	Engagement with Marketplace/ Storefront	Storefront sales by engagement strategy	Number of sales on the Marketplace Storefront by engagement channel (e.g. paid search, social, etc.) and by a set of messaging categories to be determined (e.g. type of promotion) by month	Quarterly
		Time spent on website by engagement channel	Time spent on website by engagement channel (e.g. paid search, social, etc.) by month	Quarterly

HER = Home Energy Report; eHER = Email Home Energy Report; HUA = High Usage Alert; DER = Distributed Energy Resource

Measurement and Evaluation

Using a randomized control trial model, Con Edison can look at all DER sales in the demonstration project territory of Brooklyn and Westchester County and determine which were driven by engagement in the platform and from receiving targeted, personalized communications. Con Edison will simultaneously run its portfolio of energy efficiency programs, and savings will be attributed to those programs and not this demonstration project. The energy savings benefit achieved and attributed to the demonstration project will be from the specific energy efficiency products and services unique to the demonstration project including behavioral savings from Home Energy Reports, home audit and retrofit services offered by Sealed, as well as the rebates for promoted products available on the Marketplace Storefront.

Initial 12-Month Results

Not all metrics outlined in Table 2 are measured regularly throughout the pilot. Below are some results and initial learnings about customer sentiment as of July 2017.

- Customers saved over 25,753 MWh of electricity through behavioral savings from the Home Energy Report with an average savings rate of 1.47 percent.
- Seventy eight percent of customers who log into the Home Energy Report website take an action (e.g. check off a tip or make a savings commitment).
- The open rate for eHERs (the digital version of Home Energy Reports) averaged 46 percent.
- The open rate for High Usage Alerts averaged 32 percent.
- The digital Marketplace had 501,463 visits and 12,658 products purchased directly from Con Edison, primarily LED light bulbs, wifi thermostats and powerstrips.
- SunPower rooftop PV has been promoted to 80,000 customers, this led to 350 qualified leads, 142 appointments and 4 sales
- Sealed home retrofit service: 399 qualified leads, 251 consultations held, 36 converted to sales

- Following the first customer engagement survey, 94 percent of treatment customers have read the communications, 39 percent discuss the reports within the household and 33 percent save the reports for reference.
- Compared to the control group, +6 percent of treatment customers stated that Con Edison wanted to help them save money and +10 percent of treatment customers stated that Con Edison helped them manage their monthly energy usage.
- Compared to the control group, +6 percent of treatment customers are more familiar with the DER partners by product and name.

In summary, the initial results from the Connected Homes REV Demonstration Project, measured using randomized control trial design, suggest that customers are engaging with the communications received from Con Edison, saving energy by better understanding their energy consumption and making behavioral changes, and increasingly willing to pursue distributed energy resource solutions, such as rooftop solar PV, when offers are provided by their utility. In addition, customers receiving the communications and offers from see Con Edison as being a more trusted energy partner who wants them to save money and energy.

In addition to measuring customer willingness to better engage with their energy usage and in turn have a better sense of which DER products to adopt, the demonstration project also aimed to lower the acquisition cost for DER providers. The final evaluation will report the findings on this specific metric.

Conclusion

As New York continues down the path of Reforming the Energy Vision, utility led demonstration projects will generate real world results from which to design achievable market and regulatory policy. A main pillar of New York REV is increased customer adoption of distributed energy resources and subsequently driving cost effective benefits for customers and the electric distribution grid. As described in this paper, Con Edison and Oracle have partnered to test and validate whether customers are more likely to invest in DERs if customers are engaged and educated about their energy usage, and able to learn about the right DERs for their household by communicating contextually relevant offers at the right time and through the right channel. Initial results suggest that customers are more engaged by receiving personalized energy communications and more likely to inquire about and invest in DER offers than those in the control group. The New York DER market as a whole stands to benefit by lowering acquisition costs through better customer targeting within proven and trusted utility communication channels. The results of this demonstration project, running from mid-2016 through mid-2018, will help inform the New York Public Service Commission, the utilities, DER providers and customers about what is possible in the new energy future envisioned by REV.

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CODES, STANDARDS & OTHER POLICIES

ESCERTS TRADING MARKET UNDER PAT SCHEME: A CRITICAL REVIEW

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Keywords: Energy, Efficiency, Policy, PAT, Trading

ABSTRACT

To meet the growing energy demand and to mitigate the carbon emissions from the Industrial sector, India designed a unique market based scheme for the large industries named as Perform Achieve & Trade (PAT) scheme. It is a cycle based scheme in which mandatory specific energy consumption (SEC) reduction targets were assigned to selected industries named as Designated Consumer (DC) and the DCs need to achieve their targets within a span of three years. Over achievers of the targets will be issued Energy saving certificates (ESCerts) equivalent to the amount of additional saving. The underachievers of the targets may purchase ESCerts from the overachievers.

The 1st cycle of PAT scheme have completed and Government of India has issued ESCerts for those industries who has overachieved their PAT cycle 1 target and asked the industries who are underachievers of the target to purchase the ESCerts from overachievers to meet their PAT compliance. This buying and selling of ESCerts will take place at Power exchanges which are regulated by Central Electricity Regulatory Commission (CERC). Bureau of Energy Efficiency (BEE) has also rolled out targets for PAT cycle 2 covering 621 DCs under 11 energy intensive sectors. The author in this paper tries to present the critical review of the PAT cycle 1 with assessment of various components of cycle 1.

INTRODUCTION

PAT scheme is one of the four components under National Mission on Enhanced Energy Efficiency (NMEEE). The other three components are Market Transformation of Energy Efficiency (MTEE), Energy Efficiency Financing Platform (EEFP) and Framework for Energy Efficient Economic Development (FEEED). NMEEE is one of the eight mission under National Action Plan on Climate Change (NAPCC) of India. NMEEE is dedicated to strengthen the market for energy efficiency in India through Industrial Energy Efficiency, appliance energy efficiency and financing mechanism to support the initiatives. PAT scheme is a regulatory instrument of the Government of India to drive the energy efficiency movement in large scale industries. Under this scheme, mandatory SEC reduction targets are assigned to selected industries (Designated Consumers) to achieve under a three year period cycle. The overachievers of the target will get incentive in terms of energy saving certificates (ESCerts) which has monetary value. The underachievers have to comply with the target by purchasing ESCerts equivalent to the shortfall energy target from the overachievers or paying penalty.

The baseline SEC of each DCs has been defined based on Gate to Gate approach. The SEC reduction target for each DC is based on their current levels of SEC, due to which the efficient DCs are assigned lower target as compared to inefficient DCs which will have higher targets.

The PAT cycle 1 was notified on 30th March 2012 vide notification no S.O. 687 (E) with 478 DCs across 8 energy intensive sectors. The aim of the PAT cycle 1 are:

1. Energy saving equivalent to 6.686 million ton of oil equivalent (TOE) from 478 DCs
2. Cumulative avoided electricity capacity addition of 19000 MW
3. CO_2 emission mitigation of around 98 million tonne per year.

The assessment of the key components of PAT are explained in subsequent section in this paper.

REVIEW OF BASELINE ESTIMATION PROCESS

Bureau of Energy Efficiency (BEE) and Ministry of Power (MoP) has adopted consultation based approach to design the PAT scheme. BEE has conducted more than 50 workshops across the country with different stakeholders to explain the PAT methodology and incorporated the valuable inputs received from the stakeholders. BEE collected data from more than 700 industries across 8 sectors and finalized 478 DCs to be included in PAT cycle 1. The threshold limit to become a DC in each sector has been notified in S.O. 394 (E) dated 19th March 2007.

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Table 1: PAT Cycle 1 DCs and Threshold limit

Industry Sector	Threshold Limit (TOE/annum)	No. of Identified DCs
Aluminum	7500	10
Cement	30000	85
Chlor-Alkali	12000	22
Fertilizer	30000	29
Pulp & Paper	30000	31
Thermal Power	30000	144
Iron & Steel	30000	67
Textiles	3000	90
Total		**478**

The baseline SEC of each DCs has been defined by taken average data of three years for production and energy consumption. The baseline years for PAT cycle 1 was considered as 2007-08, 2008-09 and 2009-10. The baseline SEC is calculated by using the formula:

$$SEC = \text{Total Energy Input (TOE)/Total Production (Ton)} \quad (1)$$

BEE has done the verification of the collected data internally and calculated the baseline SEC of all the DCs. BEE had also conducted the process of third party verification of the data which is Baseline Energy Audit (BEA) of the DCs. The BEA has been conducted for more than 700 industries which includes DCs and Non DCs. The BEA was under process during the the notification of targets for PAT cycle 1.

During the BEA, BEE collected information related to types of products, energy sources, process route, raw materials, energy exports, etc. with their authentic supporting documents. BEE has adopted various normalization factors to estimate the baseline SEC. Average value of three year data has been taken to neutralise the effect of any deviation from the standard operation of the plant. Renewable energy sources used for production which are not connected to grid has not been considered for estimation of SEC. Any energy which are not used for production have not been considered for SEC calculation.

TARGET SETTING METHODOLOGY

The target setting methodology adopted by BEE for PAT cycle 1 are based on relative SEC approach after grouping the DCs of each sector suitably. The grouping of the DCs are done based on process, end product and input raw material. The top down approach has been adopted to assign target to individual DCs. First the national target for energy saving is define and then distributed the national target among the sectors based on their share of consumption. The sectoral target is further distributed among different sub groups and later individual DCs. The relative SEC approach derives minimum targets for efficient plant and maximum target for inefficient plant. The percentage target for reduction in SEC across all the DCs are around 4-5 percent for PAT cycle 1. There are some DCs in Thermal power plant which has been assigned zero percent reduction target which implies that they are already operating at optimum level and they just need to maintain their performance.

After the notification, many DCs raised their concerns on the target setting methodology and quantum of target assigned to them. BEE after the notification of the target, conducted several sector and regional specific workshop to disseminate the methodology of estimation of baseline SEC, Target SEC and PAT rules. DCs across all the sectors participated in the scheme and submitted to BEE their action plan to achieve the PAT targets. The sectoral target notified under PAT cycle 1 is illustrated in Table 2.

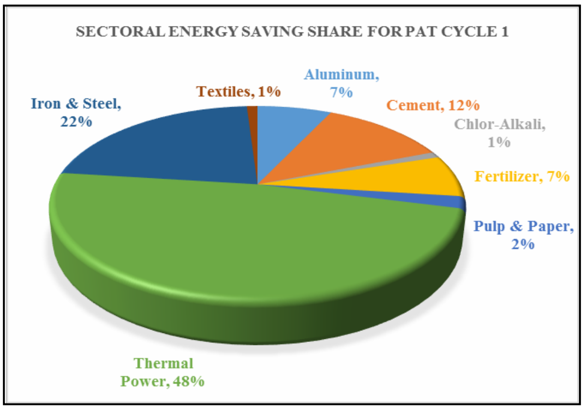

Figure 1: Sectoral Energy Saving % share

MONITORING AND VERIFICATION

The Monitoring and Verification (M&V) is one of the key component of PAT scheme. BEE has developed guidelines and excel based sector and sub sector specific data collection formats for M&V. M&V in PAT is a process of verification of SEC achieved in

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assessment year and status of DCs towards mandatory target. The assessment year for PAT cycle 1 was 2014-15 and the performance of the DCs were evaluated based on their SEC in year 2014-15 compared to notified Baseline SEC. The formula for estimation of saving/ESCerts are mentioned below:

Estimation of Energy Saving (MTOE) = Baseline Production x (SEC target – SEC achieved) (2)

BEE has empanelled Accredited Energy Auditing agencies (AEA) to undertake the M&V activities in the DCs. The qualifying criteria and responsibilities of the AEA are mentioned in PAT Rules. Each DCs have to appoint AEA for M&V within a timeline of 3 months i.e. 1st April 2015 to 30th June 2015. The data collection format and supporting documents required by BEE seems sufficient enough to justify the savings and achievements made by DCs. However, the volume of supporting documents were huge which had taken ample amount of time for DCs as well as AEA to finalize the process. Also there was lack of understanding in AEA towards the M&V process which somehow delayed the whole process. The M&V report submitted to BEE and SDA were further reviewed by the committee and modifications were made in the reports. BEE reviewed each and every forms and data submitted by DCs and AEA and the assessment of BEE made the process robust and reliable.

BEE has also developed sector specific normalization factors to incorporate the changes occurred in the DCs after the baseline year which has impacted the SEC. These normalization factors has been developed in consultation with Industrial representatives, associations, concerned government departments, sector experts, etc. The technical committee formed by MoP for each sector was involved in identification and formulation of Normalization factors for each sectors.

Based on the M&V reports submitted to BEE, 14 DCs across 8 sectors has been closed down and only 464 DCs are in operation in 2014-15. Out of which 446 DCs has been registered on PAT-Net (Online portal for submission of PAT forms to BEE) and number of DCs which has not participated in M&V are 44.

ACHIEVEMENTS OF PAT CYCLE 1

Based on the data shared by BEE for PAT cycle 1, total saving of about 8.67 million TOE has been realised from 427 DCs against the target of 6.686 million TOE which is about 30% over achievement. This energy saving is equivalent to 31 million ton of CO_2 emission mitigation and avoided peak demand of around 5635 MW. The saving realised due to energy consumption is equivalent to INR 9,500 crores with total investment made by DCs to achieve their PAT targets are around INR 24,517 crores. The details of the sector wise achievements are illustrated in Table2 below.

Table 2: PAT Cycle 1 achievements

Sectors	**Annual Energy Consumption (Million TOE)**	**Energy Reduction Target For PAT Cycle -1 (Million toe)**	**Achievements /Savings (Million toe)**	**Additional Saving (%)**
Aluminum	7.71	0.456	0.73	60%
Cement	15.01	0.815	1.48	82%
Chlor-Alkali	0.88	0.054	0.093	72%
Fertilizer	8.2	0.477	0.78	64%
Pulp & Paper	2.09	0.119	0.289	143%
TPP	104.56	3.211	3.06	-5%
Iron & Steel	25.32	1.486	2.1	41%
Textiles	1.2	0.066	0.129	95%
Total	**165**	**6.68**	**8.67**	

The results of the PAT cycle 1 not only indicates the energy saving and CO_2 emission mitigation but it also address following issues:

- Bridging the gap of energy usage bandwidth among the DCs of particular sector
- Technology transfer at affordable cost
- Promotion of ESCO
- Improved awareness towards energy efficiency
- Involvement of top management in energy efficiency related activities
- Improved data monitoring and recording system

TRADING OF ESCERTS

ESCerts are the electronics certificates which will be issued to DCs who have overachieved their target. The value of 1 ESCerts is equivalent to 1 TOE. The overachievers can sell the ESCerts to the underachievers through power exchanges. MoP has issued approximately 38.25 Lakh ESCerts to 306 DCs (Feb 2017) while 110 DCs are declared as underachievers and cumulative number of ESCerts entitled to purchased by these 110 DCs are around 14.50 Lakh ESCerts. DCs can trade at two energy exchanges that is Indian Energy Exchange (IEX) and Power Exchange India Limited (PXIL). DCs that are unable to meet the energy saving targets even through purchase of EScerts are liable to penalized under the Energy Conservation Act. The trading market are regulated by Central Electricity Regulatory Comission (CERC) and it has approved the procedure of transaction of ESCerts on 14th Feb 2017. For PAT cycle 1, no floor price or forbearence price has been defined for trading of ESCerts as the price of ESCerts will be discovered at the power exchanges. Power System Operation Corporation Limited (POSOCO) has been identified as registry for ESCerts. As per PAT Rules amendment dated 31st March 20016, the value of per metric ton of oil eq uivalent for 2014-15 is Rs. 10968, which is the penalty price for 1 TOE.

Considering the volume of availble ESCerts in market and number of buyers, the demand and supply gap is subtential. This clearly indicates that the price of ESCerts that will be defined during trading is going to be less. The driving factor for deciding the selling price ESCErts will be average amount of money invested to save one TOE in the individual DCs. For initial few trading cycles, it is expected that there will be limited trading due to mismatch of price of buyer and sellers. The trading window will open for 2 hours in each Tuesday once BEE issue order for trading. Based on the initial market assessment, the price of ESCerts are expected to be in the range of INR 3000- INR 5000 for initial trading periods. However, the actual value may differ from this value as the actual price will be defined by the buy and sell bids in both the exchanges.

CONCLUSION

PAT is a unique scheme in which mandatory target for SEC reduction has been assigned to industries. The acceptance of the target by the DCs itself indicates that the scheme has been designed taking care of different variables for industries as well as other stakeholders. DCs participated in the scheme and invested for improving their efficiency. The scheme has also accelerated the technology transfer and reduced cost of technology. One of the key achievements observed in many DCs are direct involvement of top management in energy efficiency activities which has motivated the middle and lower management to work more efficiently towards energy efficiency. The options to be adopted by DCs for consecutive Pat cycles are assessed and illustrated in figure 2.

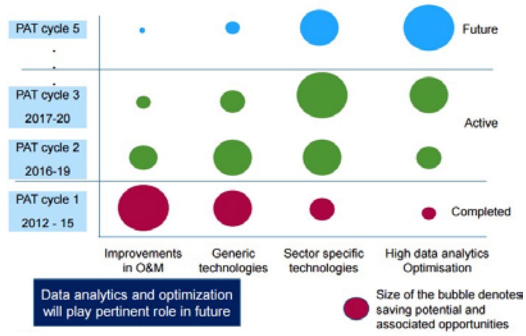

Figure 2: Options for DCs in next PAT cycles

As the PAT cycle progresses, opportunities for improvement in operational and maintenance practices will reduce. The major opportunities for energy savings will be in sector specific technologies and in data analytics. Issuance of EScerts has resulted from the continuous efforts and deep commitment of BEE and MoP towards making this scheme a successful one. Few of the difficulties faced by the DCs and other stakeholders can be addressed by discussing with existing DCs and identification of ways through which the barriers can be removed. ESCerts trading is also key component which can drive the participation and energy saving by DCs as trading for Cycle 1 is yet to begin. Many DCs claimed that timelines for various activities were limited in PAT cycle 1 like timelines for M&V

BEE has already amended the PAT rules which has addressed various issues however, empanelment process of AEAs and its monitoring needs to be more stringent. BEE should also consider the learnings from the ESCerts trading of PAT cycle 1.

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HOW TO IMPLEMENT BUILDING CODES AS AN EFFECTIVE TOOL TO SAVE ENERGY? EXPERIENCES IN EUROPE

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Keywords: Building code, Europe, building performance, co-benefits, energy efficiency

ABSTRACT

According to the International Energy Agency, some three-quarters of the anticipated building stock in India in 2040 has yet to be constructed. This expected future construction creates an opportunity for policy makers across the different government levels to define requirements for building performance, with the aim of generating a broad range of benefits for investors, owners and tenants, as well as aligning India's with its climate objectives.

Europe has had building standards in place for over 15 years. Implemented on national and regional level, those requirements are evolving progressively and include cost optimal building performance levels and a target for all new buildings to become Nearly Zero-Energy Buildings (nZEB) by 2021.

The European Union, with its 28 Member States and seven climate regions, can therefore be considered as an interesting testing lab for the development and implementation of building codes that may be relevant for their development in India.

This paper focuses on the European building legislation and its implementation, leading to positive impacts on the built environment, such as improved air quality, high building quality, reduced energy consumption, higher shares of renewable energy, alleviation of energy poverty, reduction of greenhouse gas emissions and a more productive and healthy working and living environment.

INTRODUCTION

Some three-quarters of the anticipated building stock in India in 2040 has yet to be constructed (International Energy Agency 2015). This raises the question of which policy tools can be effective to guide the construction aligned with India's objectives as amongst other the Paris Agreement.

The European Union (EU), with its 28 Member States and seven climate regions, has had building standards in place for over 15 years and can therefore be considered as an interesting testing lab for the development and implementation of building codes in India.

In the European Union (EU), the 2010 recast Directive on Energy Performance of Buildings (recast EPBD) (The European Parliament and The Council of the European Union 2010) is the main legislative instrument affecting energy use and efficiency in the building sector. This directive superseded the first EPBD (2002) and pertains to both new buildings and the existing building stock.

The first EPBD (The European Parliament and The Council of the European Union 2002) introduced an integrated framework methodology for measuring building energy performance; introduced minimum energy performance standards for new buildings (and certain renovated buildings); and introduced a requirement to certify and provide advice on the energy performance of new buildings.

Amongst other requirements, the recast EPBD introduced a benchmarking mechanism for minimum national energy performance requirements, with the objective that all new buildings in the EU should consume 'nearly zero' energy, and for the energy to come from renewable sources 'to a very large extent' from 31 December 2020.

This paper assesses the implication of EU energy policy for new buildings in EU member states, starting with setting out the importance of buildings in meeting both the EU energy and climate targets such as the COP21 Paris agreement. The paper focuses furthermore on the impact of these regulations and its main provisions, with particular attention on the assessment of "cost-optimal" levels to be used by Member States in setting minimum performance requirements.

EUROPEAN BUILDINGS AND POLICY CONTEXT

The importance of buildings in meeting EU energy and climate objectives

The building sector accounts for 40% of final energy consumption and about 36% of EU greenhouse gas (GHG) emissions (European Parliament 2016) and is therefore central for meeting EU objectives across a number of policy areas, such as reaching EU climate and energy targets, including the COP 21 Paris Agreement to pursue efforts to limit global warming to 1.5°C, as well as reducing EU dependency on imported gas and oil, and limiting the need for higher electricity production.

Focusing on new buildings

While the renovation of the existing building stock may be the most significant challenge for improving building energy efficiency in the EU, it is also important that all new buildings are constructed at close to climate neutral and zero energy levels. This is because by 2050, more than 20% of the EU building stock is expected to be comprised of buildings constructed since 2017.

Moreover, it is easier to impose stricter regulations on what will be constructed from now onwards, than it is to deal with the complexity of renovating existing buildings. Building to a high initial level of energy performance means that further interventions in the newly-built stock will be unnecessary. It also offers an opportunity to accumulate experience in deploying energy efficient and renewable energy technologies and techniques, which will positively impact the ability to renovate existing buildings.

THE EU-APPROACH

The European Union is an extreme heterogeneous space in terms of buildings, with a wide variety of building cultures and climates. Therefore, EU policies attempt to harmonise national approaches under the same broad framework, while allowing enough flexibility for each Member State to implement according to the national and local context. The EPBD recast aims to provide a holistic approach towards efficient energy use in the building sector with the objective to promote the cost-effective improvement of the overall energy performance of buildings. Therefore, the EPBD recast requires Member States to:

- Introduce minimum energy performance requirements for buildings, building elements and technical building systems;
- Set these requirements based on a cost-optimal methodology taking into account the lifetime costs of the building; and
- Build all new buildings at nearly zero-energy performance levels from 2021.

While the first two provisions address both new and existing buildings, the third is exclusively relevant to new buildings. The EPBD recast also reinforces the requirements for the energy performance certification of buildings, as well as measures for regular inspection and control of heating and cooling systems. In addition, the EPBD recast calls on Member States to introduce minimum energy performance requirements for building technical systems, i.e. for heating, hot water, air-conditioning and ventilation. (Atanasiu 2010)

Increasing the ambitions: the recast EPBD

The first EPBD (The European Parliament and The Council of the European Union 2002), agreed in 2002, required EU Member States to apply a specific methodology and set minimum requirements for the overall energy performance of buildings, and to move towards a holistic approach in their buildings regulations. Furthermore, it ensured that energy efficiency in buildings was a priority on the political agenda, as well as the dynamic setting of building regulations across the EU by increasing progressively the minimum energy performance requirements. According to the European Commission evaluation (European Commission 2011), the first EPBD represented a major change for several Member States. It required them to improve the energy performance of their new building stock significantly, and to foster the market deployment of new and more efficient technologies and materials. Notwithstanding its positive impact, several shortcomings were identified, which led to tardy or unsatisfactory transposition across the EU. EPBD implementation is a continuous process and there are still challenges to be resolved, such as low levels of ambition in some Member States, ambiguous or contentious interpretations of various articles, and poor enforcement procedures.

As a result of shortcomings identified with the first EPBD, an EPBD recast proposal was tabled, and entered into force in July 2010. The recast EPBD extended the scope of the Directive to practically all existing and new buildings (with some minor exceptions), while at the same time it introduced the obligation on Member States to set the minimum performance levels for new and existing buildings, based on a cost-optimal calculation, as indicated by a Delegated Regulation establishing a comparative methodological framework. (European Commission 2012)

One of the most notable provisions of the EPBD recast is without doubt the requirement for Member States to ensure that by 31 December 2020, all new buildings must be nearly zero-energy buildings (nZEB). An exemplary role for the public sector is also set out, requiring all new public buildings to be nZEB by 31 December 2018.

Energy performance requirements in the recast directive

The EPBD recast abolished the former rule of energy performance requirements addressed only to new buildings with a useful floor area greater than 1000m^2 and extended it to all new buildings. Therefore, Article 6 of the EPBD recast requires Member States to ensure the technical, environmental and economic feasibility of renewable energy supply, cogeneration, district heating and cooling and heat pumps are conducted before construction starts.

Annex I of the EPBD recast stipulates that the energy performance methodology used must take into consideration, among other factors, the thermal characteristics of the building, heating, air-conditioning, ventilation and hot water supply installations, as well as built-in lighting installations (mainly for non-residential buildings). Figure 1 shows the schematic illustration of the calculation scheme of the energy performance methodology.

The methodology should consider also aspects such as design, orientation, positioning and passive characteristics of the building; the indoor climate conditions and internal loads; and local factors such as solar exposure, availability of electricity from renewables and cogeneration, available district heating and cooling, and natural lighting. The Annex further states that: '*the energy performance of a building shall be determined on the basis of the calculated or actual annual energy that is consumed in order to meet the different needs associated with its typical use and shall reflect the heating energy needs and cooling energy needs (energy needed to avoid overheating) to maintain the envisaged temperature conditions of the building, and domestic hot water needs.*'

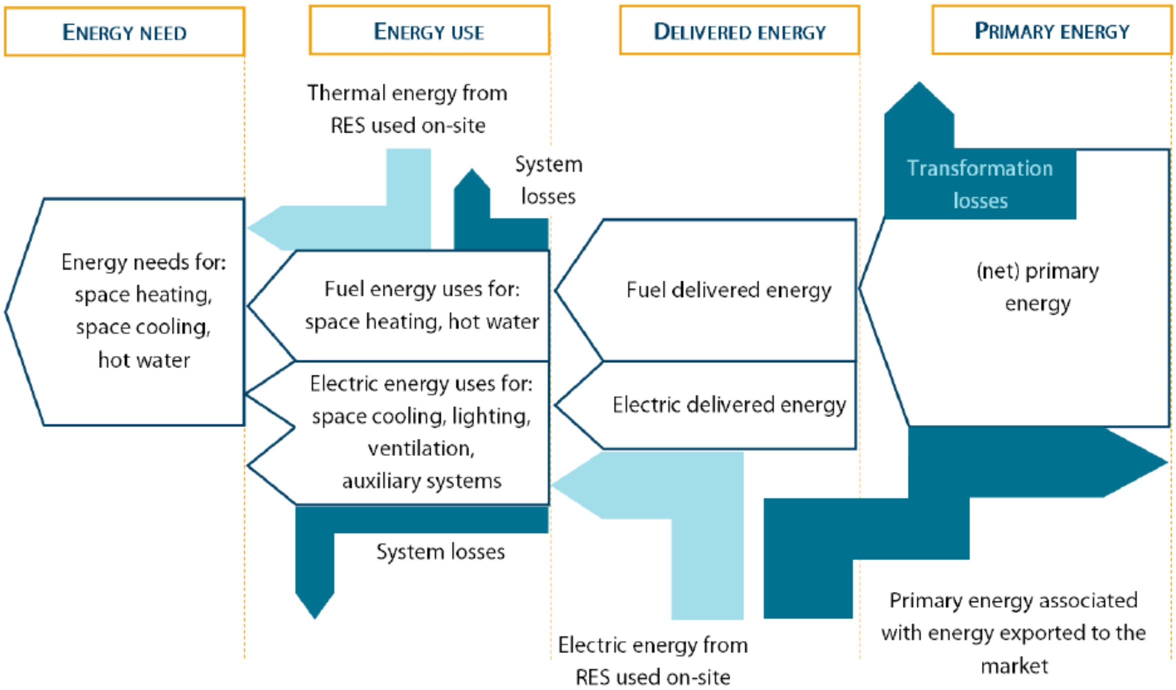

Figure 1 - Schematic illustration of the calculation scheme (European Commission's guidelines for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements)

Cost-optimal levels of minimum energy performance requirements

The recast EPBD reinforces the obligation for setting minimum energy performance requirements for buildings and buildings units by introducing the need for setting these requirements at cost-optimal levels, pursuant to a methodology set out in Article 5 of the EPBD recast, and further developed in 2012 by a specific Delegated Regulation (European Commission 2012).

This requires Member States to adopt a cost-optimal methodology as a benchmark mechanism for further improving the minimum energy performance requirements over time, for both new and existing buildings. The cost-optimal methodology introduces – for the first time – a requirement to consider the global lifetime costs associated with a building, with a view to determining future energy performance requirements. Thus, the evaluation of buildings' requirements will no longer exclusively be related to upfront investment costs, but will additionally have to take into account the operational, maintenance, disposal and energy saving costs of buildings.

Member States are required to "*assure that minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels.*" They must also "*take the necessary measures to ensure that minimum energy performance requirements are set for building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are replaced or retrofitted, with a view to achieving cost-optimal levels*" (EPBD recast Art. 4.1 and also Recital 14). The cost-optimal level is defined as "*the energy performance level which leads to the lowest cost during the estimated economic lifecycle.*" (see principle in **Figure 2**).

The cost-optimal Delegated Regulation of the EU Commission prescribes a methodology that Member States are required to use to calculate this level. To this end they must account for a range of costs and benefits, including investment, maintenance, operating costs and energy savings.

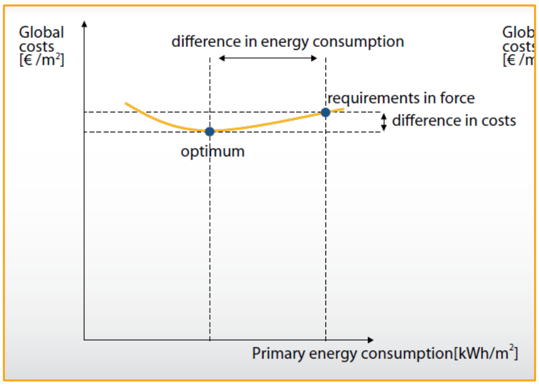

Figure 2 - Cost-optimal building performance requirements (Buildings Performance Institute Europe 2013)

To assist Member States, the Regulation is accompanied by Guidelines outlining how to apply the framework for calculating the cost-optimal energy performance level (European Commission n.d.). The complete process to assess and report on cost-optimal levels for buildings energy performance is – besides in the Commission's guidelines - extensively described in several studies (Buildings Performance Institute Europe 2010) (Buildings Performance Institute Europe 2013) (ECEEE 2011) (Engelund Thomsen and Wittchen 2015) (Ecofys 2015). The diagram of **Figure 3** summarises the necessary steps to be followed when implementing cost-optimality at national level.

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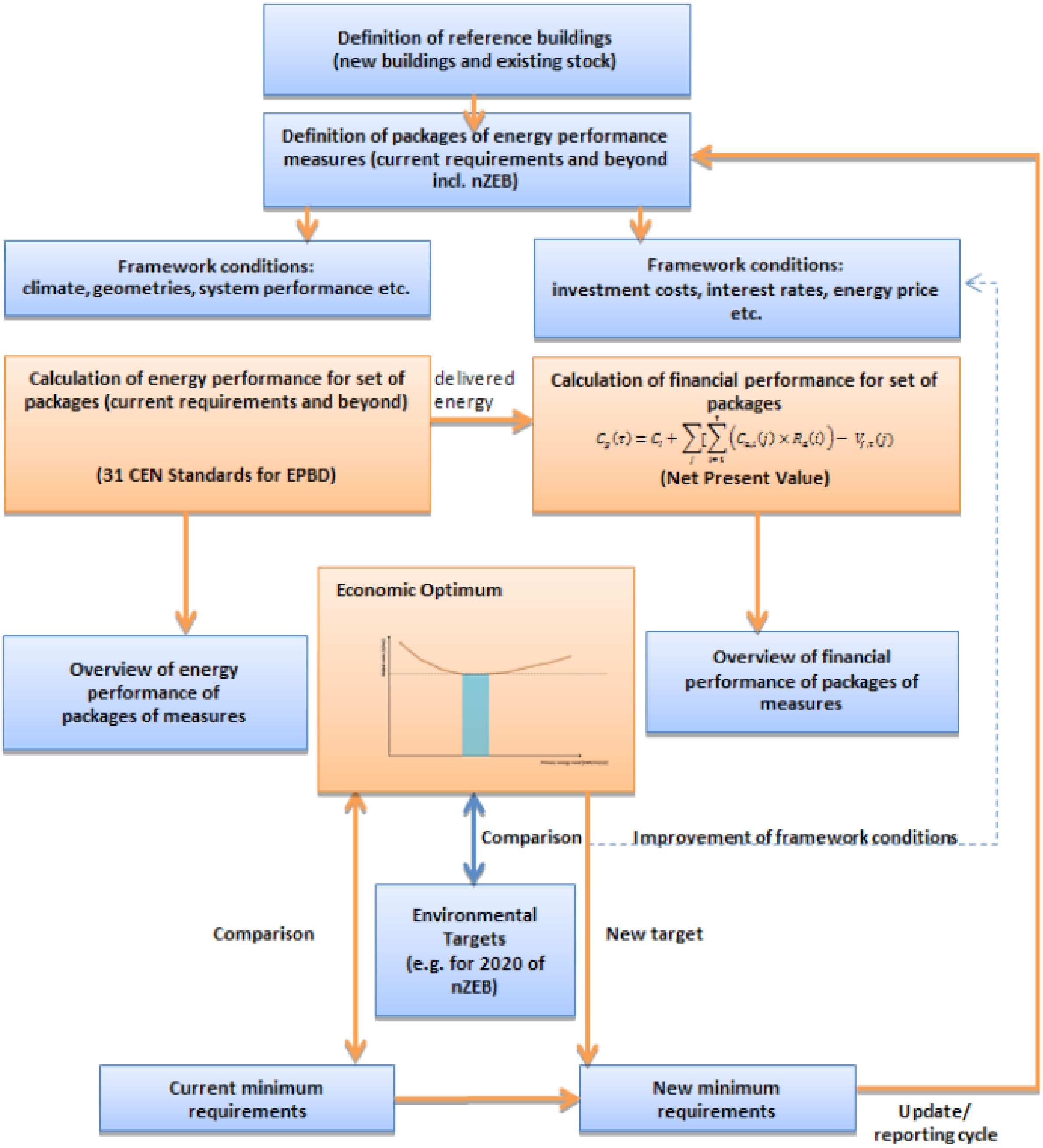

Figure 3 - Implementation steps of cost-optimal methodology (Buildings Performance Institute Europe 2010)

Member States are required to report to the Commission all input data and assumptions used for these calculations, and the results of the calculations from two perspectives: the macroeconomic level (the societal level) and the financial level (the private investor perspective). Member States can then choose which one to apply at the national level.

If the cost-optimal comparative analysis shows that the requirements in force are much less than the cost-optimal level (i.e. if the energy requirements in force are 15% or more above the cost-optimal level), Member States need to justify this gap to the Commission. If the gap cannot be justified, a plan must be developed to outline steps to reduce the gap significantly.

Figure 4 shows an example of a specific output of the German cost-optimal calculation result, presenting the global cost curves for heat supply systems with condensing boiler (gas). The vertical red line marks the accepted primary energy demand according to the German EnEV 2009 (i.e. the main requirement for Single Family Houses, approx. 70 kWh/m2yr).

the formulation leaves room for each Member State to interpret these requirements.

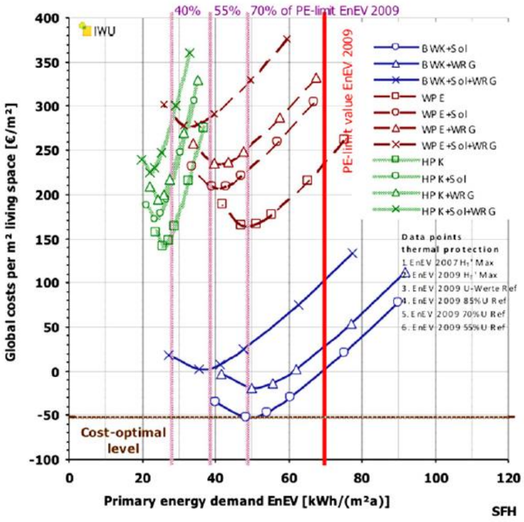

Figure 4: Example of the German cost-optimal calculation results - global costs for all heat supply systems under a baseline scenario (Buildings Performance Institute Europe 2013)

The Commission will publish reports tracking the progress of Member States.

Member States must report their adopted level of minimum energy requirements to the Commission at regular intervals, of maximum five years. The first report was due on March 2013 (Ecofys 2015), the next reporting is to be expected early 2018.

Nearly zero energy buildings

The recast Directive introduced the concept of a 'nearly zero-energy building' (nZEB), which, according to the definition provided in Article 2, means "*a building that has a very high energy performance, as determined in accordance with Annex I. The nearly or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby*".

According to the EPBD's definition of energy performance and clarifications provided in Annex I, a building has to reach a nZEB level, counting the energy needs for heating, cooling, ventilation, domestic hot water, while for non-residential buildings the energy need for lighting has to also be considered. Therefore the electricity use for appliances and other electrical equipment is not included in the nZEB scope.

While renewable energy use and specifically onsite or nearby generation is included in the nZEB definition, the formulation leaves room for each Member State to interpret these requirements.

As stated above, Article 9 of the recast EPBD further requires Member States to ensure that:

- After 31 December 2018, new buildings occupied and owned by public authorities are "nearly zero-energy buildings".
- By 31 December 2020, all new buildings are "nearly zero-energy buildings".

Moreover, Member States are required to draw up national plans for increasing the number of nZEBs. These plans must include:

- A "detailed application in practice" of the nZEB definition, reflecting local conditions and include a numerical indicator of primary energy use, expressed in kWh/m^2 per year;
- Intermediate targets for improving the energy performance of new buildings by 2015; and
- Information on policies, financial or other measures adopted for the promotion of nZEBs, including details on the use of renewable sources in new buildings and existing buildings undergoing major renovation.

The EU Commission will in turn evaluate these national plans for nZEB, and assess the adequacy of the measures envisaged by Member States in relation to the objectives of the EPBD.

While the overall ambition of the recast EPBD is therefore significant, flexibilities granted to Member States may water down the nZEB requirements

Assessments of already set nZEB performance levels, as defined by the different Member States, show that the levels of ambition in defining an nZEB vary across the board (Ecofys 2014). E.g. 12 out of 28 Member States set a definition that comprises both a numerical target for primary energy use (or final energy) and consider the share of renewables in a quantitative or qualitative way. In eight of these jurisdictions, the share of primary energy consumption to be covered by renewable energy sources is explicitly stated, while in other jurisdictions renewable sources are considered indirectly. (Buildings Performance Institute Europe 2015)

MAKING THE CASE FOR INDIAN BUILDING POLICIES THROUGH EU EXPERIENCES

While the authors do not intend to prescribe applicable policies for India, the experience of introducing building policies in the EU and EU countries makes a good case for similar policy development in India.

A crucial difference between the EU and India is that in India the vast majority of the building stock anticipated in 2040 has yet to be constructed, while the main challenge in the EU is renovating existing buildings. This also implies that regulations for new buildings in India will have a far greater impact than in the EU.

Providing a clear trajectory for standards in buildings, which are introduced step by step and tightened over time, allows the construction sector to adapt accordingly over a mid-long term, as well as contributing to India's challenge to achieving the climate goals of the COP 21 agreement. Strengthening and updating standards over time help to build on successful policies and develop experience over time.

Figure 5 shows how energy performance requirements have been strengthened over time in Flanders (Belgium), correlating the number of building permits submitted with the energy performance levels (E-peil, horizontal axe). Of particular interest is the data from 2014. While nearly all buildings complied with the minimum building requirement of E60, there is a considerable spike in those at nZEB level (E30). This due to targeted building policies, such as subsidy schemes, awareness and informative campaigns, and construction sector involvement.

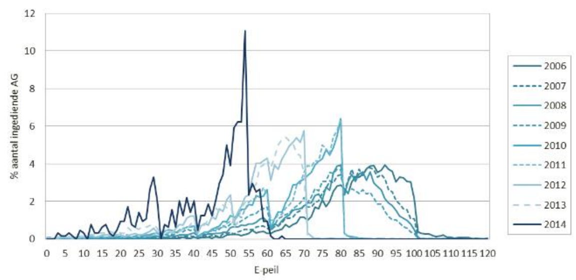

Figure 5: the effect of building requirements and corresponding policies (Flemish Energy Agency 2016)

The introduction of the Indian Energy Conservation Building Code (ECBC) in March 2017 built on previously voluntary standards to introduce energy performance standards for new commercial buildings is expected to cut energy use by 50% (Bureau of Energy Efficiency, Government of India, Ministry of Power 2017). The possibility that this could be rolled out to residential buildings in the future would drive the market and construction sector to develop and adjust to new requirements over time. It could be expected that expertise and competences obtained within the commercial building sector will transfer to the residential building sector.

In the EU, the market response to new regulation has led to the development of new business models and services. For example, "Energiesprong" in the Netherlands achieves net-zero renovation paid for by energy cost savings due to a 50% cost decrease. This is realised by developing state-of-the-art renovation methodologies, scaling up to industrialised production levels using prefabricated building elements, which allows a renovation to be executed within a week. Not only does Energiesprong bring together industry, housing providers and residents to provide a holistic and consumer orientated solution, it is also a significant new market opportunity for the industry due to the large number of renovations needed. This should drive job creation and ongoing investment. Starting in the Netherlands, Energiesprong has been rolled out in France, the UK and Germany (as well as New York State in the US). (Buildings Performance Institute Europe 2015) (Energiesprong 2016)

Engaging the construction sector in the development of new regulation is important to foster such business models to develop and ensuring compliance.

The challenge of implementing nZEB policies however should not be taken lightly, it will require high quality building works and application of advanced technologies for which specific skills are needed. In the EU, work is ongoing to ensure compliance with standards (QUALICHeCK 2017).

CONCLUSION

With the building sector accounting for 40% of final energy consumption and about 36% of EU greenhouse gas emissions, it is central to meeting EU objectives such as the COP 21 Paris Agreement.

For new buildings, the recast EPBD introduces important provisions designed to facilitate the transition towards a sustainable buildings sector. However, due to the divided competences of the EU and Member States in the field of energy, some requirements such as the cost-optimal methodology and nZEBs are very flexible and their implementation relies largely on Member State ambitions and political commitment. Therefore, it is vital to secure effective implementation. Demonstrating to Member States the associated social, economic and environmental benefits at national level can stimulate interest in moving beyond basic compliance with EU legislation.

Full and effective implementation of the EPBD recast can generate significant energy and carbon savings, and will also provide additional multiple benefits such as improved air quality, high building quality, reduced energy consumption, higher shares of renewable energy, alleviation of energy poverty and a more productive and healthy working and living environment.

While the renovation of the existing building stock – which is only covered to a limited extent by European legislation - may be the most significant challenge for improving building energy efficiency in the EU, for India it is expected for some three-quarters of the anticipated building stock in 2040 has yet to be constructed. Energy use in the buildings sector (both the residential and services sectors) is projected to change dramatically over the coming decades under the influence of population growth, the trend towards urbanisation, growth in access to modern energy and the impact of rising incomes on the ownership of appliances. (International Energy Agency 2015)

These considerations have enormous implications and call for all new buildings to be constructed at close to climate neutral and zero energy levels. Experience shows that building codes and performance requirements – progressively tightened over time - are key in achieving low energy building performance levels and seize all the benefits a carbon neutral building stock can provide.

NOMENCLATURE

EPBD = *Energy Performance of Buildings Directive*
GHG = greenhouse gas
MS = *Member States*
nZEB = *nearly zero-energy building*

ACKNOWLEDGEMENT

The research for this paper is funded by the European Climate Foundation.

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THE IMPACT OF MEASUREMENT AND VERIFICATION OPTION CHOICE ON FINANCIAL RETURNS FOR CLIENTS IN ENERGY PERFORMANCE CONTRACTS

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Keywords: ESCOs, M&V, Energy Performance Contracts

ABSTRACT

Energy Performance Contracts (EPCs) differ from traditional energy efficiency upgrades due to the degree of performance risk transferred to the supplier (ESCO) for the level of energy savings delivered. While there are many different forms of EPC a fundamental component of all is the need to agree how savings will be measured and verified, in order to determine if the guaranteed level has been achieved. The choice of Measurement and Verification (M&V) strategy is typically approached as a trade-off between the cost and complexity of the measurement method and the need for accuracy. However, different M&V strategies imply different measurement boundaries for energy savings and thus the level of savings covered by the guarantee can vary significantly. While many commentators have pointed to the importance of robust M&V arrangements, there has been almost no discussion of the commercial implications of the choice of strategy. In this study, stochastic modelling is used to take account of the large number of uncertainties inherent in any building retrofit project when exploring the consequences of the choice of measurement boundary for a lighting upgrade project. The results highlight the need for a more sophisticated understanding of the impacts of the trade-off between cost of monitoring and accuracy of results. Without this the ESCO industry risks a loss of trust as a result of a sizeable proportion of clients receiving lower than expected savings with no recourse under the guarantee.

INTRODUCTION

Energy efficiency is a fundamental part of India's strategy for addressing the interconnected challenges of energy security and reducing carbon dioxide emissions (Delio et al., 2010) with an estimated potential for 33% improvement in energy efficiency in buildings by 2030 (Klessmann et al., 2007). Both internationally and in India, EPCs have been widely promoted as a mechanism for increasing uptake of energy efficiency investments by transferring the performance risk for the energy saving measure to the contractor responsible for its installation (Prasad Painuly, 2009).

Whether EPCs should be viewed as heralding the shift from the industrialised economy to a performance based economy as suggested by Steinberger et al. (2009) or more prosaically, as a mechanism for unlocking energy efficiency investments, they have received considerable attention as part of the solution to deliver significant and rapid reductions in carbon dioxide emissions to address climate change goals (Fang and Miller, 2013; Fang et al., 2012).

In line with Duplessis et al. (2012) the definition of Energy Performance Contract used in this study is taken from EU directive 2006/32/EC:

“A contractual arrangement between the beneficiary and the provider (...) of an energy improvement measure, where investments in that measure are paid for in relation to a contractually agreed level of energy efficiency improvement.”(article 3j The European Parliament and The Council of the European Union, 2006)

Literature relating to EPCs was identified from the Scopus database for journal articles published between 2005 and 2017, using the following search terms:

- energy performance contract
- energy service company
- energy service companies

The terms ‘ESCO’ and ‘EPC’ were not used in the search as these abbreviations were found to be used in various unrelated fields. A total of 377 papers were identified and the 100 most cited were selected for inclusion in the review. Paper abstracts were then reviewed to ensure that only papers which referred to

EPCs as defined above were included. This resulted in 67 papers for review. More detailed review of the full text of the remaining 67 articles and book chapters identified a further 15 items which did not directly relate to EPCs and these were also removed. Two items were excluded as only the abstract was in English, access was not available to one item and one item had been withdrawn leaving a total of 48 items.

DEVELOPMENT OF EPC MARKETS

While the literature indicates that the market for EPCs is large and growing and EPCs offer some demonstrable benefits, many commentators have identified barriers which may prevent it reaching its full potential (Bertoldi et al., 2006; Dobes, 2013; Hansen, 2011; Marino et al., 2011). Reasons for this apparent lag and/or proposals for supporting market growth are explicitly addressed in a large proportion of the literature, in all 24 unique accounts were found in the 48 papers reviewed and a number of recurring themes were identified:

Awareness and incentives to invest

For an EPC to be a possibility there must first be a desire to improve energy efficiency and an awareness of the potential solution offered by an EPC, (2011) suggests a global lack of awareness, a view borne out by the range of commentators sharing it. Commenting on the EU ESCO market (2006) report a lack of awareness or understanding on the part of potential clients in some member states of the importance of energy efficiency or how EPCs could be used to increase it. This finding is mirrored in analyses of other markets (Aasen et al., 2016; Jensen et al., 2013; Kostka and Shin, 2013; Pätäri and Sinkkonen, 2014; Soroye and Nilsson, 2010; Suhonen and Okkonen, 2013). Nolden and Sorrell (2015) note that even in jurisdictions where awareness of the need for energy efficiency might be expected to be high, energy efficiency investments must compete for scarce capital resources. The development and implementation of energy efficiency ratings schemes has a key role to play in this (Delio et al., 2010).

Cultural barriers

The need to adapt to local market and cultural norms is discussed by many authors (Fang and Miller, 2013; Marino et al., 2010; Patlitzianas and Psarras, 2007; Patlitzianas et al., 2006; Soroye and Nilsson, 2010), Yuan et al. (2016) note that even within a single country, in their case China, there is a need to take account of regional differences. Some cultural barriers are particularly challenging to market development, for example, a moral objection to a third party profiting from public sector actions in some Nordic countries (Jensen et al., 2013; Pätäri and Sinkkonen, 2014; Suhonen and Okkonen, 2013).

Government support

Development of EPC markets relies on government action in three key guises: firstly for the establishment of the appropriate legal and regulatory framework which allows EPCs to be undertaken (Hansen, 2011; Soroye and Nilsson, 2010; Vine, 2005). The need for legislative change to financial markets in Turkey to allow access to risk capital is a good example of this (Okay et al., 2008). Secondly, governments can influence market activity through the availability of subsidies for energy efficiency investments (Patlitzianas and Psarras, 2007) or tax incentives (Zhang et al., 2008). Thirdly, governments also have an important role to play as clients, leading by example (Bertoldi et al., 2006). Delio et al. (2010) highlight the risk that policies intended to support development of the EPC market could be counterproductive in some cases, citing the example of the impact of price subsidies for electricity for the agricultural sector in India (Modi et al., 2010).

Access to finance

Access to finance is cited by many authors as a potential barrier to market development. In the Indian market, access to finance appears to be a concern for smaller ESCOs but not for the largest companies (Delio et al., 2010). Specific initiatives have been developed to address this barrier, such as the German development bank, KfW's partnership with the Small Industries Development Bank of India (Panev et al., 2014).

Transaction costs

High transaction costs are identified by a wide range of authors as a barrier to market expansion in locations as diverse as China, Finland, India and Denmark (Jensen et al., 2013; Kostka and Shin, 2013; Prasad Painuly, 2009; Suhonen and Okkonen, 2013), these findings echo earlier conclusions by Sorrell (2007) that transaction costs would be a determining factor in deciding governance structures for procuring energy efficiency projects.

Uncertainty

Backlung and Eidenskog (2013) and Suhonen and Okkonen (2013), Marino et al. (2011), Mills et al. (2006) and Vine (2005) all expressly discuss the potential for actual savings and hence financial returns to vary from the expected values. Standardisation of contracts and measurement and verification procedures is seen as a key strategy for addressing these risks (Bertoldi et al., 2006; Larsen et al., 2012; Vine et al., 1998; Zhang et al., 2008). A separate dimension of uncertainty is related to the long-term nature of these contracts with Nolden and Sorrell(2015), Pätäri and Sinkkonen (2014) and Jensen et al. (2013) all highlighting the potential unwillingness of clients to enter into long term contracts which might either restrict their ability to respond to future business demands or realise much lower than anticipated returns due to changes in estates strategies.

A more detailed exploration of the approach to risk in the EPC literature was undertaken by relaxing the ranking requirement and including the term 'risk' in the original search. This resulted in the addition of 31 articles. Relaxing the ranking criterion meant that less heavily cited studies were included, in many cases the lack of citations is likely to be due to the relative recentness of the articles the oldest of which dated from 2014. It was necessary to exclude a further 9 articles due to a lack of access. Review of the abstracts resulted in the identification of a further 3 articles which did not relate to EPCs as defined above.

The studies that remained could be thematically divided into four main categories: studies which use expert opinion to identify risks (Berghorn and Syal, 2016; Garbuzova-Schlifter and Madlener, 2016), case studies which include discussion of risks in particular contexts (Betz et al., 2016; Bustos et al., 2016; Deng et al., 2015; Joubert et al., 2016; Lee et al., 2016; Zhang et al., 2015), consideration of risk allocation as a result of sharing mechanisms typically modelled using game theory approaches (Huang et al., 2014; Iimi, 2016; Qian and Guo, 2014; Shang et al., 2015; Wang et al., 2017) and discussions of the implications of measurement and verification strategy (Meijsen et al., 2015; Shonder and Avina, 2016)

The risk identification studies cited two key sources of risk and uncertainty which were also explicitly identified in a number of case study examples: the variability of energy savings and the uncertainty around energy prices. Mills et al. (2006) suggested a list of possible causes for these uncertainties:

- Inadequate time or methodology to establish an accurate volumetric consumption baseline
- Inability to monitor behavioural changes that could result in greater consumption of energy when new equipment is installed
- Inability to monitor and mitigate actions that could decrease asset efficiency, such as poor maintenance
- Volatility in future energy rates, currency exchange rates, interest rates, etc.

They concluded that "Quantitative risk analysis is essential to correctly value energy-efficiency projects in the context of investment decision-making" (p. 198 Mills et al., 2006).

While a number of the studies reviewed here did not explicitly evaluate risks and provided more general explorations of particular projects, others provided a more detailed consideration of how risk and uncertainty can be approached. Some suggestions for best practice for the treatment of risk and uncertainty can be drawn from this:

- probabilistic simulation of energy savings using building energy simulation is important and the computational load can be reduced through the application of parameter screening
- probabilistic simulation of energy price volatility is also required
- variability of the performance of energy conservation measures over time should be considered
- variation in weather over time should also be considered.

The significance of measurement and verification in risk allocation

Many commentators identify standardised Measurement & Verification (M&V) processes as a key market enabler (or, its absence as a key market barrier). Only two of these commentators take a slightly different view, with Jensen et al. (2013) placing a higher emphasis on trust in the context of Danish municipalities and Sarkar and Singh (2010) cautioning against over-complex M&V arrangements as a potential market barrier in developing countries. In addition, a variety of US based studies quoted in Kats et al. (1997) provide evidence of greater savings in projects with robust M&V arrangements.

Wang et al. (2017) draw an important distinction between four categories of savings:

- expected - the savings which are expected to be made

- guaranteed - the level of savings which the ESCO is comfortable with guaranteeing
- verified - the measured savings
- actual - the total savings

The distinction between the final two categories is important and frequently missed, since the scope of verified savings will be defined by what is practical and cost-effective to measure and may well not be the same as the actual savings. The test of whether or not energy savings have been achieved is more precisely a test of whether or not the verified savings exceed the guaranteed savings.

Shonder and Avina (2016) highlight the potential for different measurement and verification approaches to result in different risk allocations for clients and ESCOs and different values for measured savings as a result. This difference in measured energy savings between the different IPMVP options is also reported by Ginestet and Marchio (2010).

The most commonly used approach for measuring and verifying savings is the International Performance Measurement and Verification Protocol (IPMVP) which grew out the US EPC industry standards (Efficiency Valuation Organization, 2012), with ten Donkelaar et al. (2013) reporting its use in just under 50% of 100 European projects surveyed. However, it is important to note that IPMVP does not present a detailed process for measuring savings but a framework that can be adapted to fit a wide range of circumstances. In particular, IPMVP contains 4 distinct options for measuring savings each with different measurement boundaries, since many ECMs may affect other building systems across these measurement boundaries, the total savings measured and thus guaranteed, may vary depending on the option selected.

For the EPC market to achieve its aim of increasing energy efficiency investments, it is essential that clients have confidence in the level of guarantee offered under the contract since otherwise the risks of investment will not be considered to be reduced. The potential for differing levels of savings depending on the measurement boundary selected leads to a risk that clients and contractors may have very different expectations of energy savings as a result of the investment in an EPC with important consequences at an industry level as a result of a lack of confidence in future energy savings guarantees. To date, the literature has sought to explore the market level impacts of standardised M&V approaches as discussed above but only one study was found which considered the differences in outcomes for different M&V approaches. Ginestet and Marchio (2010) compared the costs and results of each of the 4 IPMVP M&V options for an AHU upgrade. The study was undertaken using a pair of identical lecture theatres with the AHU in one upgraded and the other used for a baseline comparison. Ginestet and Marchio's results indicated that option A was only useful when operational patterns were well understood. Their results echoed Shonder and Avina's (2016) assessment of the relative costs of each option with A and C being the cheapest options and B and D the most expensive.

The choice of M&V strategy is thus related to concerns about transaction costs, with the cost of more detailed monitoring having the potential to affect the financial viability of a project. The development of specialised monitoring tools and extended period of monitoring required for the Ginestet and Marchio study is likely to be impractical in many commercial settings. This study seeks explore the implications of M&V option choice as Ginestet and Marchio did but to do so in the context of limited information which applies in many competitive procurements. The theoretical case of a lighting retrofit in an archetypal UK school is modelled to understand the consequences of alternative measurement options under IPMVP when only limited data about the context and setting is available. While thermal energy demands are very different in India and the UK, the principles of the impact of measurement boundaries on electricity consumption are valid in both contexts.

SIMULATION

A typical UK primary school (420 pupils aged between 4 and 11 years old, taught in classes of 30) was modelled in EnergyPlus (US Department of Energy, 2015). A fundamental complication of measurement and verification of energy savings is that since the energy savings are an absence of consumption they cannot be measured directly. It follows from this that establishing the baseline condition, the energy consumption which would have taken place if no energy efficiency measure had been installed is critical. Moreover, the literature on the energy performance gap has repeatedly demonstrated the difficulty in accurately calculating the energy performance of buildings in use, even where detailed design information is available. Where such information is no longer available and buildings may have been incrementally modified over the years with limited record keeping this situation is compounded.

Whilst in theory, much of this missing information could be obtained from detailed surveys, in practice, the cost of obtaining this information and the time needed to do so mean that only limited survey work is undertaken. To capture this uncertainty surrounding the baseline condition of the archetypal school the probabilistic approach identified in the literature review is required.

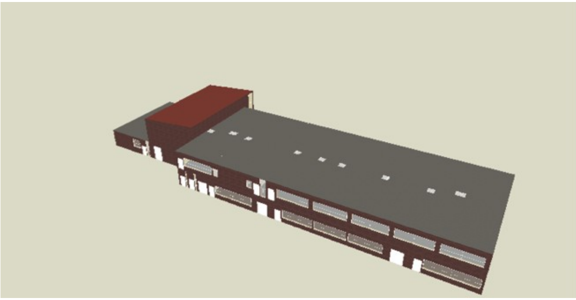

Figure 1: Archetypal UK primary school modelled in EnergyPlus

Screening

A literature review coupled with the lumped parameter approach proposed by Garcia Sanchez et al. (2014) was used to identify 91 variable input parameters, covering building fabric, systems, settings and occupant behaviour. Capturing the full range of variation over this large input space is time-prohibitive as the individual models are relatively time- consuming to run (approximately 3.5 minutes for parallel simulation of 8 primary school models). Consequently, a screening approach was necessary to select the most influential parameters which can be permuted in subsequent model runs with values for the un-influential parameters being fixed. Global Sensitivity Analysis (GSA) considers variations across the full input space and is appropriate for a complex, non-linear model such as a building simulation model where interactions between input parameters are expected to be important (Saltelli et al., 2008). The screening approach used in this study has been described in Fennell et al. (2017).

Testing the effects of different measurement boundaries

The impact of different measurement boundaries was explored for a single ECM, a lighting upgrade comprising 2 parts: relamping, modelled as a reduction in lighting gains and lighting controls, modelled as a change in the lighting hours. Difficulties of data collection mean that very little data exists detailing lighting practices in UK schools (Drosou et al., 2015). In Drosou et al. (2016) a study of lighting behaviour in 4 UK classrooms suggested that lights were used for most of the time that classrooms were in use. Since Drosou et al.'s data related to 2 secondary schools and the current study is based on a primary school where classrooms are in continuous use a simplified profile was used for the lighting schedules, with a single on and off time. A single occupancy schedule is used for the whole building which was considered to be appropriate for a primary school where occupancy density is high and most spaces will be in continuous use. Diversity was introduced in the sample by treating the on and off times as variables sampled stochastically from symmetric triangular distributions. The lower bounds for on time and off time are based on a typical UK school day of approximately 9am to 3pm (Qualifications and Curriculum Authority, 2002). Upper bounds for on and off time are estimated based on potential for early morning cleaning schedules and evidence in Taajamo et al. (2014) of an average 51 hour working week for UK teachers. The resulting lighting schedules are shown in figure 2.

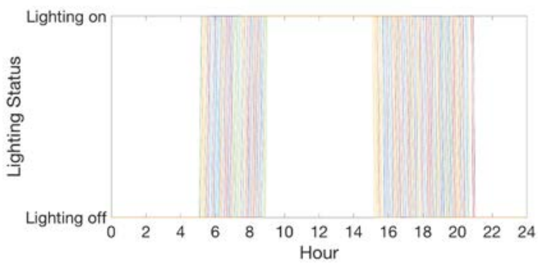

Figure 2: Lighting schedules prior to retrofit

Following retrofit, lighting hours are matched with occupancy hours to reflect the installation of occupancy sensors. Lighting fraction is introduced as a variable to allow for a proportion of lights to be switched off during the day. One of the very few sources of data for lighting use in schools is Drosou et al. (2016) where the authors report lights being used in a secondary school classroom for 60% of the school day in a building with occupancy sensing. This was taken as the lower bound for the lighting fraction as the space utilisation rate in primary schools is typically higher than in secondary schools in the UK.

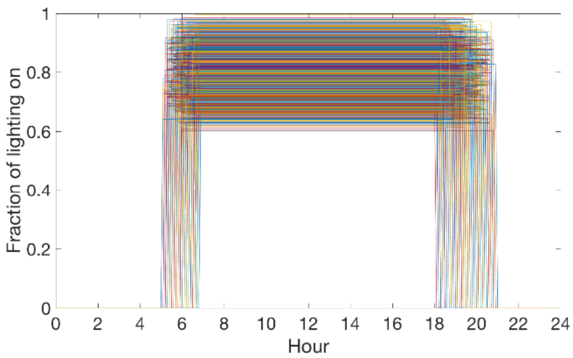

Figure 3: Lighting schedules post retrofit ***Table 1: lighting gain values***

	PRE-RETROFIT	POST-RETROFIT
Distribution of samples	symmetric triangular	normal
Classroom	12-21 W/m^2	4.4 W/m^2 (SD 0.22)
Office	12-14 W/m^2	5.4 W/m^2 (SD 0.27)
Hall	12-13 W/m^2	5.7 W/m^2 (SD 0.27)
Ancillary	8 - 10 W/m^2	3.1 W/m^2 (SD 0.16)

IPMVP, (Efficiency Valuation Organization, 2012) sets out 4 different approaches to measuring energy savings:

- Option A: Field measurements of specified key performance parameters and estimates for other parameters are used in engineering calculations. The measurement boundary is defined by the calculation undertaken and so may not encompass all aspects of the ECM
- Option B: Field measurements are taken of the energy use of the ECM-affected system. Measurements can be short term or continuous and would normally also cover the period prior to installation to establish a baseline level of consumption. The measurement boundary is the system considered. Other systems which might be affected are not included within the boundary.
- Option C: Energy use is measured at the whole or sub-facility level. Savings are calculated from analysis of the whole facility energy use pre and post ECM installation and regression analysis is typically used for routine adjustments.
- Option D: Savings are determined through a calibrated simulation model of the energy use of the whole facility or sub-facility. Measurement boundaries for options and C and D are conceptually the same and so option D is excluded from this analysis.

Savings were calculated pre and post-retrofit for using 3 different methods:

- Option A savings were calculated by assuming a baseline figure of 2000 annual lighting hours with the exception of offices which are assumed to have a baseline of 2500 annual lighting hours, (Philips, 2010). 2000 hours per annum equates to 10 hours of lighting per day. Post retrofit, a 20% reduction in lighting hours is assumed as a conservative estimate based on manufacturers' claims, (Guo et al., 2010). No allowance is made for uncertainty in these estimates to reflect standard practices identified in interviews undertaken by the authors as part of a broader study.
- Option B results are based on the lighting energy consumption calculated by Energyplus.
- Option C results are based on the whole facility electricity and gas consumption calculated by Energyplus.

RESULTS AND DISCUSSION

The reduced model was based on a total of 19 influential parameters following the screening process documented in Fennell et al. (2017)

6 parameters had a significant effect on electricity consumption (S_i 0.05): classroom equipment gains, classroom lighting gains, general equipment on-time, general equipment off-time, general lighting on-time, general lighting off-time.

13 parameters had a significant effect on gas consumption (S_i 0.05): intermittent heating set point, regular heating set point, intermittent heating set back band, regular heating set back band, general full occupancy end-time, general heating on-time, ventilation temperature, infiltration rate, boiler part load ratio, boiler efficiency, domestic hot water loop exit temperature, fibreboard thermal conductivity, classroom ventilation rate. Of these 13, 3 had a much greater effect: regular heating set point, ventilation temperature and infiltration rate.

As discussed earlier, post-retrofit lighting hours are linked to occupancy and so occupancy parameters were included in the list of variable parameters. An additional variable was included post-retrofit to model the percentage of lighting in use. 1200 runs were undertaken for the pre-retrofit condition with the non-influential parameters fixed at their mean value. Sample values for the parameters which were influential but unchanged by the lighting upgrade were reused in the post-retrofit condition.

Figure 4 shows in blue the annual electricity savings calculated on a whole building basis and in red, the lighting energy saving, reflecting the option C and B savings calculations respectively. The annual electricity saving calculated using the option A method is 1.6 x 10^{11} J, this is shown as a broken line.

These results indicate that there is good agreement between the option B and C calculations. It is also clear that the energy savings are closely linked to the number of lighting hours pre-retrofit. In the majority of the cases modelled here, lighting savings will be in excess of the option A predicted value. However, for the lower quartile of lighting users, savings will be lower than the value predicted as their original consumption was lower than estimated, in these cases, the performance guarantee offers no protection since the savings are deemed to have been met based on the engineering calculation. This is a concern since the inclusion of a performance guarantee typically adds cost to a procurement either directly or by limiting the range of potential suppliers to those who have the covenant strength to provide a guarantee. In these cases a client has incurred an additional cost, in excess of the underlying installation cost for a guarantee which offers them no protection.

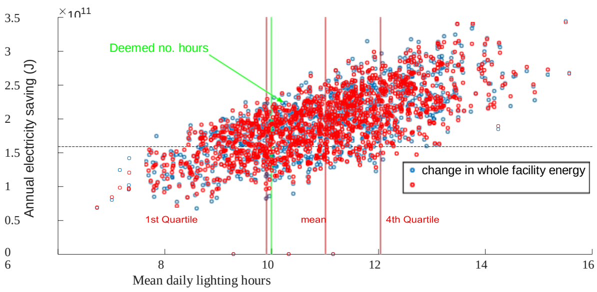

Figure 4: Distribution of annual electricity saving

Although these results might suggest that choosing a whole building approach to measuring and verifying energy savings is always in the client's interests, ESCOs may not be willing to accept the additional risks that this approach imposes on them. In particular, ESCOs are exposed to the wide ranging impacts of occupant behaviour which are outside their control. While some commentators have raised concerns relating to over-burdensome requirements for establishing baselines in Indian public sector projects (Yang, 2016), others have noted a tendency to over-simplify measurement (International Finance Corporation, 2011) and the need for greater measurement rigour (Alliance for an Energy Efficient Economy, 2017a). As Stetz et al. (2001) note, "Since the purpose of M&V is to provide assurance that project savings exist, improper and excessive reliance on stipulations may effectively nullify savings guarantees." While research on the Indian EPC market is not yet extensive, as the market expands and encompasses commodification and standardisation of projects, pressures to simplify M&V approaches are likely to increase. In the Indian market, where lack of trust is cited as the root cause of many of the barriers to growth (Alliance for an Energy Efficient Economy, 2017b), ensuring that energy savings guarantees provide the protection that clients expect is fundamental to market growth

CONCLUSIONS

Lighting retrofit projects offer the opportunity to significantly reduce the electricity consumption of existing buildings. Greater attention needs to be paid to the impact of measurement boundaries and M&V strategy on the actual value of the guarantee for clients. Choosing a low-cost option in the presence of significant uncertainty about the baseline position may lead to a sizeable proportion of clients receiving lower than expected savings with no recourse under the guarantee. EPCs rely on a guarantee of savings to create an incentive for investment in energy efficiency but clients may see savings fall short of expectations even though the guaranteed saving has technically been achieved. This effect will be greater for clients with lower overall hours of lighting use and underlines the danger of using an option A approach where patterns of use are not well understood, a concern raised by Ginestet and Marchio (2010) in relation to an AHU upgrade. It is likely that these results would apply to other energy efficiency retrofits as well and if this risk is not clearly explained to clients it is likely to lead to a loss of confidence in the concept of energy performance contracts as a whole.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the Engineering and Physical Sciences Research Council (EPSRC) `EPSRC Centre for Doctoral

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Training in Energy Demand (LoLo)' grant EP/L01517X/1. Andrew Z.P. Smith would like to acknowledge the support of the Engineering and Physical Sciences Research Council (EPSRC) `Research Councils UK (RCUK) Centre for Energy Epidemiology' grant EP/K011839/1.

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DEVELOPMENT AND ADOPTION OF VOLUNTARY LIGHTING SPECIFICATIONS TO DRIVE EFFICACY AND ASSURE PRODUCT QUALITY

Christina Halfpenny, Executive Director, Design Lights Consortium (DLC)

Keywords: SSL, lighting, standards, adoption, controls

ABSTRACT

The adoption of solid-state lighting (SSL) technology in the U.S. and Canada has been accelerated by a mechanism that differentiates products by setting minimum specifications for performance and efficacy. Since 2010, the DesignLights Consortium® (DLC) has maintained a list of third-party verified, commercial SSL products that meet certain quality and performance criteria. This list, the SSL Qualified Product List (QPL), is used by efficiency program administrators in 35 U.S. states and five Canadian provinces as well as numerous procurement offices as the basis for product selection in retrofit and new construction applications.

With over 1800 manufacturers participating in the program, the QPL has worked to drive efficacy gains of over 40% through its Technical Requirements over seven years. Since 2010, the QPL has grown from a few thousand products from only 100 manufacturers to over 280,000 actively-listed products[1]. Awareness of the QPL as a technical resource and product selection tool has become widespread among both new market entrants and established market leaders.

As the SSL market has experienced dramatic growth in recent years, the DLC Technical Requirements have evolved to provide a reliable resource for quality, high performance SSL products. There are a few critical ways the DLC uses this voluntary specification to influence product quality and efficacy improvements: (1) by working with industry experts and efficiency administrators on market changes and standards development; (2) by periodically updating requirements for QPL listing; (3) by expanding product categories to facilitate new SSL applications; and (4) by phasing out lower-performing products.

INTRODUCTION

Working with industry experts and efficiency administrators on market changes and standards development.

The QPL was developed as an efficiency tool to aid in the identification and selection of high performance SSL technology. The primary objective of the QPL was to establish a baseline for technical requirements that met criteria for efficacy and it was quickly decided that additional criteria were appropriate for overall performance. In addition to efficacy, performance requirements are in place for lumen maintenance, reliability (warranty), CRI/CCT, Zonal Lumen Density and Light Output, Power Factor and Harmonic Distortion, as well as a qualification requirement to include the demonstration of safety certification and reporting on dimming capabilities and integrated controls. Requirements are based on industry and testing standards developed by the U.S. Department of Energy (DOE) and the Illuminating Engineering Society (IES).

Products demonstrate that they meet the DLC specifications by submitting third-party accredited laboratory test results for verification of performance. Unlike the U.S. Environmental Protection Agency (EPA)'s Energy Star program[2], the DLC reviews and verifies test reports for commercial luminaires. Manufacturers pay an application fee for each submittal and the application fee supports the review of the test reports, the qualification process and ongoing specification development work. In addition to member fees for efficiency administrators who use the QPL and some grants, the majority of theprogram is supported through application fee revenue from manufacturers. All laboratories testing to technical requirements are third party and charge separate and unique fees. Laboratory testing facilities must be accredited within the effective period of review.

[1] The DLC also hosts a QPL for networked lighting controls https://www.designlights.org/lighting-controls/

[2] https://www.energystar.gov/products/how-product-earns-energy-star-label

For energy efficiency program implementers, many of whom are DLC members, the QPL provides a convenient means of determining incentive program eligibility and ensuring that the commercial lighting products installed through efficiency programs are of a sufficient quality to provide high levels of customer/end user satisfaction. The SSL QPL also serves as a highly efficient means for program administrators to identify high performance products that meet a widely recognized set of technical requirements. As a "master list" of qualified products, the QPL provides consistency in the commercial lighting market. In addition, voluntary participation in the QPL serves as a mark of quality and credibility for lighting product manufacturers in a rapidly-evolving market. For lighting designers, procurement officers, and end-use consumers, the QPL provides a means of specifying or identifying products that meet quality and efficiency requirements and that support energy-reduction efforts.

By differentiating quality commercial SSL products for the market, the DLC specification serves a wide variety of stakeholders, including efficiency program administrators, lighting product manufacturers, lighting designers, specifiers, state and local entities, procurement agents, and commercial end users. These same stakeholders, as well as technical experts from national labs and universities, are engaged in the development of the specifications. Draft specifications are developed by subject matter experts within the DLC and released publically for comment. Feedback is encouraged from industry experts and end-users alike. A formal process to assess the feedback and respond to comments is undertaken by the DLC team for each specification change and policy development effort. The outcome serves to create a balance between different stakeholder interests that can continue to drive efficacy and performance, without undermining innovation and product design or driving up costs. The stakeholder input process facilitates an understanding of the opportunities, limitations, and stakeholder goals for the specification.

For India in particular, The Bureau of Energy Efficiency and the Energy Efficiency Services Limited venture are established organizations that could benefit from adopting these voluntary standards. The standard development process is transferrable, it can be self-funded through application fees and could be managed within the BEE. Stakeholder engagement generates interest and commitment to the Technical Requirements. The standard can be adopted by government agencies such as states and municipalities, and large procurement entities, the resulting QPL can act as a filter for performance and quality as well as a tool for product selection. One example is from the Massachusetts Green Communities program encouraging LED street light adoption.[3] For manufacturers, product qualification is an attractive distinguishing factor for sales, the qualification and documentation of performance aids in the product selection process for ESCOs, procurement agents, and designers.

As India continues to identify ways to seek load reduction and increase electrification, QPL development and adoption can work to ensure compliance and consistency with advanced lighting products.

Driving efficacy and product quality by periodically updating the requirements for the QPL

As the SSL market has grows and evolves, periodic revisions and updates to the Technical Requirements are needed to guide efficacy and quality in a fast-moving industry. Updates to specifications play a crucial role in maintaining appropriate criteria that both reflect recent industry advancements and to encourage further product improvements.

Users of the QPL can rely on the specifications to reflect technology innovation and hold a minimum baseline for performance. Product requirements can be filtered by the users for further accommodations in the product selection process.

Analysis of QPL-listed product data illustrates the significant impact these specification changes can have by the demonstrated improved performance of subsequent product submissions. **Figure 1, from an internal document on the QPL impact on efficacy in the US and Canada** shows the change in average efficacy of QPL-listed products over time, and demonstrates the role that the DLC QPL has had in encouraging consistent industry improvement on efficacy performance. The average efficacy of products that are newly listed to the QPL has consistently increased at a rate of 7.3% per year since 2012, reflecting the ability of manufacturers to

[3] http://www.mass.gov/eea/docs/doer/green-communities/eap/led-street-lights-2-pager.pdf

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continually develop products with higher efficacy values. This rate of improvement noticeably increases in the periods following a specification change.

As manufacturers work to improve efficacy performance, the DLC delists products that no longer meet revised specifications. This delisting, combined with continual improvement in efficacy, leads to a constant increase in the rolling average efficacy of all products listed on the QPL over time (shown by the dashed red line in Figure 1). This is best illustrated by the average efficacy of listed QPL products at the beginning of 2014, when a delisting of products that did not meet DLC Technical Requirements V2.0 combined with efficacy improvements among newly listed products resulted in a sharp uptick in average efficacy of listed products. Note: This data does not reflect the efficacy change in Technical Requirements V4.0, which resulted in a rolling average of 30% increase in efficacy across all product categories.

While a major goal of the QPL is to encourage the use of products with high efficacy values, efficacy is not the only attribute that matters for commercial lighting products. Technical specifications can ensure that efficacy improvements do not come at the expense of other performance criteria, such as color. The U.S. and Canadian markets are sensitive to color variations in lighting, and poor color quality in fluorescent technology is has created a barrier to the adoption of advanced LED lighting.

Products must emit good-quality light which satisfies the preferences of the end user and the needs of particular lighting applications and settings. Technical specifications must consider overall lighting color performance using multiple indicators, including Correlated Color Temperature (CCT) and Color Rendering Index (CRI). While color is a highly subjective quality of lighting products, participating efficiency administrators in the U.S. and Canada have observed higher levels of customer satisfaction when upper limits are placed on CCT. In particular, customer preferences tend to favor indoor products with a CCT below 5,000K, and residential lighting applications below 2,700K. Specifications are designed to ensure that product efficacy is preserved or improved even as companies develop a variety of product offerings with different color performance characteristics.

Analysis of QPL data provides strong indications that the industry has continued to produce efficacy improvements even while offering wider product variety in terms of color performance. Furthermore, previous analysis of QPL products in 2014 showed that there are limited direct trade-offs between efficacy and color performance metrics among products on the SSL QPL. Over time, the average CRI of QPL-listed products has moderately risen and the average CCT of products has slowly declined, even as substantial improvements in efficacy performance have been made.

While the degradation or potential degradation of color performance needs to be avoided in specification development, foreign markets and cultures vary in preference for the color of light. More evidence is available to inform appropriate color temperatures for different applications, such as education, health care and office environments. Tolerances can also be established to suit the various needs of users and guidance can be developed to aid in the selection of products with the consideration of color temperature and performance.

Safety and reliability requirements were recently added to the Technical Requirements due to the prevalence of safety certifications in the U.S. and Canada and the fact that claims on product reliability were varied and inconsistently-supported among manufacturers. A requirement for product warranty was developed to address these issues, with input from industry on reasonable and responsible requirements.

Lumen maintenance, Zonal Lumen Density, Light Output, Power Factor and Harmonic Distortion are in line with industry standards and the specification can reference industry standards and testing requirements.

Finally, dimming and integrated controls have become increasingly available and offer additional energy savings opportunities. Disclosing the capability for dimming and integral controls is a part of the qualification process and including this product information on the QPL better informs the product selection process. In some cases product features and performance are reported, but are not requirements for qualification. Many manufacturers with products that offer advanced features have requested those features as requirements for the specifications, however, it is important not to limit the qualification process to criteria that only a few manufacturers can meet or over specify the functionality of the technology, which could inhibit innovations. The industry is undergoing great change and the flexibility to continue to test new functionality is an important driver for innovation.

Expanding product categories to facilitate new SSL applications

Market research suggests that SSL products will continue to gain market share, emerging as the dominant lighting technology over the next decade. Navigant forecasts robust growth for LEDs in the North American market in the coming years. Commercial LED luminaires overall are forecast to grow at a 24.6% compound annual growth rate (CAGR) from 2015 to 2020, while LED streetlights are forecast to grow at a 63.2% CAGR over the same period. As SSL technology becomes more prevalent in the variety of applications for the commercial sector, it is also important to expand the scope and diversity of product types. Production volumes continue to increase with the expanding market and as a result, cost-cutting measures are often implemented. These-cost cutting measures can have unintended consequences in both efficacy and performance. Clear specifications that are used as requirements for procurement and installation maintains the performance needed from the lighting application. The QPL acts as a compliance tool for verification of the desired performance.

The DLC QPL continues to grow as SSL technology continues to diversify in commercial applications. The QPL covers qualification for 80+ primary use categories of lighting products, including networked lighting controls (NLC) for interior and exterior applications. The DLC works with industry and performs ongoing research and consideration for new product categories in response to increased offerings from manufacturers and requests from efficiency administrators and end users. In the past, expansion of specifications to new product categories has accelerated the pace of product performance improvements and in some cases, has facilitated the development of new applications for SSL technology as manufacturers deliver new product offerings in response to the market demand that a qualified product addition helps signal.

As product offerings expand, the QPL can help not only set the baseline, but aid in identifying the top performing products for specific applications. The documentation and validation of performance specifications are important elements to establish and maintain credibility of products as well as determine appropriateness for the category or primary use of the lighting product.

For example, for a street lighting project, a qualified products list can act as a requirement for procurement to ensure product performance or a reference to compare multiple products proposed for a large scale installation. It is more than the specification that is needed for large scale adoption, it is the verification of performance to ensure that quality is considered in the product as well as reliability. Additionally, a QPL can provide guidance to aid in the product selection for large scale procurement of street lighting systems that work in the geographic area while addressing unique cultural preferences. Mexico implemented a large municipal street lighting program with unfortunate results of fixture failure, despite having a specification in place.[4]

The SSL QPL works alongside a Qualified Products List for networked lighting controls (NLCs), and the system capabilities are required and some disclosed through reporting. This both enables the comparison of systems and establishes a baseline of functionality that is understood within the specifications.

Phasing out lower performing products

When the specifications change, products that no longer meet the performance requirements are systematically delisted from the QPL. This provides users that reference and rely on the QPL with the tools they need to exclude these products from their programs.

This systematic updating of specifications is critical in an industry as rapidly-evolving as commercial solid-state lighting. The delisting process enables a healthy and competitive commercial lighting market by providing users assurances regarding the energy performance and quality of included products. It also rewards lighting manufacturers for technological improvement and high quality manufacturing by differentiating their products from the underperforming offerings of their competitors.

Largely as a result of increased efficacy requirements and subsequent delistings, the QPL has seen a distinct generational turnover of products over the course of the program's history.

By differentiating quality commercial SSL products for the market, the DLC has enabled the SSL market's accelerated pace of growth and incentivized continuous improvements in the commercial lighting industry.

In particular, past changes to the DLC Technical Requirements have increased the rate of efficacy improvements, phased out lower-performing and outdated products over time, and provided a means for market leaders to be distinguished through the introduction of the *DLC Premium* tier for QPL listing.

CONCLUSION

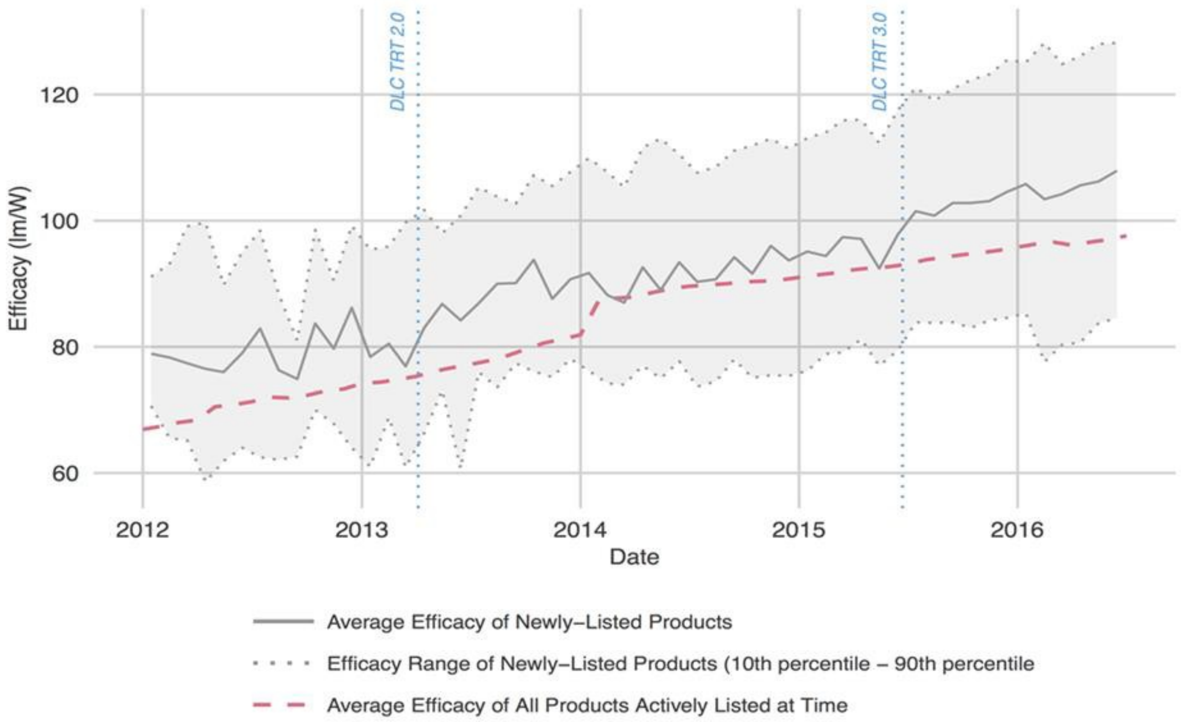
Through the widespread adoption of a voluntary standard, SSL efficacy and performance has a consistent baseline for industry to meet. The specification creates consistency across the industry and provides credibility to manufacturers of high quality lighting products. The efficacy requirement for the QPL has increased an average of 40% (an overall average increase of over 30 lm/W) over 5 years, which has manifested through thousands of installations.

The SSL industry as well as networked lighting controls continue to grow and the risk for poor quality products also grows. Standards help to mitigate the risk by creating a baseline for performance. The voluntary approach developed by the DLC through the stakeholder engagement process and the widespread adoption of the specifications has been found to be a quintessential tool for efficiency administrators, procurement agents, and ESCOs.

India has seen tremendous success with the EESL LED lamp program and is aggressively working to convert and install LED street lights around the country. As building development continues at rapid rates, compliance with codes and standards can be very challenging.

A specification for commercial lighting applications and a subsequent qualification process has a push-pull dynamic where purchasers require it and manufacturers begin to sell the qualification as a third party indicator of quality. Manufacturers, government officials and lighting experts can be engaged to design the most appropriate requirements for the market and the culture, committing to the specification as a result.

Ongoing consideration and of efficacy and product quality ensure that a transformation to SSL is sustaining and a QPL for end users can accelerate the adoption of high performing, commercial SSL technology.[5]



[5] Figure 1: Measured efficacy of all products listed to the QPL through mid 2016. Drawn from internal document, QPL data.

ESTABLISHING A COMMERCIAL BUILDINGS ENERGY DATA FRAMEWORK FOR INDIA – APPROACHES, USE CASES AND INSTITUTIONS

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ABSTRACT

Buildings account for over 40% of the world's energy consumption and are therefore a key contributor to a country's energy as well as carbon budget.

Understanding how buildings use energy is critical to understanding how related policies may impact energy use. Data enables decision making, and good quality data arms consumers with the tools to compare their energy performance to their peers, allowing them to differentiate their buildings in the real estate market on the basis of their energy footprint. Good quality data are also essential for policy makers to prioritize their energy saving strategies and track implementation. The United States' Commercial Building Energy Consumption Survey (CBECS) is an example of a successful data framework that is highly useful for governmental and non-governmental initiatives related to benchmarking energy forecasting, rating systems and metrics, and more. The Bureau of Energy Efficiency (BEE) in India developed the Energy Conservation Building Code (ECBC) and launched the Star Labeling program for a few energy-intensive building segments as a significant first step. However, a data driven policy framework for systematically targeting energy efficiency in both new construction and existing buildings has largely been missing. There is no quantifiable mechanism currently in place to track the impact of code adoption through regular reporting/survey of energy consumption in the commercial building stock. In this paper we present findings from our study that explored use cases and approaches for establishing a commercial buildings data framework for India.

INTRODUCTION

Enhancing energy efficiency of the commercial building stock is an important aspect of any national energy policy. Understanding how buildings use energy is critical to formulating any new policy that may impact energy use. During 2002-12, the services sector in India registered an annual growth rate of about 10% and accounted for over 60% in gross value addition in 2012 – one of the highest rates of growth in this sector in recent times in the world (MOSPI 2015, GOI 2015). In view of this accelerated growth, and given that buildings account for the bulk of electricity consumption in the commercial sector as a whole, there is significant potential to improve the sector's energy performance through improvements in buildings. This paper presents specific use cases that would benefit from national commercial building energy data collection, outlines potential institutional mechanisms for targeting these use cases, provides some discussion on key performance indicators (KPIs) relevant to these use cases, and briefly outlines the approach to establishing a commercial buildings energy data framework in India.

CONSIDERED USE CASES

The study considered a set of potential use cases to develop a comprehensive and expandable commercial buildings data framework for India that will have the possibility to transform policy making and the tracking of its impact on the commercial buildings stock. (Iyer, M. et al. 2016) The potential use cases address the commercial building sector at the city and building level, while encapsulating both new and existing buildings. At the city level, the use cases helps determine the commercial building sector energy consumption and energy consumption by EE buildings (ECBC, green rating systems complied buildings), including the existing retrofitted buildings. The three use cases considered in this paper are outlined in Table 1 on the following page. The priorities were determined based on an understanding of observed building energy data uses in India, stakeholder discussions, as well as other policy

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based on an understanding of observed building energy data uses in India, stakeholder discussions, as well as other policy needs including code updates, evaluation and implementation guidelines, and the more recent developments such as Smart Cities Mission.

The Commercial Building Energy Consumption (CBECS) Survey conducted by the U.S. Energy Information Administration is an excellent example of a national survey that has found success in terms of its ability to serve a wide range of use cases- from national to local, regulations to market transformation programs and codes. CBECS is relied upon by governmental policymakers and other stakeholders for developing metrics and rating systems (for example, ENERGY STAR, which in turn is the basis for the U.S. Green Building Council's LEED standard and city-based building efficiency programs, among many others), benchmarking (for example, the Better Buildings Challenge and the 2030 Challenge), tracking industry progress in energy efficiency, and energy forecasting (for example the National Energy Modelling Systems (NEMS)). Careful consideration of the desired use cases and ensuring that the data collected are conducive to these use cases is paramount.

KEY PERFORMANCE INDICATORS (KPIs) AND DATA COLLECTION CONSIDERATIONS

The KPIs that are useful to assess the performance of a building are generally developed and prioritized based on specific use cases and the needs of the various stakeholders. The parameters considered in this study for the data collection template were based on their collection feasibility.

When applying use cases to improve the energy efficiency of buildings, particularly when setting building and/or city benchmarks and rating systems, it is important to categorize buildings based on several parameters such as climate, building age, building use, etc., as KPI benchmarks and targets can vary based on these parameters. For example, KPI targets for hotels would be different from targets for hospitals or offices. Further, KPI targets for 5-star hotels may be different from those for 3-star business hotels. Table 2 recommends parameters to be included in order to categorize commercial buildings.

Table 1: Use Cases Classification

Use Cases	New Building	Existing Building	Priority	Primary Audience
Develop, Update, and Implement Building Energy Codes and Guidelines	●	○	High	BEE, BIS*, MOUD, ULBs
Develop and Update Building EE Rating and Labels	○	●	High	Rating organizations (e.g. BEE, USGBC*, IGBC*, GRIHA*)
Modeling the Building Sector Energy Consumption; Understanding the Impact of Buildings at the City Level	●	●	Medium	MOUD*, MoP*, Smart Cities Mission, NITI Aayog*, BEE*, ULBs*
● Fully applicable ○ Partly applicable NA Not applicable				

Table 2: Categorization of Parameters for Buildings

Categorization Parameter	Description
Climate Zone	Hot & Dry, Warm & Humid, Composite, Moderate, Cold
Activity	Primary use of building, e.g. Hospital, Hotel, Educational establishments, Retail establishments, Restaurants, Offices etc.
Activity Sub-category	Hotels: Heritage, Luxury, Budget, Resort. Hospital: Single-Specialty, Multi-Specialty, Super-Specialty, Clinics, Diagnostic Labs Retail Establishments: Shopping Malls, Large, Medium, Small Retail Stores Educational Establishments: Institutions of Higher Education, Schools Offices: Information Technology (IT), Information Technology enabled Services (ITeS), Public, Non-IT
Age*	Building age, based on specific ranges, e.g. 0-5 years, 5-10 years, 10-20 years and above 20 years
** Building age is an important parameter in Indian context as the country has been recently experiencing rapid rise in air-conditioned buildings along with incorporation of building energy conservation codes (ECBC) and green building rating systems*	

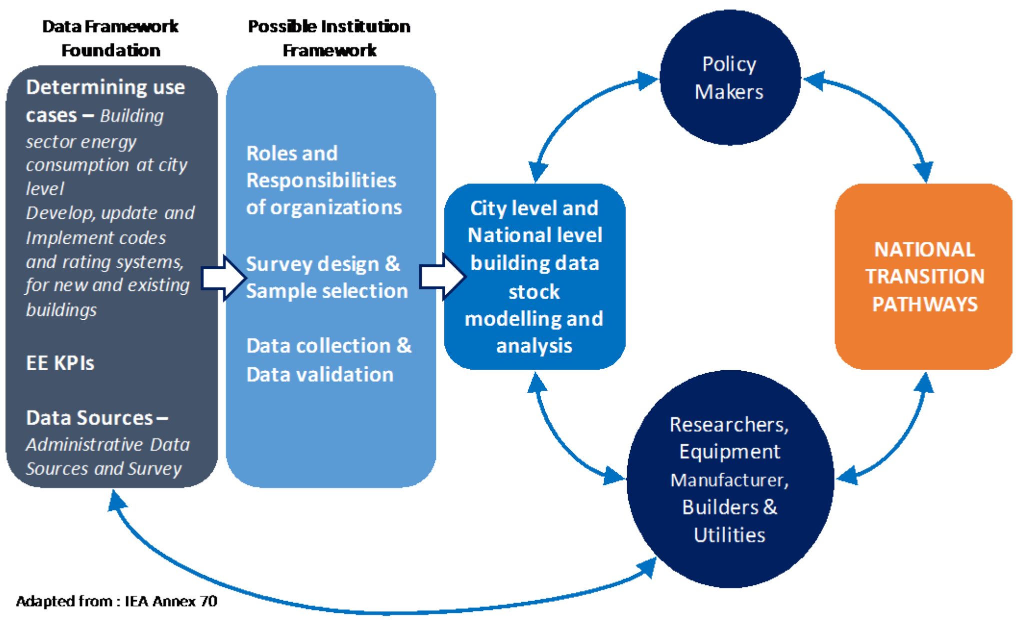
Data collection for building energy analysis is almost always resource intensive, time consuming and highly prone to data quality issues. Therefore, the scope and priorities for data collection should be carefully assessed and determined based on several key considerations, primarily the intended use cases and allocated resources. Broadly, given the use cases outlined in Table 1 above, the following categories of data would be required for the commercial building stock:

- Categorical data such as building activity type, age and location.
- General building-level information such as contact information, size, occupancy characteristics (e.g. typical operating house, number of daily employees/visitors). This category also includes data fields specific to building types, e.g., number of hotel rooms, number of hospital beds, types of meals served in restaurants.
- Whole building energy consumption for electricity and fuels.
- End use system characteristics for cooling, heating, lighting, water pumping, cooking and service equipment. Data fields for this category include system capacity (e.g. total cooling connected load), demand (e.g. total hot water requirement per month), efficiency (e.g. lighting power density), and system type.

ESTABLISHING AN INSTITUTIONAL FRAMEWORK FOR DATA COLLECTION AND DISSEMINATION

A robust institutional framework is essential in order to effectively facilitate data collection and analysis, and reporting and tracking of building stock energy performance(see Figure 1 below). This framework can help ensure standardized reporting of data and ultimately a coherent data outcome. A comprehensive and current building energy use dataset, among other things, enables (1) Adoption of superior energy-efficient building design, operation and maintenance practices, and (2) Better specification and procurement of end-use equipment and systems.

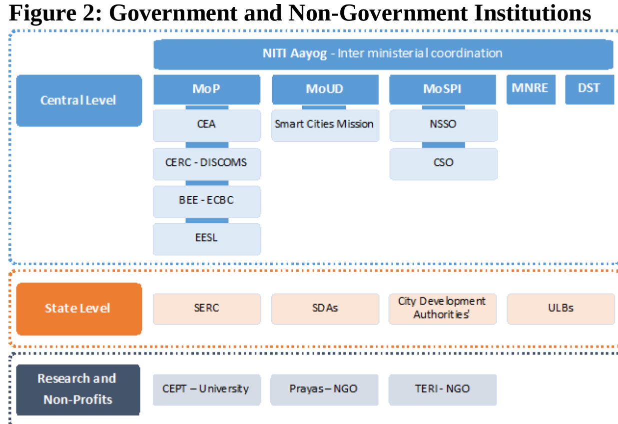
Figure 1: Commercial Building Data Framework



Institutions

Effective and comprehensive analyses and modelling of energy use and energy performance of India's commercial building stock requires data on energy use, building structure and equipment and users/occupants. At present no single institution collects, analyzes and disseminates data on building energy performance. However, several government ministries and departments collect some data on energy, buildings and appliances and equipment that is required for administrative purposes within their respective departments. Figure 2 below summarizes government institutions at the central, state, and research or non-profit levels that collect such data.

Figure 2: Government and Non-Government Institutions



The benefits of current and comprehensive data on commercial building energy consumption and performance are far-reaching and extend beyond government initiatives and programs. Stakeholders at the city, state and national levels would benefit from such data in various ways. Additionally, they could be key contributors by providing data and expertise to institutionalize building energy performance reporting. Such stakeholders are described below.

- Utilities and DISCOMS could provide consumer data such as electricity usage, contract demand, connected load, electricity from DG and RE sources, as well as the expertise in collecting and analyzing such data.

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- Facility managers and ESCOs, responsible for managing facility costs and energy consumption could share collected/monitored data on building energy consumption, equipment energy performance, building activities and occupancy.
- Real Estate Developers, Equipment and Building Materials Manufacturers Developers and manufacturers could support the program by assisting in data collection on buildings and equipment, especially given that they may periodically conduct market surveys in order to assess needs.

Table 3 and Table 4 on the following pages present an overview of the current data collection, analysis and dissemination functions of various organizations.

LEGISLATION (ACTS POLICIES & REGULATIONS)

Providing state and city governments with the mandate and infrastructure to collect, analyze and publish building energy performance data is a critical step in institutionalizing a large-scale data collection effort. The Energy Conservation Act (2001) classifies buildings with connected loads of 500kW or more, or contract demand of 600 kVA or more as Designated Consumers (DC), and gives state governments the authority to direct them to perform periodic energy audits. However, the majority of commercial buildings fall below the threshold connected load and contract demand to be considered a DC, and thus are not required to comply.

Table 5 (see below) provides an overview of the existing legislation that pertain to data collection,, analysis, and dissemination relevant to commercial building energy use. As discussed further in "Recommendations", these existing policies could be utilized to institutionalize data collection on energy use for the entire commercial buildings sector.

Table 3: Government Institutions' Collection & Dissemination of Building Energy Data

Institution	Data Collection, Analyses & Dissemination
NITI Aayog	• Formulates National Energy Policy • Develops and manages India Energy Security Scenarios (IESS) tool for modelling energy supply and demand scenarios • Exploring how to implement Energy Data Management at National level • Signed MoU's with IEA and EIA to improve Energy Data Management
Ministry of Power (MoP)	• Has statutory bodies, (CEA and BEE), with specific mandates and functions that collect, analyze and disseminate data
⇒ Bureau of Energy Efficiency (BEE)	• Collects energy consumption data from "designated consumers" in the industry sector • Data collection on building energy performance under ECBC is voluntary • Collects sales data on labelled appliances • Limited public access to data; specific data required for research can be requested
⇒ Central Electricity Authority (CEA)	• Collects data on electricity generation and consumption • Has mandate to publish electricity data • Reports on electricity generation and consumption are available on their website
Ministry of New and Renewable Energy (MNRE)	• Collects data on RE appliances availed under schemes for subsidy, incentives, loans; however, there is no tracking of RE appliances bought outside the scheme

Institution	Data Collection, Analyses & Dissemination
Ministry of Statistics and Programme Implementation (MOSPI)	• Collects some energy consumption data through Census and National Sample Survey Office (NSSO), for e.g. electricity, fuel consumption and appliances in households • Collects enterprise level data about building demographics through economic census conducted every 5-7 years. • Provides support in designing surveys, data collection & data analysis • Has mandate to disseminate statistics • Publishes Annual Energy Statistics Report • Central Statistics Office (CSO) disseminates data to international bodies (UN, IMF) • The Annual Survey of Industries (ASI) collects some energy data such as electricity consumed, electricity generated, fuels purchased and consumed. • An upcoming Annual Survey of Service Sector (ASSS) could be used to collect energy data on commercial buildings
⇒ National Statistics Commission (NSC) *(NSSO and CSO comes under NSC)*	• Recommends measures to improve statistical system and data collection in India
Ministry of Urban Development (MOUD) ⇒ Smart Cities Mission	• Aims to improve public services, accountability and transparency through the use of technology, providing information and services online
State Designated Agencies (SDA)	• Some SDAs identify buildings with a relatively larger contract demand as "designated consumers" and mandate energy audits every year, alongside collection of detailed energy consumption data
Urban Local Bodies (ULB)	• Urban local bodies collect detailed data on building structure, envelope, area, age and activity for planning approval and for collection of property taxes
Department of Science and Technology (DST) ⇒ National Informatics Centre	• Responsible for portal data.gov.in through which NDSAP is being implemented
EESL	• Collects data on LED street light installations and LED bulb distribution for households • Publishes *SLNP Dashboard* with up-to-date information on total LED streetlight installations per state, average electricity saved per light per day, total electricity saved per day, CO_2 emission reduction per day and avoided capacity • Publishes *National Ujala Dashboard* with up-to-date information on number of LED bulbs distributed per state, total electricity saved per day, total cost savings per day, CO_2 emission reduction per day and avoided peak demand

Table 4: Other Organizations' Collection & Dissemination of Building Energy Data

Institution	Data Collection, Analyses & Dissemination
TERI (Non-profit)	• Publishes *TERI Energy and Environment Data Directory and Yearbook*, which includes high level data on commercial and household energy consumption
Utilities	• Utilities collect energy consumption and TOD consumption for billing purposes, which is accessible online to consumers • Some utilities, such as Tata Power Delhi Distribution Limited, conduct surveys to collect energy, building and equipment data
ESCOs	• ESCOs collect detailed energy information when conducting audits and implementing EE projects
Green and NZEB Buildings	• Infosys and the CII-Godrej buildings have instituted extensive Enterprise Energy Management programs for which they collect and analyze building energy data

Table 5: Legislation Supporting Data Collection and Dissemination

Act / Policy / Regulation	Data Collection & Analysis	Data Dissemination
Energy Conservation Act, 2001	• BEE & SDAs can recommend any energy user as a "designated consumer" (DC) • Gives BEE & SDAs the mandate to direct "designated consumers" to perform energy audits and furnish energy consumption data periodically	• No specific provisions mandating data dissemination
Electricity Act, 2003	• Mandates CEA to collect electricity data • Mandates all entities involved in generation, transmission, distribution of electricity to provide data required by CEA	• Mandates CEA to publish electricity data
• CEA - Furnishing of Statistics, Returns and Information (Regulations, 2007, MoP)	• Mandates all entities involved in generation, transmission, distribution of electricity to provide data in a timely manner in a specified format	
• Energy Conservation – Form and Manner and Time for Furnishing Information With Regard to Energy Consumed and Action Taken on Recommendations of Accredited Energy Auditor (Rules, 2008, MoP)	• DCs are expected to report on energy consumption annually (within 3 months of end of financial year) • Reported data must be authenticated by energy manager appointed by DC and furnished to BEE	• No specific provisions mandating data dissemination
Census Act, 1948 amended 1994	• Mandatory for all citizens to participate • Includes some information on household electricity & fuel consumption, appliances	• Mandates publishing of census data
Collection of Statistics Act, 2008	• Grants central and state governments the power to collect statistics on economic, demographic, social, scientific and environmental aspects • Informants are bound to furnish the required data; refusing to furnish data is punishable • Authorizes statistics officer to access any record or document in the possession of the informant in order to collect the required data	• Mandates confidentiality when publishing data
National Data Sharing and Accessibility Policy (NDSAP) (2012, Department of Science and Technology)	• Aims to set standards for data, metadata, data management and technology • Facilitates data access and sharing among the public and government departments to avoid duplication of data collection • Government ministries and departments required to upload high value data sets within 3 months of policy notification, and thereafter every quarter	• Applies to all data and information generated, collected and archived using public funds; • Recognizes that non-sensitive government data can be shared with civil society – "all shareable data to be made available on an as-is where-is basis" • Recommends a technology-based culture for data sharing and access, with standards for open access, restricted access and other levels of access

RECOMMENDATIONS

Mandate for Building Energy Performance Data Collection and Dissemination

Existing provisions within the Energy Conservation Act, 2001 and the Collection of Statistics Act, 2008 could be used to identify all commercial buildings as "Designated Consumers" and mandate the collection and reporting of all data related to building energy performance.

The National Data Sharing and Accessibility Policy (NDSAP), Department of Science and Technology, could be utilized to support the dissemination of building energy performance data in a timely manner to enable both the government and the public to access and use such data.

A "One-Stop" Information Portal for Energy Data Dissemination, Analysis and Modelling

Creating a single portal for all building energy performance data would be the first step in making the data easily accessible to all branches of the government and the public. This would also enable the creation of standards and processes for metadata, as well as data collection, validation, transfer and protection.

NITI Aayog could lead this effort with the support of various ministries and governmental and non-governmental organizations. NITI Aayog already formulates the National Energy Policy and develops and manages the IESS energy modelling tool. NITI Aayog is also exploring the idea of Energy Data Management and has signed MoU's with IEA and US DOE EIA to help develop such a program.

MOSPI and the National Informatics Centre (NIC), Department of Science and Technology, both of which disseminate data to the public, could pool their efforts and expertise in building a common Building Energy Performance Data System under the purview of NITI Aayog.

CONCLUSIONS

A viable institutional framework will help facilitate regular and coordinated data collection, analysis, creation of policies, and evaluation of policies followed by policy updates to achieve the desired impact. The institutional framework identifies the roles and responsibilities of relevant ministries and organizations, lays down procedure for survey selection; and outlines data collection and validation for data driven policies through ECBC, Smart Cities Mission, Green Building Rating tools and data Disclosure mandates. Following are some key outcomes from the study:

- NITI Aayog is well positioned to form an inter-ministerial steering committee and can also request assistance from international organizations;
- MOSPI's statistical expertise in designing samples and conducting surveys and collaborative spirit could be tapped to help the leading organization with data collection;
- DISCOMs which are identified as DCs under PAT project could be strategically used to support data collection;
- Limited budgets and resource constraints impede the cause of building sector data collection and analysis to some degree.

The launch of India Smart Cities Mission will help establish stringent EE building sector policies and their methodical implementation. India's NDCs to address climate change also outlines EE in the buildings sector as a mitigation strategy for climate change. Below are key recommendations to successfully institutionalize the data framework:

- Mandates for data dissemination: Under EC Act and Statistical Act, organizations like BEE and MOSPI have been disseminating data; however, additional mandates could catalyze a more systematic data dissemination effort. Some examples include:
  - Through Indian Smart Cities Mission, energy consumption related data disclosure can be mandated. This could be initiated by MOUD at the central government level or through Urban Development departments at the state level;
  - Extending the existing mandate surrounding ECBC compliant buildings in various states should enable data collection and dissemination from these buildings as part of ECBC compliance process;

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- Develop a robust strategy to collect existing data: No new legislation is required to collect existing data. DISCOMs already have building energy consumption data and ULBs have building category & structure data. However, establishing a mechanism to enable independent data collection at the city or state level to be channeled into a national building data collection framework may require the involvement of a nodal agency at the national level. A government entity should take charge and execute this initiative. Following are some key steps for this entity:
    - Utilizing existing data with the DISCOMs and ULBs more effectively -- DISCOMs and ULBs have their unique identification numbers for each building. They could be directed to standardize their identification numbers, which can enable database design and simplify data extraction and validation for use by different organizations;
    - Post collection of data from utilities and ULBs as a first step; a survey can be conducted for more detailed building energy consumption information on a subset of buildings. To simplify the data collation and compilation process, utilities and ULBs with data in an electronic format could be targeted first.
    - Large organizations like hotels/ hospitals chains, which have a presence across the country, can be requested to supply data under a voluntary/mandatory buildings data disclosure initiative.
- Allocate budget and technical resources for data collection: Before initiating a large scale data collection effort, develop budget estimates and find funding sources.
- Two-tiered Approach to Data Collection - City and National level:
    - A national level effort could be implemented either through new commercial buildings survey, or through MOSPI's proposed Annual Survey of Services Sector (ASSS) encompassing comprehensive energy related data from buildings/building units. As a second tier, a more detailed but smaller survey can be conducted in select cities to obtain detailed energy consumption data from individual buildings.
    - City level efforts could begin with a few select cities in different regions/climate zone/ tier types, which can be scaled up to the national level through a bottom up approach.

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TRANSITION TO ENERGY EFFICIENT BIOMASS COOK STOVES FOR SUMMATIVE POINT SOURCE EMISSIONS REDUCTION AND IMPROVED RESPIRATORY HEALTH

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Keywords: Energy Efficient biomass cook stoves, Particulate matter, Spirometry, Solid bio-fuels

ABSTRACT

Globally 40% of the world population (approx. 2.6 billion) rely on use of unprocessed solid biofuels for cooking while in India 67% of overall households use solid biofuels (Census 2011 analysis). The household generated point source emissions on using energy efficient improved cook stoves have global technical potential for reduction of 1 Giga ton of CO_2 emissions annually. Indoor air pollution due to improvised biomass cook stoves and use of solid biofuels is a source of respiratory health hazard and has been ranked as a major causative factor contributing to national burden of disease by WHO. The use of solid biofuels puts pressure on the forest and grassland cover and discriminately adds to the drudgery of women and children. Cleaner energy sources still remain beyond the reach of the major populace due to socio-economic reasons and a rapid transition to energy efficient biomass cook stoves is a recognised alternate to reduce emissions.

This paper examines links of solid biofuels with the respiratory health of the persons involved with cooking (cooks). The work is based upon a study conducted in rural households of Jaipur district. Symptomatic (questionnaire based) and diagnostic (spirometry) methods were deployed to assesses the measured lung function parameters of cooks (n=90) and the non-cooks (n=94) due to exposure to particulate matter ($PM_{2.5-1}$) .The size characterization of fine particulate matter was made using precision aerosol monitor. Infrared thermal imaging and spatial temperature gradients were measured to assess the temperature asymmetry in proximity to traditional cook stoves in rural households.

The study could establish a significant increase in the morbidity to respiratory disorders in cooks compared to those who are not directly involved with cooking in rural households that use unprocessed solid biofuels for cooking. It further indicates that the elevated temperatures in close proximity of traditional cook stoves may exacerbate respiratory disorders caused due to exposure to fine fractions of particulate matter.

INTRODUCTION

- **A CASE FOR ENERGY EFFICIENT BIOMASS COOK STOVES**

The household air pollution (HAP) often decimated as a 'point source' in air emissions inventory has emerged as a dominant source for exposure as majority of the time is spent indoors beside its summative contribution to global emissions. Black Carbon (BC) generated from biofuel use is of importance due to its global warming potential and major contribution of BC in India has been attributed to bio mass cook stoves. (V. Ramanathan et. al., 2008). The energy efficient cook stoves have the capability to significantly reduce the BC generation. In a comparative study on BC generation by traditional mud stove and improved energy efficient stoves it has been estimated that indoor cooking time BC were 50 to 1000 µg m^{-3} for the traditional mud cook stove while 5–100 µg m^{-3} by the forced draft stove. (Abhishek Kar et al., 2012)

Globally 2.85 billion people and 166 million households (67%) in India use solid biofuels for their cooking needs (ESMAP, 2015, Census of India 2011; Global alliance for clean cook stoves, 2013). The proportion is predominately higher in rural areas where unprocessed solid biofuels remain a popular choice.

The Global Burden of disease study (WHO, 2012) has identified 15 risk factors responsible for the maximum disease burden. In India the household air pollution (HAP), mainly due to use of solid biofuels, and ambient particulate matter are the 2nd and 7th highest causative factors respectively .Further lower respiratory infection is amongst the top three factors for disability adjusted life years (DALY). Use of rudimentary solid biofuels results in yearly mortality of 4.3 million people globally (WHO, 2014).

Solid biofuels use for cooking needs in inefficient cook stoves are not only a source of health hazard but

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they also generate global warming pollutants *e.g.* black carbon (BC) from cooking and space heating itself contributes to nearly 25% of total BC globally generated.(H.Rehman et al., 2011).The consumption of biofuels leads to deforestation and localized environment degradation. Emissions at scale significantly contribute to outdoor air pollution (World Bank, 2011) beside women and children who are normally assigned the task of wood collection are exposed to accidents and drudgery.

The pervasive use of non /semi commercial solid biofuels by the majority masses thus emerges as an important sector in itself for energy efficiency interventions and merits a focused attention for sustainable transition to improved cooking solutions and converging benefits of better respiratory health, regional environment and global climate.

- **INDOOR AIR QUALITY AND RESPIRATORY HEALTH HAZARDS**

BIOFUELS AND POLLUTANTS

The use of unprocessed solid bio fuels; use of conventional cook stoves , non-provision of grates , inadequate ventilation and pollutant discharge arrangements all lead to accumulation of combustion related pollutants within the small confinement of kitchen area. The combustion of solid fuels produces smoke , which is potentially harmful as it contains a mixture of hazardous pollutants like fine particulate matter ($PM_{2.5}$), CO, benzo[a]pyrene, formaldehyde, nitrogen-di-oxide (NO_2), polycyclic organic compounds and metals such as arsenic (Shen G.*et al.*, 2014, Lissowska et al., 2005) . Domestic cooking is an important source of house hold air pollution and is associated with significant morbidity and mortality (Meera Subhramanium, 2014, Boman et al., 2003). The biomass cooking is characterized by incomplete combustion and generates a large number of injurious primary carbon particles of finer fractions (Dickensen et al*.,* 2015, WHO, 2014).

HEALTH IMPACT OF POLLUTANTS

The sub-micron, ultrafine (<1.0 μm) particles which due to their small size and large surface area , carry toxins like VOCs & PAH with high pulmonary deposition efficiency and hence, are considerably important for respiratory and cardiovascular disorders. The fine ($PM_{2.5\ -1.0}$) and ultra-fine(<PM_1) particulates can carry large amounts of adsorbed or condensed toxic air pollutants such as oxidant gases, organic compounds, and transition metals (Oberdörster 2001) deep into the alveolar region(W.J.Martin et al.,2014, Purvis et al., 2003 , Kleiman et al., 1999, Espinosa et al., 2001).

ASSESSMENT OF RESPIRATORY HEALTH

The extensive use of solid biofuels in inefficient cook stoves has a direct linkage to the respiratory health of the exposed individual i.e. cook. An assessment of the pulmonary functions of the cooks can thus aid in analysing the direct effects of the pollutants and a comparison of lung functional parameters with non-cooks can bring out the difference due to exposure. The respiratory health of cooks in rural areas has mostly been reported based on symptomatic studies; however the literature on diagnostic studies is limited.

This study thus aims to provide details on respiratory status of cooks using unprocessed biofuels during cooking activity in rural areas of Rajasthan deploying both the diagnostic (spirometry) and symptomatic (American Thoracic Society based questionnaire) tools for assessment of pulmonary responses. Further, studies have reported the modifier effect of elevated outdoor ambient temperature on PM in exacerbation of respiratory and cardiovascular disorders and related hospital admissions and mortality in urban environment through time series studies (Freitas et al., 2009; Li et al., 2012, Alfésio L. F. Braga et al. 2002). In case of rural households, the close proximity of the cook during cooking activity to the stove (mainly traditional mud plastered) leads to exposures to much higher temperatures than the ambient. This thermal asymmetry compounded with higher PM due to use of unprocessed solid biofuels is therefore of significance in light of above studies.

METHODS

The study presented in this paper was conducted in rural areas of Jaipur, in the state of Rajasthan, located in western part of India. Rural households with different kitchen configurations ; kitchen inside living area, kitchen with half partition with living area, open kitchen, fully separated kitchen; were covered in the study. The respiratory disorders were conjunctively assessed by deploying symptomatic (questionnaire based) and diagnostic (spirometry based) methods. The modified Hindi language version of questionnaire developed by the American Thoracic Society (ATS), Division of Lung Disease (DLD) (ATS-DLD,1978) was administered for carrying out health survey of the subjects. The questionnaire is intrinsically designed to closely assess the occupational aspects and impacts of air pollution on human respiratory system while eliminating the effects of any predisposition to respiratory diseases. The diagnostic interventions involved assessment of key lung function parameters using portable spirometer. The Statistical Package for Social Science (SPSS) version 18.0 has been used to ascertain that causal linkages are established through appropriate statistical analysis of the data. Infrared thermal imaging and spatial temperature gradients were used to assess the temperature asymmetry in proximity to traditional cook stoves in rural households and size characterization of fine particulate matter was made using precision aerosol monitor (Grimm). GRIMM portable aerosol monitor (model 1.108) is an aerosol spectrometer capable of continuous measurement of particles in the air. It has volume controlled air flow (1.2l/m) with an integrated replaceable PTFE filter. Two optical sensors provide near real-time particle number concentration measurements at a maximum logging rate of 6 seconds. The range covered by the instrument is 0.3-20 µm over 15 size distribution channels. These measurements by GRIMM are determined in one of two basic modes, particle concentration (counts/liter) or in mass concentration (µg/m^3). It is very useful instrument for measuring the particle number concentration and their size distribution with a reproducibility of +-3%. However, being a particle counter it cannot directly measure the particle mass concentration. Performance of GRIMM for measurement of fine particles has been acknowledged in past studies. (Dae Seong Kim et al. 2014)

RESULTS AND DISCUSSIONS

SPIROMETRY

The Spirometry tests are widely recognised pulmonary function (PF) diagnostic assessment tests which are used to noninvasively ascertain the prevalence of air way diseases such as asthma, bronchitis &emphysema and to gauge the extent of lungs impairment. A Spirometer ascertains the lung volume (inspired/expired), the time taken to exhale the volume, flow rate and compares measured lung functions with known standards. The primary variables in spirometry are described in Table1.0.The internationally standardized spirometry test evaluates forced expiration after a complete inhalation, and determines forced vital capacity (FVC) and the forced expired volume during the first second (FEV1).

***Table 1*: Primary Variables in Spirometry**

Abr.	Name	Unit	Description
FVC	Forced vital capacity	Litre	Represents maximum volume of air exhaled after a maximal inspiratory manoeuvre.
FEV_1	Forced expiratory volume in 1 Sec.	Litre	The FEV1 corresponds to the maximal volume of air exhaled in the first second of the FVC manoeuvre ,
FEV_1 / FVC	FEV_1%	Ratio	This is the ratio of FEV_1 to FVC. In healthy adults this should be approximately 75–80%.
PEF R	Peak expiratory flow rate	Litre/ Sec	This is the peak value of the expiratory manoeuvre.
FEF 25–75% or 25–50%	Forced expiratory Flow 25–75% or 25–50%	Litre/ sec	It is the flow measured between 25% and 75% of the forced expiratory man oeuvre
TV	Tidal volume	Litre	During the respiratory cycle, a specific volume of air is drawn into and then expired out of the lungs. This volume is tidal volume.

RESPIRATORY HEALTH

In the subject group of the study, all the cooks were females. Table 2 shows the statistical analysis of all the subjects in different age groups based on reported respiratory symptoms.

The incidence of reported symptoms is more in case of cooks except for phlegm in the case of non-cooks (> 40 years). The higher percentage of reported symptoms clearly reflects the adverse effects of pollutants on cooks compared to non-cooks.

Respiratory Symptoms	<25 Years			25-40 Years			>40 Years		
	Cooks (n=28)	Non-Cooks (n=28)	p value	Cooks (n=29)	Non-Cooks (n=39)	p value	Cooks (n=33)	Non-Cooks (n=27)	p value
Wheezing	3.6	0	0.50(NS)	20.7	15.4	0.40(NS)	42.4	40.7	0.55(NS)
Coughing	39.3	21.4	0.12 (NS)	75.9	23.1	0.00** (S)	54.5	48.1	0.40 (NS)
Phlegm	7.1	7.1	0.69 (NS)	31.0	23.1	0.32 (NS)	54.5	70.4	0.16 (NS)
Dyspnea	10.7	0	0.12 (NS)	10.7	0	0.12 (NS)	24.2	7.4	0.08 (NS)

***Table 2:* *Comparison of cooks & non- cooks based on respiratory symptoms*.**

NS = Non Significant, Significant at 0.01 level**

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The spirometry results of all subjects are given at Table 3 for the important pulmonary parameters; forced vital capacity (FVC), the forced expiratory volume (FEV_1) for air exhaled in 1 second of FVC manoeuvre and the percentage ratio of FEV1to FVC which assesses obstructive or restrictive respiratory diseases.

Table 3*: *Average Value of Lung Function Parameters of all subjects

Lung Function Parameters	Cooks(n=90)	Non-Cooks(n=94)	z value
FVC% Predicted	76.58±12.25	83.05±15.84	0.84(NS)
FEV_1% Predicted	86.82±7.31	87.18±15.91	0.00**
FEV_1/ FVC (%)	82.19±7.48	89.94±8.26	0.00**

NS = Non Significant, Significant at 0.01 level**

There is a high level of significance for the lung function parameters FEV1 % predicted and the ratio FEV1/FVC %. The average values of key pulmonary parameters for cooks are also lesser than those of non-cooks, which clearly indicates the difference due to short term and long term exposure due to pollutants. In itself these values are not critical at this stage however on persistence of the exposure these may result in severe chronic respiratory disorders. There are several studies (Bruce et al., 2000; Boman et al., 2003), which have reported pollutants as the driving factor for reduction in all pulmonary function test parameters.

The observed cooking practices in rural households involve squatting on floor at reachable proximity to traditional cook stoves. The cooks are thus exposed to temperatures in a range of 33-53^{o} C and such temperature asymmetries with co-existing high concentrations of fine fractions of particulate matter ranging from 336 to 8114 µg/m^3 may result in poor respiratory health of the cooks. Initial data analysis with multiple regression indicates temperature and PM_{10} to contribute positively (though insignificantly) to FEV 1/FVC % **as** per Table 4 below.

Table 4:* *Multiple Linear Regressions with FEV 1/FVC % as the Dependent Variable

Model	Unstandarized Coefficients.		Stand. Coeff.	t	Sig.
	B	Std. Error	Beta		
Constant	62.645	10.894		5.750	.000
PM10	.001	.001	.174	1.262	.213
TEMP	.481	.284	.233	1.692	.097

The housing characteristics, type of fuel, cooking methods, difference in time activity patterns, season are some of the variables that may affect the exposure profile of individuals.

INITIATIVES FOR IMPROVED COOK STOVES

In India the transition to improved biomass cook stoves has gone through many transformative stages. The National Pilot Project for demonstration of improved biomass cook stove was initiated in year 1983 and its success led to the launch of National Program on Improved cook stoves (NPIC) in year 1985.This program, a mix of R&D and field extension/commercialization was implemented through multi model and multi-agency approach targeting 30 million households till year 1997. The program continued till year 2004. Drawing lessons from NPIC the Ministry of New and Renewable Energy (MNRE) in year 2009 launched National Biomass Cooking Initiative (NBCI) with a primary objective to enhance the use of improved cook stoves. This program had many unique features for facilitating development of state of the art testing and certification centers, monitoring & evaluation, stress on R&D for promotion of cost effective, efficient, durable cook-stoves. NBCI targeted deployment of 2.4 million improved cook-stoves at household level and 0.35 million units at community level till year 2017.

At the onset of NPIC demonstration phase the cook stoves of thermal efficiency 15% (as against 5-10% of mud cook stoves) were acceptable for propagation. Subsequently the Indian Standards for bio mass cook stoves were first evolved in year 1991 which were later upgraded in year 2013 (BIS 13152 part 1) with a minimum threshold acceptance value of 25 % thermal efficiency for natural draft and 35% for forced draft cook stoves. In addition the minimum performance parameters have been defined for CO (<=5 g/MJd) and PM (<=350mg/MJd for natural draft & 150mg/MJd for forced draft). US EPA (5G) method is being used at the test and certification centers for measuring PM emissions.

Further, in May, 2016 Pradhan Mantri Ujjwala Yojana (PMUY) was launched which targets 50 million LPG connections for Below Poverty Line (BPL) families by year 2019 for a rapid transition to cleaner fuels. The Indian Government also targets to provide electricity (24x7) for all families by year 2022. Therefore at this stage appropriate electrical aided cook stoves should be extensively promoted while simultaneously strengthening an ecosystem of mass marketing with field support of efficient biomass cook stoves.

CONCLUSION

The study establishes the well documented significant increase in the morbidity to respiratory disorders in cooks compared to non-cooks in rural households that use unprocessed solid biofuels for cooking. It further highlights that the elevated temperatures in close proximity of traditional cook stoves may exacerbate respiratory disorders caused due to exposure to fine fractions of particulate matter. The use of cooking fire has been in use since antiquity and still being used with cook stove variance by a large global populace. Interventions for energy efficient and low emission cook stoves can significantly help to reduce emissions and improve respiratory health.

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MAINSTREAMING ENERGY EFFICIENT BUILDING DESIGN PRACTICES IN STATE PUBLIC WORKS DEPARTMENTS

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Keywords: Energy Efficient Building Design, Public Buildings, Public Works Departments, Design Process

ABSTRACT

State Public Works Departments (PWDs) and other similar government departments responsible for the construction of public buildings in the states have an important role in making the public building energy efficient and thermally comfortable as well as in the implementation of the Energy Conservation Building Code (ECBC). Well-designed, energy-efficient public buildings have a large demonstration effect. Many countries have adopted the strategy of show-casing energy-efficient design, technologies and design practices by first adopting them for the public buildings. The Schedule of Rates (SoR) and other technical documents of PWDs are also referred by the private sector builders, thus influencing the construction industry practices of the private sector as well.

The paper is based on the experience of working with the PWDs and other state departments responsible for construction of public buildings in three states: Karnataka, Rajasthan and Andhra Pradesh. A three-step approach was adopted for engaging with the state agencies: a) conducting seminars to create awareness, b) providing technical support for integration of energy efficiency strategies in the design of specific public building projects, and c) development of state-specific guidelines for design of energy efficient and thermally comfortable public buildings. The paper presents the approach and learnings. It also present ideas for better and effective engagement with the state PWDs to help in mainstreaming energy efficient building design practices in state PWDs.

INTRODUCTION

Energy Conservation Building Code (ECBC) was formulated by the Bureau of Energy Efficiency (BEE) in 2007 (BEE 2007). ECBC sets minimum energy standards for commercial buildings having a connected load of 100kW or contract demand of 120 KVA and above. The implementation of the code depends primarily on the state governments (state governments notifying the code for the state or amending the existing General Development Control Rules) and the urban local bodies (for amending building regulations to incorporate ECBC provisions) (Rawal et al. 2012).

The construction of public buildings in states is generally carried out by the state government departments e.g. Public Works Department (PWD), other state government departments or public-sector enterprises. These agencies are an important player in the implementation of ECBC, as:

a) They are responsible for the construction of state governments buildings and hence are responsible for the adoption of the code in buildings constructed by them.
b) They are the technical experts at the state level and hence play an important role in the framing the adapted version of the state building energy conservation code.
c) Faster adoption of the ECBC by state government construction departments and agencies and inclusion of materials and technologies used for the construction of energy efficient buildings in the Schedule of Rates (SoRs), provide a fillip to the market for these materials and technologies as these are referred widely by the private sector construction companies
d) As the public buildings are visited by public, well designed energy efficient and thermally comfortable (EETC) public buildings can have large demonstration effect and can help in creating awareness about building energy efficiency.

Many countries have adopted the strategy of show-casing energy-efficient design, technologies and design practices by first adopting them for the public buildings (Liu et al. 2010)

As a part of a bi-lateral development cooperation project aimed at supporting BEE programme on building energy efficiency, activities were undertaken to provide technical assistance to state government construction departments and agencies. The programme is ongoing and activities have been taken up in three states – Karnataka, Rajasthan and Andhra Pradesh. It is to be noted that all the three states were the first few states in the country to notify ECBC. However, the process of on-ground implementation of ECBC remains slow in all the three states.

METHODOLOGY

The methodology for engaging with the state level construction departments and agencies consisted of three measures:

1. Awareness Creation: Organisation of awareness seminar(s) in each state to create awareness about energy efficient building design. These seminars were organised in association with the state departments and were mainly attended by the officials (architects and engineers) of state PWDs. In some cases representatives from the local chapters of associations of building professionals and builders also attended the seminars. The awareness seminar content covered the following topics a) Introduction to EETC buildings b) Integrated design process c) Passive design strategies d) Energy efficient space cooling technologies and systems e) Case studies of EETC public buildings. In some cases, field visits to EETC buildings were also organised as a part of the awareness creation exercise.

2. Technical Assistance: Having set up the links in the state and after gaining basic understanding of the process and institutions involved in the design and construction of public buildings, the next step was to provide technical assistance to integrate EETC strategies in the design of specific public buildings being designed and constructed by these state agencies. This assistance was offered in two ways:

   a) Technical assistance for revision of template design for small public buildings which are replicated in various districts: The assistance consisted of i) analysis of the proposed design of the building by carrying out sun-path analysis, day light analysis and in some cases building energy simulations ii) providing design inputs during a 1-day workshop and submitting a detailed technical report subsequently. No follow up technical support during construction was provided.

   b) Technical assistance by conducting design charrettes and during construction for large public buildings: The assistance consisted of i) detailed analysis of the proposed design of the building by carrying out building energy, day light, computational fluid dynamics (CFD) simulations ii) providing design inputs for integrating EETC strategies by conducting a 3-4 day long design workshop iii) providing need based technical support during construction to assist in the implementation of the EETC design.

3. Design Guidelines: The third step was the development of guidelines for design of EETC public buildings for the state. The guideline document in the form of a manual is to be used by the designers of public buildings.

ANALYSIS & RESULTS

AWARENESS CREATION

Following are the learnings gained while conducting awareness seminars

a) Focussed presentations on integrated design process, design strategies and case studies were appreciated by the participants. However, participants wanted more information on application and cost, which were sometime lacking in the seminar presentations. The site visits to EETC buildings after the seminar proved effective. As many of the participating officials were field personnel, they preferred field visits and discussing details of implementation (e.g. application of insulation materials, selection and installation of external movable shading systems, etc) during site visits.

b) Though majority of the participants understood presentations made in English, they were more fluent and comfortable speaking in their mother tongue. Having one project team member fluent in the local language helped in facilitating interactions during the seminars.

c) The seminar organisation required pre-seminar preparatory meetings with government departments. These interactions were helpful in gaining familiarity and understanding roles of various departments and their expectations. This helped in making the seminar content more relevant to the state. It was observed that most of the state agencies have only basic information available on their websites, hence these interactions were also useful in gathering information regarding organisation structure, projects, etc.

TECHNICAL ASSISTANCE

Revision of Template Designs of Smaller Buildings

The PWDs have standard design templates for district level buildings, such as, district offices, district courts, hostels, etc. The typical process adopted for the design of such building involves making a master template, which is a detailed architectural design for the particular building type. The client (concerned government department) sanctions the number of buildings to be constructed in selected districts in a fixed budget. The construction process starts as and when the land is acquired. The site conditions may differ in all districts however, usually the building design remains the same. These buildings being small in size and budget, are generally mixed mode buildings in which only a few rooms are air-conditioned.

Technical support was provided for four buildings. Key information of these buildings and the EETC measures are provided in Table 1.

The results of the analysis of these buildings and EETC strategies identified are summarised below

a. Reducing heat gains from the building envelope: The heat gains from the building envelope primarily consists of heat conduction through roof, wall and glazing and directly transmitted solar gains. Reduction in heat gains was achieved through: i) proper orientation of the building to minimise heat gains, though in some cases, the site conditions restricted a change in the orientation; ii) In all the cases, roof was un-insulated concrete slab and addition of insulation was recommended in the revised template design; iii) In all the cases, the wall construction was of standard brick masonry, wall insulation was recommended in all the cases to restrict the heat gains. The Window to Wall Ratio (WWR) was in a reasonable range of 15-25% for all the buildings and the windows had provision for fixed shades. In the district courts at Banswara and Bengakuru and the District office at Bijapur, external movable shading was recommended for windows on the eastern and western facades

b. Improving daylighting: All the buildings being primarily day-use buildings offered scope for improving daylighting. Daylight simulations for typical spaces were carried out. In all the cases, the building floor plate was not very deep (< 20 m), which provided favourable conditions for good daylighting. Daylight improvement was achieved through reorganising of rooms in the floor plans and adjustment in room layouts to ensure better daylight availability on workstations. In some of the cases such as the District Office at Bijapur and the District Court at Banswara, redesign of the window (adding fixed pane at the top of the window) was recommended for improved daylight.

c. Natural Ventilation: All the buildings are mixed mode buildings, with large part of the building without air-conditioning. The potential of natural ventilation was investigated and changes in the design of the windows were suggested to improve natural ventilation. The window design changes also incorporated appropriate safety features so that the windows can be kept open for night ventilation.

The exercise to provide technical support for the revision of template design show the potential that exist for improving energy efficiency and thermal comfort in public buildings. However, the impacts of this exercise are still not fully visible and realised. One of the key learning was that inclusion of new materials (e.g. hollow burnt clay blocks or building insulation), building systems (e.g. window shutters, external movable shading systems) or new technologies (e.g. two stages evaporative cooling) in the PWD SOR is a must for these solutions getting implemented. Through the initiative of the ECBC cell and PWD, SOR revision has taken place in Karnataka, which is a welcome development.

On the other hand, delay in construction, e.g. the District Court building at Banswara, for which technical assistance was provided in 2014, has put a question mark on the implementation of the revised template design for this building. Retirement and transfers of key officials involved in the template revision process has resulted in temporary break in communication and has impacted the implementation process.

Technical assistance by conducting design charrettes for large public buildings

Detailed technical assistance was provided for the design of head office of the Rajasthan Forest Department, Jaipur having a built-up area of around 10,000 m^2. At the time when technical support was provided, the orientation and building massing was already finalized, hence the focus was more on building envelope and the space cooling system. Being the office of the forest department, the client wanted a sustainable building design.

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During the design workshop, the main emphasis was on reducing heat gains, improving day lighting, energy efficient lighting and cooling systems and integration of renewable energy. Following energy efficiency measures were agreed upon and were implemented:

- Roof insulation: Roof was insulated with 40 mm polyurethane foam (PUF) resulting a U-value of 0.6 W/m^2.K. Also, light coloured terrazzo tiles at top was incorporated to have high reflectivity.
- Wall insulation: External wall constructed as cavity wall filled with insulation. A 50 mm extruded polystyrene (XPS) insulation was used, resulting a U-value of 0.5 W/m^2.K (without taking account thermal bridging).
- Efficient glazing: Double glazed unit (6-12-6 mm) with U-value: 1.8 W/m^2.K, SHGC: 0.24 & VLT: 36% was used to reduce heat gains and get enough daylight. Relatively shallow floor plate of the building helped in daylighting.
- Energy efficient lighting: LEDs and T5 were used.
- Energy efficient cooling system: A centralised high efficiency water-cooled chiller (COP: 5.8) was implemented for air-conditioning the building. Given the water scarcity in Jaipur, a sewage treatment plant (capacity: 15 m^3/d) was installed and treated waste water is used for the cooling towers.
- Solar photovoltaic (SPV) system: A 45kW$_p$ grid-connected roof-top SPV system with net metering is installed to meet part of the building energy requirement.

The building became operational in 2015 and has been monitored for a year. A comparison of the monthly EPI for the simulated case and actual performance. Energy simulation showed that EPI of the building was 77 kWh/m^2/year before the technical assistance; it was reduced to 53 kWh/m^2/ year after integrating energy efficiency features and the monitored EPI of the building is 43 kWh/m^2/year.

This building clearly demonstrates the benefits of EETC buildings. In this case, the intensive and continued technical assistance was the key to the strategies being implemented. This support also demonstrated a better engagement and understanding of the concepts of EETC design by the project team from the state department.

DESIGN GUIDELINES

A detailed guideline document to assist architects and designers in the design of EETC public buildings has been developed for Karnataka. Similar documents are under development for Rajasthan and Andhra Pradesh. The guideline document for Karnataka has following main chapters i) basics of integrated design process ii) climate analysis and thermal comfort iii) climate responsive design iv) efficient cooling systems v) integration of solar energy. The document provides detailed analysis of the four types of climates which are found in Karnataka. In addition, the design guidelines also recommend changes in the standard design process followed by the PWD to ensure that the architecture and engineering departments work coherently since early design phase to develop an energy efficient building design. The publication was developed in close collaboration with the state PWD and was reviewed by PWD before publication. A training seminar was also conducted for the PWD architects and engineers after the release of the document. The design guidelines were released in September 2016, the project has plans to get a feedback from PWD on its impact after completion of one year of its release and plan further actions.

CONCLUSION

Based on the experience gained during the project, the project team has identified some of the key elements of a comprehensive strategy for mainstreaming energy efficient building design practices in state PWDs. Some of the key features are described below:

Need for a comprehensive capacity building strategy

A comprehensive capacity building strategy is needed for mainstreaming.

i. Expanding the reach of capacity building programmes: The project focussed on building capacities of the design teams (PWD architects and designers) posted at the PWD headquarters. For mainstreaming, the capacity building effort needs to be expanded to cover: a) private sector architect and engineer consultants engaged by PWDs for design work (as more and more design work is being outsourced by PWDs); b) PWD site engineers posted in districts and civil contractors responsible for the construction of the public buildings (as often the design team based in PWD headquarters has limited role in the construction); c) Apart from PWD, there are many other departments which are responsible for public building construction in states e.g. in case of Andhra Pradesh, there are a group of construction departments such as, Road & Buildings Department, Panchayati Raj, etc.
Awareness generation activities should cover key building user or client departments as well. They

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should be made aware about importance and advantages of EETC buildings. The expanded group of stakeholders for capacity building are shown in **Figure 1**.

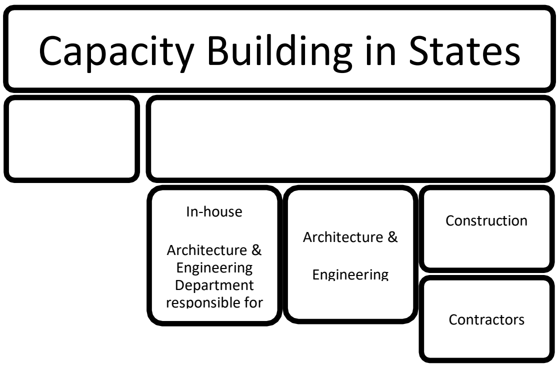

Figure 1: Expanded group of stakeholders to be included in capacity building programmes in states

ii. In-house trainers: The capacity building activities undertaken by an external agency (e.g. this project) are usually one-time activities. For sustaining the capacity building exercise an in-house pool of trainers is needed. During the interactions, a pool of PWD architects and engineers having good understanding of energy efficient buildings were identified. The future efforts should focus on developing a mechanism where these professionals are trained and take up the role of in-house trainers.

Need for systemic changes in PWDs

The experience also indicates that certain systemic changes are needed in PWDs for mainstreaming.

i. Adoption of Integrated Design Process: One of the barrier in designing energy-efficient buildings lies in the process followed by state agencies for designing buildings. While working with one of the state PWD, it was noticed that the architecture and engineering departments work independently of each other. The architectural design is first prepared by the architecture department which is then forwarded to the engineering department for MEP design, tendering and construction. The architecture team have very limited role once the architecture design of the building has been completed. One of the key recommendations made by the project team was to follow the Integrated Design Process (IDP) approach so that the architecture and the engineering departments work together in the initial design stage. This process will require certain procedural changes in the government process.

ii. Revision of State Schedule of Rates (SOR): When a building comes to the architecture department from a client department for design, it comes with an approved budget based on thumb rules. It is difficult to get this budget revised on the higher side for an energy-efficient design and hence the energy-efficient design should be implementable within the approved budget. This is particularly true of the template buildings. The only way to ensure this is to include energy efficient building materials/systems in the Schedule of Rates.

Reaching out to public through exemplary public buildings

Because of the high footfalls, well-designed public buildings could be used to educate public about the design strategies and benefits of EETC buildings. Use of posters, audio-visual capsules, digital display of building performance, guided tours are some of the ways to reach out to public. Such an approach on a limited scale was tried in the state forest department head quarter building at Jaipur and the results were encouraging.

ACKNOWLEDGEMENT

The authors would like to thank BEE and the Swiss Agency for Development and Cooperation (SDC) for undertaking the activities with PWDs. We would also like to thank all the concerned state agencies, which included, Rajasthan State Road Development Corporation, PWD Karnataka, PWD Rajasthan, Rajasthan State Forest Department, State Energy Conservation Mission (SECM) Andhra Pradesh, Roads and Buildings Department of Andhra Pradesh and the Capital Region Development Authority (CRDA) of Andhra Pradesh.

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from early adopters" World Bank Working Paper no. 204

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Table 1: Building projects that were supported for improvement in template design

State	**Rajasthan**		**Karnataka**	
Building type and location	**Distt. Court, Banswara**	**Rehabilitation Centre for mentally retarded Women & Children, Barmer**	**Distt. Court, Bengaluru**	**Distt. Office, Bijapur**
Built-up Area (m^2)	7,900	Acad.: 21,130 Hostel: 12,400	5,500	12,000
No. of floors	G+1	Acad.: G+1 Hostel: Ground Floor	G+1	G+2
Climate Zone	Hot-Dry	Hot-Dry	Temperate	Hot-Dry
Composition	5 Court halls & Judges Chambers	Acad.: Therapy Rooms, class rooms, etc	4 court halls, 1 mini court room & Judge's chamber	Offices

EETC strategies	• Revised Configuration of rooms around courtyard for better daylighting & ventilation • Change in window glass specifications, introduction of light shelves, increase the WWR to 26% and use of external movable shading (chiks) on the east & west facades • Use of insulation in walls and roof to bring down the U-value to 0.44 $W/m^2.K$ and 0.40 $W/m^2.K$ respectively • Night cooling and exposed structure for natural ventilation • Use of water cooled split air-conditioners and indirect evaporative cooling	• The building massing of the academic block was revised to reduce heat gains, improve daylighting and natural ventilation • Fixed shading of different sizes was suggested for different facades. In addition external movable shutters were recommended for eastern and western facades • Rearrangement of room layouts to ensure adequate daylighting on working spaces. • Use of roof and wall insulation to lower the U-value • Use of hybrid cooling systems (evaporative cooling with ventilation chimneys) for the hostel block along with fixed louvers in the courtyard • Use of solar water heaters for hostel • Use of occupancy sensors for the hostel block	• Swapping of dead spaces such as toilets and stores with court rooms or judge's chambers for better daylighting and ventilation • Night ventilation and window operating schedules to cool the building structure • Use of water cooled split air-conditioners for judge's chambers	• Change in orientation of building for longer facades to face absolute N-S • Use of roof and wall insulation to lower the U-value • Redesigning of windows to ensure better daylight and natural ventilation • Design of external movable shutters in the corridors on the eastern and western facades • Rearrangement of a few spaces for better daylighting • Use of water cooled split air-conditioners in a few rooms

EVALUATING ENERGY EFFICIENCY POLICIES AND PROGRAMMES IN INDIA

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Keywords: Evaluation framework, Energy Efficiency, Impact Evaluation, Process Evaluation, Market effects evaluation

ABSTRACT

Energy efficiency (EE) is crucial to India's energy and climate policy. In India, the Bureau of Energy Efficiency (BEE), Energy Efficiency Services Ltd. (EESL) and electricity distribution companies (DISCOMs) are implementing a number of energy efficiency programmes of varying scales. Some of these programmes have seen a fair amount of success and has triggered development of many similar or large scale programmes. Taking this as a background, this paper takes a review of the existing EE programme evaluation methods. It also suggests ways in which these methods can be applied to upcoming energy efficiency programmes in India.

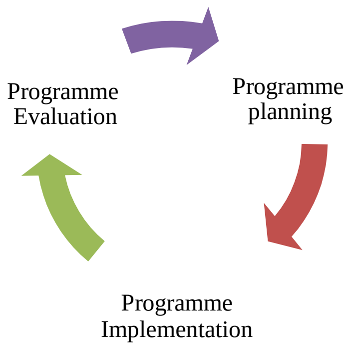
All energy efficiency programmes need to be evaluated comprehensively to identify causes behind their success or failure and predict sustainability of their results. This can improve the credibility of the programme and provide important lessons for effectively designing future programmes. Energy efficiency policies and programmes can be evaluated on three major aspects: impact evaluation (assessing the reduction in energy and peak demand), process evaluation (assessing the effectiveness of programme delivery) and the market effects evaluation (assessing the changes in the market due to the programme).

Evaluation of energy efficiency programmes in India has been limited to impact evaluation through monitoring and verification only. One primary reason for lack of comprehensive evaluations is the absence of mandate for the same in the relevant Acts and regulations. This is exacerbated by the common perception among stakeholders of evaluation being complex and expensive. Finally, lack of publicly available data on programmes and policies precludes any independent evaluations. Our recommendations for overcoming these barriers include the Forum of Regulators (FoR) to develop model regulations for comprehensive evaluations, incorporate evaluation in the programme design with a dedicated fund for its execution and make all the relevant data available in public domain.

INTRODUCTION

In India, energy efficiency (EE) programmes are scaling up rapidly. The Bureau of Energy Efficiency (BEE), India's statutory nodal agency for EE, has national level programmes like Standards and Labeling (S&L), and Perform, Achieve and Trade (PAT). Energy Efficiency Services Ltd. (EESL), India's public sector energy services company (ESCO), is running a large scale programme called Unnat Jyoti by Affordable LEDs for All (UJALA) for LED bulbs and is planning to extend it to other appliances and equipment like fans and pumps. The UJALA programme has distributed more than 230 million LED bulbs till May, 2017 and claims to be saving about 30 billion units annually (about 13% of India's residential electricity consumption in India) (http://www.ujala.gov.in/).

Accurate, consistent, and transparent evaluation of these programmes is necessary (National Action Plan for Energy Efficiency, 2007) to establish the validity and sustainability of the claimed savings and to prove EE as a low cost resource. Evaluations also help in identifying barriers experienced during programme implementation and providing lessons for effective designing of future programmes. Finally, evaluations also determine the causality and sustainability of market transformation, if any. To ensure evaluations meet these goals, they should be viewed as a part of a continuous and usually cyclic process of programme planning, implementation and evaluation, as indicated in Figure 1.



Measurement and Verification

Figure 1: Cyclic process of programme planning, implementation and evaluation

Once evaluations are considered to be a part of this cycle then the category of evaluation (impact, or process, or market effects evaluation or a combination) can be determined. The rigor of evaluation depends on many factors like the type of programme, funding available, vintage of the programme and the technology, and the scale of its impacts. Programmes that have significant impacts, or use new technology or new delivery mechanism may be evaluated comprehensively vis-à-vis programmes with smaller impacts or proven technologies (SRC International AIS, 2001).

In the next section, we describe different categories of evaluations and various methods used to conduct them along with suitable examples. We then conduct a critical review of the evaluation studies conducted in India till date and easily available in public domain. This is followed by a brief discussion on the primary reasons for the lack of comprehensive evaluations in India and our recommendations to overcome them.

EVALUATION CATEGORIES

Energy efficiency programmes are generally evaluated after energy saving measures have been applied i.e. they are ex-post evaluations. They are evaluated for three aspects: their impacts (mainly gross energy and demand savings), processes (programme delivery) and market effects (changes in the market due to the programme).

Impact evaluations

This category of evaluations determines the gross energy and demand savings and co-benefits of a programme. This is usually done by employing any of the following three methods (Steven R. Schiller, Schiller Consulting, 2012):

- Measurement and Verification
- Large scale data analysis
- Deemed savings

Measurement and Verification of an EE programme is generally conducted using International Performance Measurement and Verification Protocol (IPMVP) (IPMVP, 2002). The protocol prescribes

calculation of energy savings as a difference between energy use before and after implementation of energy savings measures and accounting for various adjustments. The equation used to calculate energy savings is given by:

Energy savings = Base year energy use – Energy use after installation of measure +/- Adjustments…. **(1)**

The 'adjustments' are made for weather/seasonal changes, occupancy changes, changes in appliance numbers or type or any unexpected changes that may occur after installation of measure.

IPMVP proposes four options to determine energy savings. In option A, savings are determined by measuring a key parameter like operating hours or power drawn. All other values are predetermined based on historical or manufacturer's data. In option B, savings are determined by measuring all the parameters to which the measure was applied, no predetermined values are allowed in this option. Option C is used when multiple energy efficiency measures are applied to a facility or a building. Evaluation is done by using meters or sub-meters. The analysis is done by bill data comparison or by using regression methods. In option D, energy savings are calculated by simulating the energy use of the whole facility. Hourly or monthly billing data is used for savings estimation. These methods are costly and used only when there is a specific need to evaluate savings per project like industrial energy efficiency programmes or performance contracting programmes. Various examples of programme evaluation using these options based on the measure type and its application are given in the IPMVP protocol. These are available at www.evo-world.org.

Large Scale Data Analysis

Large scale data analysis involves analysis of metered billing data of participants (treatment group) and non-participants (control group) to evaluate savings. It is generally used for programmes with relatively large number of participants with similar characteristics (e.g. low income households in a city). Large scale data analysis can be done using two

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methods: Randomized control trials (RCT) and Quasi-experimental methods (QEM). In RCT, first a study population is defined (e.g. homes eligible for an appliance replacement programme or an outreach programme for a city). Then the study population is randomly assigned to the treatment group or control group. Energy savings are estimated by comparing the billing data of two groups during the evaluation period. The pre-programme billing data can also be analysed to determine external factors affecting the energy consumption. This is called the difference in differences method (see Example 2).

In QEM, the control group is not randomly assigned. Hence they suffer from selection bias and may produce a biased estimate of savings. Amongst various methods under QEM, before-after method is the most common. In this, energy use of the participants prior to programme enrolment is compared with the energy use of the same participants after programme enrolment. The other method is matched control group, where non- random control group of participants similar to the treatment group is constructed. Savings are determined by comparing energy use of two groups after implementation of the programme. The challenge with this method is that there are certain observable characteristics that could be matched (e.g. level of energy use, presence of air conditioner, same area) but also some unobservable characteristics that could not be matched (attitudes or willingness to participate in the programme). In the third method, variation in adoption, energy use of participants is compared with energy use of participants who will enrol in the programme at a later point. This method addresses both observable and unobservable characteristics.

Example 2: RCT method (difference in differences) was used while evaluating the Cash for Coolers programme in Mexico (Davis, Fuchs, & Gertler, 2014). The programme was designed to replace old refrigerators and air-conditioners with new energy efficient models. Impact evaluation was carried out by doing regression analysis on the billing records of participating consumers. The regression analysis factored for weather, household size, seasons, and population trends by using special variables. The analysis found out that the refrigerator replacement reduced electricity consumption by 7%, which was one fourth of the predicted reduction, while the air-conditioner replacement actually increased the electricity consumption by 2%. The savings potential from the programme was estimated based on various assumptions on usage and replacement pattern which differed from the observed behaviour. For instance, newer more efficient appliances were replaced rather than old inefficient ones, usage hours were over-estimated, and the sizes of new appliances were greater than assumed.

Deemed Savings

Deemed savings (DS) method uses predetermined values to estimate energy and demand savings for a programme. These values are obtained from prior evaluations involving actual measurements and analysis of the implemented measure. Typically in the U.S. each utility has technical reference manuals (TRM) containing values for operating hours, installation rates, baseline consumption, and equations to determine gross and net savings. These manuals are updated periodically with the values for each parameter obtained after actual measurement. Only those measures with predetermined and updated values of all the necessary parameters can be evaluated using this method.

In DS, there is no field measurement of energy use, only verification of installation and operation of the energy efficient equipment is ensured. Deemed savings approach is the least accurate and least expensive options amongst the three evaluation options described here.

Example 1: A residential lighting programme in Illinois was evaluated for its' sixth year in 2014 (Tami, Greco, Andryauskas, & Zhou, 2015). The programme aimed at market transformation by giving discounts to Energy Star products and by conducting outreach and marketing efforts. Impact evaluation was done using predetermined values of key parameters (hours of use, base wattage, installation rate) and methods given in the TRM. These values were obtained from evaluations done in earlier years 2008-2013. During the evaluation, only installation of bulbs was verified for sample households during the evaluation. The impact evaluation found out that there was a significant difference in the projected and evaluated savings. This was primarily because programme implementer used different values and methods to project the savings than those given in TRM. The evaluation team recommended using methods given in TRM so that programme tracking and reporting is improved for future evaluations.

Deemed savings is also being used to estimate the savings of the UJALA programme. A survey was carried out to verify installation and operation of LED bulbs in a sample of participating households.

But, the participants were not asked about their replacement and usage pattern. It was assumed that all the LED bulbs replaced 60W incandescent bulbs. Earlier load research surveys were used for estimation of other parameters like hours of operation and days of operation were also assumed (PwC, 2015). As mentioned earlier deemed savings method can be used only when all the 'assumed or predetermined' values are either measured in earlier evaluations or have a reliable source like manufacturer's data. In absence of these data, deemed savings methods may result in erroneous estimation of energy savings.

Impact evaluations also estimate the net energy and demand savings. This involves eliminating the effect of free riders and spillover from the gross savings achieved by the programme. Free rider is a programme participant who would have implemented the measure even in the absence of the programme. Spillover accounts for the actions participants or non-participants take without the programme's financial or technical assistance. For any programme, net impacts are positive if there are minimum free riders and maximum spillovers. Some of the methods available to evaluate net savings are predetermined net-to-gross ratios, surveys (see Example 3), cross- sectional studies and large scale data analysis.

Example 3: The Massachusetts Residential Retrofit and Low Income Programme was evaluated to find out net energy and demand savings (The Cadmus Group, 2012). The evaluation team determined the free-ridership, participant spillover and non- participant spillover by using survey technique and statistical modelling. Questions were asked to the participants and non-participants to assess the influence of the program on their decision making process. This allowed the team to determine the likelihood of the measure being installed in the absence of the program. The team found out that the spillover for participants and non-participants was more than free riders for the programmes hence the net impact was positive.

Impact evaluations may also analyse the co-benefits or the non-energy benefits of an energy efficiency programme. There are no standard methods to evaluate these benefits. One may choose to enumerate these benefits like reduced emissions and environmental benefits, productivity improvements, jobs created and local economic development, greater individual comfort, or benefits to the energy system (e.g. price stability, grid reliability and power quality).

Example 4: New York Energy Smart Programmes were evaluated to understand the non-energy impacts they have on participants (Summit Blue Consulting, 2006). The survey found out that apart from the energy savings achieved, participants value the aspects of better visual comfort or longer lifetime for lighting replacements, better thermal comfort and air conditioning effectiveness for building retrofits, lighting quality and indoor quality in case of a commercial programme. The evaluation found out that participants are willing to pay more to get these benefits.

Process evaluation

Process evaluations assess the programme delivery i.e. they examine the efficiency and effectiveness of programme implementation procedures and systems. They give recommendations for changing the programme's goal, structure, and implementation approaches. They facilitate better and cost effective programmes and often supplement impact evaluations by exploring the causes of savings achieved. These evaluations usually consist of asking questions to those involved in the programme, analysing their answers and comparing results to the established best practices.

Process evaluation focuses on four areas:

- Programme design
- Programme implementation
- Programme administration and
- Participant response

The primary methods used for process evaluation are surveys and in-depth interviews with programme administrators, programme implementation staff, policy makers, programme participants and non-participants, and participating and non-participating market actors.

Process evaluations are particularly valuable when: the programme is new or has been changed substantially from its earlier version; the benefits are largely over or under achieved; there is limited programme participation; or the participants are reporting problems.

Example 5: An Appliance Retirement Programme in Connecticut was evaluated for its impact, process and market effects (Nexus Market Research, 2005). The programme aimed at removing barriers against retiring old appliances: inconvenience, disposal costs and unfamiliarity with operating costs of old appliances. They offered pick- ups at customers' homes, held events at nearby locations to turn-in their old appliances, paid participants to retire their units and educated customers about the high costs of running older appliances. Process evaluation of this programme involved in-depth interviews, review and analysis of programme databases and telephone surveys of participants and non-participants. It revealed certain strengths of the programme like its 'turnkey' nature, requiring little administration from the distribution utility and positive relationship and good-will with customers. The evaluation however pointed out that it suffered from three primary weaknesses: participation in turn-in events was unpredictable and highly dependent on weather; the programme could not control customer behaviour before or after the programme nor influence motivations for participation; and finally the communication made to consumers by way of bill inserts was not effective after a certain time period. The recommendations of the evaluation team were to substantially restructure the programme to improve its cost-effectiveness and delivery but continue with the programme as the participants appreciated the programme and expressed high levels of satisfaction.

Market Effects evaluations

This category of evaluations distinguishes and quantifies the effects of energy efficiency programme on the suppliers and customers. Market effect evaluations have typically been conducted for programmes that target market change. These evaluations often require a significant effort because they require data collection from a wide range of market actors and the efforts are spread over many years. Some methods to assess market effects are (Rosenberg & Hoefgen, 2009):

- Self-reports of net programme effects
- Cross-sectional approaches
- Structured expert judging
- Historical tracing or Case study method

In case of self-reporting approach the customers and supply side market actors are asked about the influence of the programmes on installation of energy efficiency measures. The data collection is done through telephone or in-person interviews. As the method relies on customer recall, it is recommended that the interviews should be done fairly quickly after the implementation of the programme.

Cross-sectional approaches compare unit sales, market share, in non-programme areas (baseline) to areas served by the programme. The differences between the programme and non-programme areas can be attributed to effects of the programme. The data required is primarily in the form of sales data from retailers and distributor. Survey data from supply side actors and/or customers could be the second best way of assessing market effects using this method.

In expert judging, panels of experts are asked to forecast two trajectories of market acceptance for the products or services in question: one that takes into account the effects of the programme and one that does not. The latter represents the baseline. The difference between the baseline and cumulative sales will be the net effects of the programme. The selection of panel in this method is particularly critical especially where products are new to the market.

Historical tracing or the case study method is a qualitative approach where a researcher examines cause and effect relationship explaining the outcomes. The data requirement for historic tracing studies consists of in-depth interviews with programme principals, staff of other programmes operating in the market and market actors as well as documents of various kinds.

Example 6: An upstream lighting programme for CFLs in California was evaluated for market effects (The Cadmus Group Inc., 2010). Prior to the evaluation, the team studied the evolution of lighting markets in the U.S. and came up with important research questions like: are new actors entering the market and attributing their entry to the influence of the programme or have upstream incentives reduced the price of CFLs. Cross-sectional method of comparing non-programme states similar to California was used along with sales data from 16 different states. The evaluation team did surveys and interviews of all the stakeholders along with home audits. Collected data was then analysed using multistate modelling and regression analysis to estimate the market effects of CFL programmes in California. The team found out that the programmes did have a small but a positive effect on CFL awareness, availability, price and saturation in California as compared to other states. The team recommended the following for future CFL programmes: recording of baseline data and better consumer education about types of CFLs, their applications and disposal methods.

Figure 2 summarizes all the categories and methods used for evaluating energy efficiency programmes. The actual choice of the category and method of evaluation for a particular programme depends on nature of the programme, objective of the evaluation, history of evaluations, and resources available.

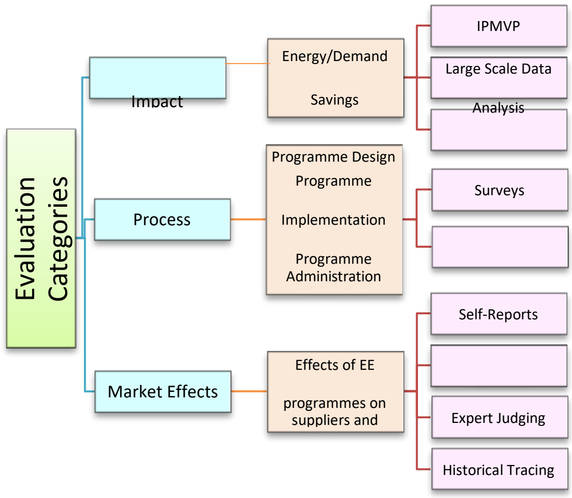

Figure 2: Evaluation Categories and some methods of evaluation

EVALUATION STUDIES IN INDIA

Evaluation studies of energy efficiency policies and programmes in India are scarce. Most of the studies available in public domain have focused on monitoring and verification rather than a comprehensive evaluation. We discuss a few studies in this section.

PricewaterhouseCoopers (PwC) conducted monitoring and verification of Street Lighting Programme and the Domestic Energy Efficient Lighting Programme (DELP) to estimate energy savings, peak load reduction and reduction in GHG emissions. For the streetlight programmes they measured and compared energy consumption at selected feeders before and after installation to arrive at the savings estimates. Total emission reductions from the 35 million LED street lights at the national level were estimated to be 6.57 million tCO_2. For the DELP programme meant for households, only installation and operation of LEDs was verified. All the parameters like wattage, operating hours and days of operation in a year were assumed. The energy savings were estimated to be 102.9 billion kWh (PwC, 2015).

In case of Bachat Lamp Yojana monitoring and verification was done according to the methodology prescribed for the Clean Development Mechanism projects (UNFCCC, 2016). Meters were installed for continuous measurement in sample households (stratified random sampling was used) to determine daily operating hours before and after installation of CFLs. Standard emission factors were used to determine emissions before and after replacement. The difference in the two values was then calculated to find out emission reduction (*Monitoring Report Form (CMD-MR)*, 2010).

In case of the agricultural pump replacement pilot programme in Solpaur, monitoring and verification was done by a third party contractor. Savings were calculated by using Option A of IPMVP. Periodic measurements of power drawn on sample pump sets were taken and hours of use were predetermined. The savings were calculated by deducting the wattage of efficient pump from the baseline wattage and multiplying them by the predetermined operating hours. A total of 15.3 million kWh were estimated to be saved by replacement of 3530 agricultural pumps in Solapur (CRI Pumps, 2016).

In all these cases only energy saved or reduced emissions were calculated. The Bachat Lamp Yojana found very few investors after the global carbon market crashed. A systematic evaluation of BLY programme could have pointed out that the linking of carbon markets to promote the programme is not having the desired effect on programme uptake. In case of the agricultural pump replacement programme, it is necessary to consider factors like water table of the location, the cropping pattern, the availability of electricity and pump usage patterns. The selection of the pump as per local requirements and condition is very critical to deliver savings. Focusing only on monitoring and verification does not offer programme implementers to do mid-course corrections if required. For instance, process evaluation of the pump programme could have pointed out the flaw that one type of pump cannot be suggested for all locations or that a positive response from participating farmers is important to the success of the programme. In case of DELP programme when deemed savings approach is used, it is critical to substantiate the assumed values by concrete measurement data from prior evaluations. Energy savings may be over- estimated or under-estimated if these values are taken arbitrarily.

One example of comprehensive evaluation in India can be the evaluation of the Nashik CFL programme (Prayas (Energy Group), 2007). Engineering methods and consumer surveys were used to conduct the evaluation. Some key lessons that emerged after the evaluation (high failure rates and high power factor of CFLs may wipe out the savings or the programme needs to be communicated properly) can be taken into account while designing future programmes. The evaluation pointed out that programme tracking and monitoring can allow mid-course corrections and eventually deliver a successful programme which can achieve far better results.

Another comprehensive evaluation effort was done by International Institute for Energy Conservation. They evaluated BESCOM efficient lighting programme in March 2006. The programme was incepted under Energy Conservation and Commercialization (ECO II) initiative of USAID. They evaluated impacts, processes and market effects of the programme. For impact evaluation they used standard engineering equations to arrive at the estimates of participants' pre and post installation electricity consumption. Benefits to the customers were assessed using customer surveys and not actual measurement of hours of use or kW. Benefits to BESCOM were assessed using sales data before and after the programme. Customer satisfaction, marketing efforts and internal procedures and systems of BESCOM were assessed under process evaluation. This was done using face-to-face interviews of participants and non-participants, participating suppliers, distributors and retailers and programme administrators. Programme penetration and a review of programme eligibility criteria and incentive levels was the objective of market effects evaluation. This was done using surveys of participating and non-participating customers, and direct sales customers(International Institute for Energy Conservation, 2006).

In India, the state designated agencies (SDAs) are expected to carry out energy efficiency initiatives at the state level. Various programmes done by SDAs are LED village campaigns, demonstration projects to showcase effectiveness of energy efficient technology, awareness campaigns and workshops and training programmes (https://www.beeindia.gov.in/content/sdas-0). Even though these programmes are at a small scale they need to be evaluated so that the role of SDAs in implementing the provisions of the EC Act, 2001 is strengthened.

The Standards and Labeling (S&L) programme is being conducted by BEE since 2006. The savings achieved by using star labeled appliances is displayed on the BEE website for some years but there only a few studies on awareness of S&L programme. These studies show that awareness levels for labels vary between 19% - 63% pan India (Chatterjee & Singh, 2012)(Dhingra, Walia, & Mukherjee, 2016). As S&L claims to be a programme that aims to give an informed choice to consumers there is a need to understand if consumers do make their purchasing decisions based on the information on labels. These process and market effects evaluations are missing for this programme. Another such programme of the BEE is, 'Perform, Achieve and Trade' (PAT) (https://www.beeindia.gov.in/content/pat-3). It is a market based mechanism to enhance energy efficiency in energy intensive industries. Industries can trade their energy savings certificates in the market on the basis of savings achieved. This is a new mechanism that promotes use of energy efficient appliances and methods in industries. The programme needs to be evaluated to ensure the success of such a mechanism. All the data on specific energy consumption of industries after PAT implementation, trading of certificates and improved processes needs to be available on public domain. Such evaluations and information will not only help big energy intensive industries in reducing their energy consumption but also set a benchmark for other industries to replicate the processes. It will help deepen and broaden the PAT scheme further.

Considering all the key points of programme evaluation we have tried to include an example of comprehensive evaluation of India's S&L programme in Table 1.

REASONS FOR LIMITED ENERGY EFFICIENCY EVALUATIONS IN INDIA

In this section, we briefly discuss the reasons that have resulted in limited energy efficiency evaluations in India.

No mandate for BEE and lack of regulatory oversight

Energy Conservation Act, 2001 (Ministry of Law, Justice and Company Affairs, Gazette of India (60), 2001) established the Bureau of Energy Efficiency (BEE) and set rules and regulations for its working. The Act has no provisions that mandate independent and periodic evaluation of the policies and the programmes implemented by BEE. The Electricity Act 2003, National Electricity Policy 2005 and amendments, and National Tariff Policy 2006 and amendments mention the importance of DISCOMs implementing Demand Side Management (DSM) programmes but are vague on all the operational aspects including the evaluation of these programmes. Model DSM regulations released by Forum of Regulators (FoR) in 2010 (Forum of Regulators, 2010) were adopted by a few state electricity regulatory commissions (SERCs). These model regulations require DISCOMs to prepare evaluation plans for proposed DSM programmes according to guidelines issued by the respective ERC. It also requires the ERC to periodically commission third party evaluation of the programmes implemented by DISCOMs. Neither has any DISCOM submitted any detailed evaluation plan for its programmes nor has any state ERC issued guidelines for evaluation till date (Prayas (Energy Group), 2014). State ERCs have periodically mentioned the need for DSM programmes and their evaluation in the tariff orders. They have also allowed budget allocation for overall DSM activities but the regulations do not specify the percentage of DSM funds to be kept aside for evaluation. The DISCOMs have mostly ignored the suggestions and the state ERCs have not followed up. The state designated agencies were established under section 15(d) of the EC Act, 2001 for the purpose of coordinating, regulating and enforcing various provisions of the Act in the state level. But they also have no mandate for conducting comprehensive evaluations of their programmes. Thus a clear lack of mandate for independent evaluation of BEE's policies and programmes and lax regulations and oversight on programmes conducted by DISCOMs and EESL are the primary reasons for absence of comprehensive evaluation reports.

Common perception that evaluation is, burdensome, premature and expensive

In India, evaluation of an energy efficiency programme is generally associated with actual measurement of the energy saved. Measurements are done by Energy Savings Companies (ESCOs) or certified energy managers and auditors by way of metering of a selected sample of projects. This is not only costly but at times tedious. For instance time-loggers were installed in selected CFLs distributed under Bachat Lamp Yojana (*Monitoring Report Form (CMD-MR)*, 2010) and also in selected LEDs distributed under DELP in Puducherry. However, a number of consumers un-installed the loggers or regularly moved the bulbs to different locations making the monitoring difficult.

These observed difficulties in conducting evaluations also combine with a general view that evaluations are not really worth all the effort. Two arguments are generally put forth for not conducting evaluations: the small scale of programmes in India and that the energy impact of these programmes on DISCOMs is minimal.

The first argument is that DSM programmes in India are at a nascent stage and mandating evaluations will increase the complexity unnecessarily. A comprehensive evaluation not only investigates the quantum of savings but also the causes of the savings. They also assess the effectiveness of the processes which is required to scale-up pilot programmes. They enable corrections in a programme when it is manageable and affordable. Hence, contrary to the argument, pilot programmes also require rigorous evaluation than an established programme to scale-up. Also, DSM programmes are no longer small in India. EESL is planning to launch a series of large scale programmes based on the UJALA model (https://goo.gl/DBLATW) which can potentially result in significant savings.

This brings us to the second argument put forth for downplaying the importance of evaluation. The massively popular UJALA programme is based on a bulk procurement model to reduce the price of energy efficient appliance and does not require subsidies from government or DISCOMs. The buyer pays for all the benefits achieved from the energy savings and is entirely responsible for them. The benefits to DISCOMs and the government are additional and free. As there is no payment to EESL based on realized savings it is argued that there is no need for accurately estimating the saving and consequently no need for a comprehensive evaluation.

There are some counter-arguments here. First, as we have discussed, a comprehensive evaluation can bring out much more lessons than the savings realized. Second, even with limited focus on savings, the large scale of the programme should alert DISCOMs to identify and forecast a realistic estimate of savings. For instance UJALA programme claims savings equivalent to about 13% of India's residential electricity consumption (http://www.ujala.gov.in/). Third, there are methods like deemed savings and large scale data analysis which can obviate the need to install meters every time an evaluation is planned. These methods can be used effectively to estimate savings provided all the prerequisites of using a method which are described in previous sections are fulfilled.

The next point put forth is that evaluations are costly. Internationally, basic evaluations are done by keeping aside approximately 3-5% (Messenger, Bharvirkar, Golemboski, Goldman, & Schiller, 2010) of the total programme costs. Similarly in India, as programmes evolve in scale, maturity and complexity more money can be used for rigorous evaluations.

Lack of data in public domain

Publicly available data can prompt independent evaluations of energy efficiency programmes by academicians, research organizations, and civil society organizations. This can complement or in India's case act as understudies for the formally commissioned reports. However, data required for such independent evaluations on energy efficiency programmes is not available in the public domain in India. For instance, regulators do not mandate DISCOMs to make programme design related documents available in public domain. EESL published a design document on Domestic Efficient Lighting Programme (DELP) (EESL, n.d.) but did not do the same for UJALA or its other recent programmes. BEE also has limited information in public domain on processes and market effects of its major programmes like Standards and Labelling (S&L) and Perform, Achieve, and Trade (PAT). Data on end-use and sales can also be useful. For instance, BEE and EESL conducted load research studies in 30 states under a programme to build the DISCOMs' capacity for implementing DSM programmes (Prayas (Energy Group), 2016). This data if made public can be used as an approximate baseline to evaluate the savings. Similarly, aggregate data on shipment of star-labelled appliances can be useful in estimating the trend in the sales of higher rated appliances. Thus, lack of relevant data in public domain restricts independent evaluations.

Way Ahead

We recommend the following things to improve evaluations in India.

The Forum of Regulator's DSM implementation framework was adopted in its entirety by many state regulators (Forum of Regulators, 2010). Similarly, FoR can issue model regulations specific to conducting evaluation of Demand Side Management (DSM) programmes of DISCOMs. This should include comprehensive evaluation including direct impacts, process impacts and market impacts. Given the significant impacts that large scale EE programmes may have, the state regulators can develop their own regulations in absence of model regulations from DSM. MERC in its DSM implementation regulations mentioned that they will soon notify Evaluation Measurement &Verification guidelines but have not done till date. Progressive regulatory commissions can take a lead on this. However, it is also important to follow up on the compliance of these regulations. One mechanism can be the formation of DSM Consultative Committee (DSM-CC) as convened by the Maharashtra Electricity Regulatory Commission. DSM-CC consists of members from DISCOMs, Academics, Technical experts, and civil society organizations and meets periodically to discuss and approve the DSM programmes.

Evaluations should be factored in the programmes' design with a dedicated source of funding allotted for the same. BEE and EESL can conduct evaluation studies as a part of its capacity building exercise of DISCOMs where it conducted load research studies. DISCOMs can also conduct studies on their own given the importance of the savings impact on their Annual Revenue Requirement. These can be part of their DSM activities with the cost being passed to consumers. EESL's recent investments in the DSM programmes have resulted in freeing up DISCOM's funds for DSM activities.

As much as possible data should be made public and active collaborations can be looked for. Specialized research organizations, academicians or civil society organizations can be collaborated to get the skills on social sciences, operations management, and market research required for comprehensive evaluations.

CONCLUSIONS

Evaluating energy efficiency policies and programmes is crucial to increase their credibility and to facilitate better design in the future. A comprehensive evaluation includes impact evaluation (assessing the reduction in energy and peak demand), process evaluation (assessing the effectiveness of programme delivery) and the market effects evaluation (assessing the changes in the market due to the programme). Evaluations are much more important in the pilot stage as the lessons can be used to effectively scale-up the programmes.

Evaluation of energy efficiency programme has been limited to impact evaluation. One primary reason for lack of comprehensive evaluations is the absence of mandate for the same in the relevant Acts and regulations. This is exacerbated by the common perception among stakeholders of evaluation being complex and expensive. Finally, lack of publicly available data on programmes and policies precludes any independent evaluations.

We recommend that Forum of Regulations (FoR) can issue model regulations on conducting comprehensive evaluation of DSM programmes similar to the regulations on DSM implementation framework issued in 2010. This can lead to faster adoption of these regulations by state regulatory commissions. As EESL is implementing large scale DSM programmes, BEE can commission independent evaluations of these programmes to understand their impact and assess their effectiveness. State regulatory commissions can ensure evaluations plans and funding requirement are factored in the programme design. Finally, we recommend that all the relevant data on policies and programme is made public to increase transparency and facilitate any independent evaluations.

Programme Name **Standards and Labeling**	What needs to be done	How - Evaluation activities and data sources
Market effects evaluation • Assess if sustainable changes have occurred in the market as a result of standards and labelling programme	• Market size (sales and prices) and market segments • Data on supply side -manufacturers and retailers, business models, nature of distribution channels, stocking/selling practices • Technology development and prices • Inclusion of new appliances in S&L programme and up gradation of standards	• Existing data on shipment and sales from manufacturers or government or industrial associations • Surveys or in-depth interviews with retailers, manufacturers, industry associations, consultants, experts • Literature on price and technology trends- domestic and international • Comparison with international standards • Survey or review on how frequently standards are upgraded and new appliances are included under the programme
Impact Evaluation • Determining energy and demand savings • Determine influence of the label on purchase decisions to determine net effects	• Energy savings- Determine baseline, energy use after installation • Emission reductions • Awareness of labels, ease of understanding labels	• Previous standard or non-star labeled appliance can as a baseline, comprehensive load research reports to identify usage hours (reports are periodically updated with new values) • Energy use of sample households before and after installation by metering or utility bill data • Engineering methods, statistical models, end-use metering, short-term monitoring and combination of methods to determine energy use • Average emission factors based on estimates or emission factors based on specific generation data can be calculated • Surveys with consumers to understand their awareness level of labels and its influence on purchasing decisions
Process Evaluation • Monitoring, Verification and enforcement of S&L • Communication and outreach • Administration	• Understand the selection of appliances under mandatory and voluntary, transition from voluntary to mandatory • Standard and labels enforcement methods • Analysis of test protocols and reports • Methods used for communication and outreach • Resources (human, financial) used to run the programme	• Programme data base, registration forms • Analysis of processes used to give labels and standards verification • Independent tests to be performed in labs to verify adherence to the standard • Analysis of communication strategies used and their effectiveness by doing surveys of consumers, manufacturers, retailers and distributors • Survey of programme staff to evaluate adequacy of resources

Table 1: Comprehensive Evaluation of India's S&L Programme

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VIDYUTRAKSHAKA
A CITIZEN INITIATIVE FOR SAVING ELECTRICITY IN HOUSEHOLDS

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Keywords: DSM, Behaviour change, Energy efficiency in households, Vidyut Rakshaka

ABSTRACT

Much of the expected benefits from demand side energy efficiency interventions are determined by end-user behaviour. Yet, the behaviour dimension of energy use and consequently the actual impact of efficiency programs is least understood globally. In India too there is limited empirical research done to understand how households use electricity and motivating factors for people to conserve or use energy efficiently.

Conceptualized as a citizen-led program to reduce electricity consumption in Bangalore, VidyutRakshaka (VR) was able to demonstrate a 16% reduction in monthly electricity consumption of about half of the participating households in a pilot over a period of six months. Analysis based on historical consumption trends shows that VR is able to shift households with increasing consumption trend to saving electricity. VR primarily worked by creating awareness, conducting energy consumption assessments, providing customized recommendations to save primarily through behaviour change followed by switch to efficiency measures. Resources were provided to the participants to overcome key information barriers. To drive behaviour change, VR adopted a peer / neighbourhood benchmarking approach to drive positive influences.

VR has demonstrated a successful demand side management initiative in electricity consumption. Its unique strengths are building capacity in local communities through one- on- one customized engagement and leveraging social / community influences. Our paper discusses the approach used under VR to engage with citizens, the data and the implications and strategies for a scale-up.

INTRODUCTION

Electricity is a critical energy source for any nation and its link to social wellbeing and thus the link to development has been well established (WEO, 2004). However, electricity generation is a large contributor to GHG emission and hence optimisation of production options is part of global agenda to counter climate change (Herring et. al., 2009). Energy sector contributed to about 71% of India's greenhouse gas (GHG) emissions in 2010 (MOEF report, 2015). Further, while electricity is positioned as a tool to alleviate poverty at the nation level, one cannot ignore the issues of *intra-country equity* in consumption standards. Dharmadikary and Rutuja in their report on assessing energy needs for a decent living conclude:

".. two conclusions are that we have to evolve more sustainable means of generating energy and that an equitable distribution of energy (at global and other levels) will probably be a necessary condition for sustainably meeting the energy needs of all for decent living."(Dharmadikari and Rutuja, 2015)

Human Development Index (HDI) computed by UNDP considers Universal access to electricity as one of the contributing factors. However it can be inferred that increasing consumption beyond a minimum threshold level of electricity does not contribute to increase in HDI. On one side India will need to strive and provide electricity access with minimum consumption (to meet the aspirations of decent living) to every citizen and on other side moderate the consumption levels of the rich and growing middle class, which is primarily an urban phenomenon.

The other key unanswered question in electricity distribution is arriving at the threshold for decent living and well being. While Dharmadhikary and Rutuja (2015) advocate a disaggregated approach for energy planners to address this gap, the infrastructure

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of electricity supply, distribution and current technologies may be serious limiters in providing enough planning data for micro level planning. Social consensus on understanding these limits is almost impossible in the given situation.

In addition to the generation and distribution exclusion, understanding economic exclusion is equally critical. Lowering of economic barrier to consumption can lead to unsustainable levels of consumption while continuous increases of tariff block the capacity of the underprivileged to even meet their needs. This balancing of optimal economic cost is another challenge.

UNDERSTANDING ELECTRIITY CONSUMPTION

Sustainable consumption is as significant if not more, compared to generation and distribution of electricity. Aspirations related to ownership of appliances have both critical use (falling under "necessary consumption" which positively correlate to wellbeing) and non-critical use (falling under "want based consumption"-which represents aspirational needs of the society). Non - critical consumption in addition to meeting needs of perceived well-being is also part of the process of identity formation, social distinction, cultural meaning and has aspirational value (Jackson, 2005). These two streams have to be addressed separately as well as in a differentiated manner, when it comes to any conservation effort.

Dietz's study (Dietz et al, 2009).highlights the different behavioural plasticity (understood as ease in eagerness to adapt/ change) for various categories of household electricity conservation efforts in US household. The challenge of identifying plasticity in behaviour for various electricity consumption actions, is not uniform across communities. Nudging consumers to replace assets with efficient ones through incentives has the highest adaptation possibility (High plasticity), while adaptation of non incentive driven assets have a low plasticity. Herring et. al. while critiquing the approach of efficiency ignoring the "rebound effect"[1], argue that sufficient attention is not paid towards sufficiency[2], which can lead to long term benefits (Herring et. al., 2009, PP-16). Herring et. al. in their observation on public policy on rebound effect, highlight the unwanted feedbacks developing out of policy incentives, if not thought through sensibly. (Herring et. al., 2009, PP-195).

UNDERSTANDING COMMUNICATION

Communication is the most effective tool in soliciting citizenry cooperation and participation for initiating a behaviour change as well as to sustain it. Anca et al (2012) in their report for European energy commission highlight various types of communication which help in energy savings.

Table ES.1 Potential energy savings due to measures targeting behaviour

Intervention	Range of energy savings
Feedback	5-15 %
Direct feedback (including smart meters)	5-15 %
Indirect feedback (e.g. enhanced billing)	2-10 %
Feedback and target setting	5-15 %
Energy audits	5-20 %
Community-based initiatives	5-20 %
Combination interventions (of more than one)	5-20 %

Figure 1: Behavioural change interventions proved effective for energy savings (Anca-Diana (EEA), 2012)

In another study, Fischer on the role of feedback on household electricity consumption gives two reasons for sustainable electricity consumption behaviour not coming into prominence for an individual. First, invisibility of consumption does not allow a consumer to be on top of the consumption in the absence of a feedback. Secondly, the nature of centralised electricity generation does not present the ecological damage to the consumer for a moral appeal. (Fischer, 2008).

There are very limited studies available on learning from programs addressing conservation efforts for electricity among residential consumer in India. Behaviour change experiment in a small community in Mumbai followed a novel method of printing smiley face and frown face on electricity bills for those lower and higher than neighbourhood average respectively (Behavioural design, 2014). It demonstrated that the intervention group started reducing their consumption, proving social influence does play a role.

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[1]A empirical observation where technology driven efficiency leads to increase in overall consumption of certain goods and services, like fuel , electricity.

[2] Defined broadly as limiting the consumption of goods and services either to better satisfy personal desires such as health or meaningful work or to contribute to collective goals such as long-term environmental sustainability (Herring et. al., 2009,PP-16)

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VIDYUTRAKSHAKA (VR)

Given that the peak deficit in electricity supply keeps increasing (at about 70 GW in 2017), McKinsey & Company's report 'Powering India – The road to 2017' recommends that 'Adding capacity alone will not suffice as a response to India's soaring demand for power' and suggests to 'Create an action plan for an over 10% gain from Demand Side Management'.

Figure 1 shows the increasing demand supply gap in electricity as reported by Karnataka Electricity Regulation Commission (KERC) in 2014.

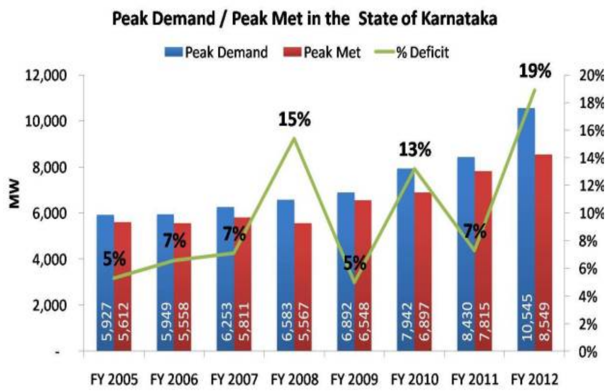

Figure 2: Demand supply gap in Karnataka, KERC 2014

In response to this need for driving electricity conservation from the demand side, and the glaring gap in data based evidence on household electricity consumption in the country, the VidyutRakshaka (VR) program was conceptualized. VR promotes and facilitates active citizen participation in not only electricity conservation effort but also to contribute to data driven models to understand disaggregated behaviour on consumption.

Programs like VR can contribute to electricity conservation efforts by nurturing aware citizenry with no negative implications. In fact, such programs will also reduce the burden (financial and otherwise) on the utilities to manage such demand side conservation programs (Vskv Harish et al, 2014). The disaggregated data thus collected will be a useful planning input which can optimise India's Energy plan towards a low carbon society.

VR attempts use of communication as a primary tool for initiating and sustaining change. A detailed data based logical appeal of individualistic nature is designed to initiate change while feedback processes are meant to enforce sustainable change. VR also attempts to address spatially differentiated community behaviours and individual attitudes towards electricity conservation. .

This paper discusses the approach used in VR to engage with citizens, the experiences in implementing this program, the outcome, and strategies for scale-up.

COLLABORATION WITH THE UTILITY SERVICE PROVIDER

A 2014 article looking at action plan, policies and regulations of DSM in India lists barriers for DSM program and suggests that collaboration between utility driven and non-utility driven programs can overcome some of these barriers (Vskv Harish et al, 2014).

The VR program was conceptualised as a collaborative effort with the utility's perspectives also contributing. The Utility has been sharing the historical consumption data of participants who have signed up for the program. Results are periodically shared with the utility for feedbacks and improvements.

CHOICE OF BANGALORE AS PILOT LOCATION FOR VR

The statistics for South Indian states reflect the increasing trend in demand supply gap. As per A. Gangopadhyay et al (2016) from National Institute for Advance Studies, the average energy deficit in Karnataka went up from 2% in 2006-07 to 10% in 2014-15, touching 20% in the summer month of April. It is projected to touch 17% in 2022. Bangalore consumes about one third of state's total power and this was pegged at 2300 MW or 42 Million units per day in 2012, with the demand supply gap ranging from 0 to 600 MW through any average day. Households form 77% of BESCOM consumers and contribute to 22% of electricity sales (KERC, 2014).

VidyutRakshaka phase I was launched for households in Bangalore, in two different localities – in Malleswaram, a locality in North east of Bangalore and a gated community south west of Bangalore.

The chosen two localities are demographically different in many aspects, including the history, development, culture and profession. Malleswaram is an old residential area populated with independent houses or low rise apartments. The area also

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represents a variety of socio-economic status with houses ranging of 1 to 4 + BHK (Bedrooms per households), which is representative of the size of house as well as the varied class of residents. Residents in Malleswaram are old timers having born and brought up in that area. On the other hand, the chosen layout in Sarjapur is only about a decade old, with independent houses occupied by residents working mostly with corporates, many of whom having moved to Bangalore for jobs. The houses range from 2 BHK to larger ones. This community is represented by a single association which manages their common amenities. Incidentally this community was one of the first to achieve rainwater harvesting in all households and were reusing all their sewage treated water for ancillary usage. The ecological awareness in this community is perceivably higher than Malleswaram.

By choosing these areas we expected VR to generate varied data points (disaggregated) for analysis of electricity consumption behaviour.

VR METHODOLOGY

The VR methodology can be summarized in distinct steps detailed in Figure 1 which are explained in sections below.

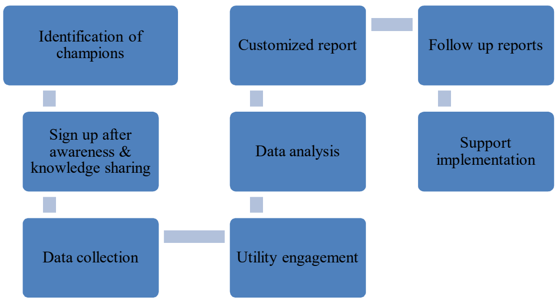

Figure 3: VR Methodology

Identification of champions and stewards: In Phase I of VR, we have signed up about 525 participants (households) from the two localities. The households within these localities were not selected as random samples or on the basis of any pre-defined economic or consumption criteria, but through a process of mobilisation through champions. The champions were meant to be residents from the community with record in active civil society representation or acted as evangelist for the cause of conservation and have a pull in the community.

As the program evolved, VR had good success in engaging with institutions and stewards as champions meeting the same criteria of active social engagement. For Phase I, for the gated community in Sarjapur, the Resident Welfare Association (RWA) played the role of the champion along with some of their members, while in Malleswaram, CSOs like Malleswaram Swabhimana Initiative, Rotary Club, Inner Wheel, Lions Club, Nightingale Club, and the local branch of the utility service provider BECOM acted as champions.

TIDE used trained youth (called Stewards) to act as champions, particularly in Malleswaram area, and also to do the sign ups and the survey. These stewards were picked up from places like vocational training institutes and local NGOs. They were given training in need for and aspects related electricity conservation, about VR methodology apart from soft skills. Going beyond sign ups, VR was able to bring interesting transformation in the stewards, in their outlook towards career advancement and environmental conservation.

Sign up after awareness and knowledge sharing: Whether to the champions or others, the appeal to join VR was in two streams, one economic (monetary savings as incentives) and second moral, an obligation to society at large and sustainability of well- being.

A pitch was used giving the background on the need for an electricity conservation program. This highlighted global, national and local concerns like GHG emissions, Energy poverty and inequality in the country, Demand supply gap in Bangalore among other points. To appeal on economic front, the rising cost of electricity and saving potential through nil cost, low cost and higher cost investments were highlighted.

During the sign up, each participant was given an awareness booklet with generic but detailed recommendations to save electricity in different consumption category. The booklet gives tips to save electricity, along with quantitative data on pay back where possible.

Data collection: After the sign up, stewards were deployed to collect baseline data. In Phase 1, this involved two components:

a) Electricity bill data for the past one year

b) A questionnaire was used to capture behaviour, asset ownership and usage patterns of electricity consumption in each

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house hold.

While most participants answered the questionnaire, it was a challenge to get electricity bill data for more than a few months at the most.

Utility engagement: As Phase I was proceeding to the data analysis stage, the local utility service provider BESCOM was informed about the VR program which immediately recognized it as a worthy initiative. An NDA was signed for data sharing. This enabled us to get historical consumption data for participants (after obtaining their No Objection). In return TIDE has committed to sharing the data analysis and the outcome of the VR program.

Data analysis: The data on consumption and usage were collected and processed in excel for locality wise analysis in different BHK categories. The consumption was looked at on a per month basis and a per capita basis (based on occupancy details shared by the participants).

The VR methodology uses three distinct novel self learning models to drive the behaviour change and switch to EE interventions.

a) Ideal model
b) Neighbourhood model
c) Historical model

While the first two are aggregated models, the third one is specific to each participant. And out of these three models, the neighbourhood and historic models were used for both per month average and per capita average consumption analysis.

Ideal Model:

While the Ideal model is city specific and remains the same for both the localities, it is different for each of the BHK category. It is built for a particular standard of living in a city for each BHK, building ideal electricity consumption across five usage categories namely Lighting, Heating, Cooling, Appliances and Entertainment. This model is built to be iterated, to self-learn and improve with actual consumption data from participants. Each participant's consumption is analysed under these categories and slotted as ABOVE or BELOW the IDEAL MODEL.

Neighbourhood model:

Among the myriad factors influencing household electricity consumption, Normative Social Influence is found to be playing a definitive role. Thus advising consumers that people similar to them (e.g., peers, neighbours) are using *less* energy or taking certain energy-saving actions, in addition to conveying social approval of such actions, will likely motivate them to conform to these positive 'energy saving' norms and reduce their consumption (Fredericks et al, 2015).

Thus a neighbourhood model was built for the two participating localities to bring in the local context. For each neighbourhood, the actual consumption data of the households was analysed BHK wise and distribution of consumption was plotted. A benchmark or average was computed after removing outliers. Each individual household's consumption was then compared with this neighbourhood distribution in the respective BHK category and was slotted as ABOVE, BELOW or AT NEIGHBOURHOOD MODEL.

Historical Consumption model:

With data available for most of the participants from December 2012 from BESCOM, a historical consumption model was built for each participant to catch the trend in their consumption. While providing a powerful insight for the individual consumer, at the aggregated level, it also gave evidence on how electricity consumption is changing (rising) year by year.

With the VR initiative as base timeline, historical data of 12 months prior period was used to create the pre VR category and 12 months subsequent to VR data was used for Post VR category.

Households whose trend of consumption when analysed monthly tended to be decreasing were categorised as savers and those whose consumption trends increased were categorised as spenders. The household where clear trends could not be observed from the data were termed inconsistent.

On this basis, five distinct shifts in consumption were observed as explained in Table 1.

Table 1: Characterization based on historic consumption trend

Category	Description
Consistent Savers	Pre VR Saver : Post VR Saver
Savers to Spenders	Pre VR Saver : Post VR Spender
Spenders to Savers	Pre VR Spender : Post VR Saver
Consistent Spenders	Pre VR Spender : Post VR Spender
Inconsistent	Keeps fluctuating , no consistent trend

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Customized report with Characterization of participants: Using the models described above, while considering both monthly average and per capita levels helped arrive at a community level consumption benchmark for each BHK within the locality.

- Energy Savers (consuming below the community average)
- Energy Champions (consuming within +/- 5% of the average)
- Future savers (consuming above average)

It was deliberately decided to go with the lowest category if and when there is a conflict between per month and per capita consumption. This was done so as to provide an impetus to the participant to push to lower consumption where possible. This approach also removes the bias which can occur with very high or very low occupancies.

A customized report was generated for each participant which lists the characterization as described in previous section. This is followed by a detailed analysis of consumption based on the different categories of usage, described her as 'Usage category'. For each of these usage categories (lighting, etc), a comparison against ideal model was provided along with customizations applicable for that household were given for saving.

Some level of prioritization was also done while giving recommendations, starting from simple but effective ones to those requiring investments. While customizing recommendations based on the participant's usage, his or her preference for No cost, Low cost and High Cost interventions was also taken into account.

The report finally set a goal for saving for every participant, derived from either of the following:

- Different between average and participant consumption based on neighbourhood model or ideal model whichever value was the higher, and limited to 30 units
- Since BESCOM follows slab based billing, reduction to lower slab reduces the electricity bill considerably. To highlight this, difference between units consumed and units under the last tariff slab was given as the goal for saving for those households which exceeded the last slab by 30 or less units.

The threshold of 30 units was assumed so the goal is achievable with some simple interventions to begin with.

Apart from these, the report carried resource section on electricity saving and also a brief background on the analysis itself.

Follow up reports: About six months after the first report, a follow up report was generated for the participants after obtaining consumption data from BESCOM for the same participants. Their performance subsequent to the first report was analysed and status as 'Increased' or 'Decreased 'or 'Status quo'was arrived at.

Recommendations were reinforced where appropriate, to push for savings.

Support for implementations: VR is committed to provide product agnostic, knowledge led support for implementing recommendations. Based on the interest by the residents of the gated community a knowledge session on Solar PV roof tops was arranged with subject matter experts.

RESULTS AND DISCUSSION

The goals of the project were to

- Gather data based evidence on consumption patterns in households across different demographics in a city (Disaggregated consumption patterns)
- Explore energy reduction possibility through usage pattern changes, and introducing energy efficiency and renewable energy options where possible.

VR Phase I has succeeded in both and also brought out some very interesting data backed observations as detailed below.

- **VR has motivated participants to save and demonstrated that it is possible to take a consumer driven pathway to bring down consumption.**

Consumption data prior to VR and post VR shows a saving trend.

Total average monthly consumption in 452 households across different BHKs and in both the localities = 80,388 Kwh

We had estimated a Conservative saving potential through VR recommendations of 13711 Kwh

Actual saving seen in 6 months since program started = 13183 Kwh = 16.4%

252 out of 448 households reduced their consumption in the 6 months after receiving the report, as proved by consumption data.

- **VR provides evidence on differentiated or disaggregated consumption justifying differentiated planning for conservation.**

Spread of consumption among the two localities shows a trend where Malleswaram households are distinctly on the lower side of the consumption (Figure 4).

And among the same BHK category, one neighbourhood shows higher average (or benchmark) than the other as seen in Figure 5. As the size of households increase (1 BHK to 4 BHK) the trends of consumption per capita is differentiated, which can be seen in Figure 6.

It is also seen that the behaviour of the two localities varies with respect to the categories of electricity consumption, viz, Lighting, Heating, Cooling, Entertainment and Appliances are also very different, as illustrated in Figures 7 and 8.

This kind of behaviour trend brings out the need for a differential and customized community wise appeal for saving rather than fixed thresholds. Flexible community wise averages passively shared (through characterization) with a conservative appeal is probably more practical.

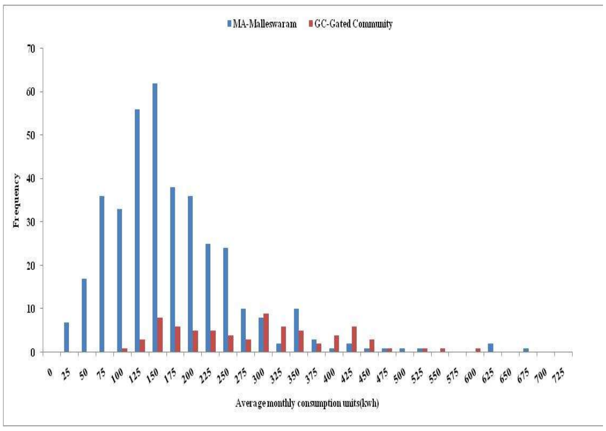

Figure 4: Spread of consumption in the two pilot localities

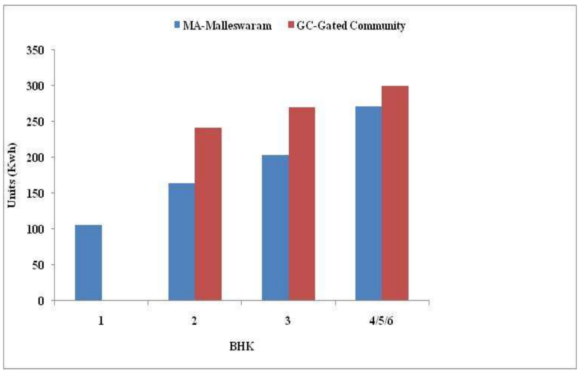

Figure 5: Average monthly consumption trend among the two pilot localities

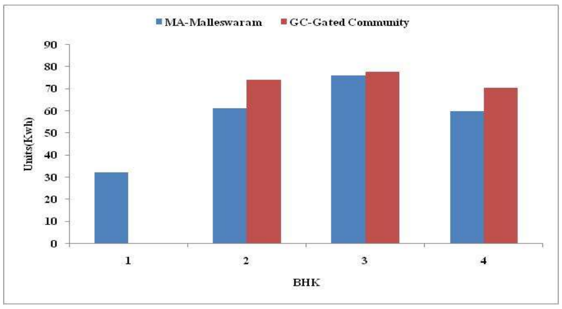

Figure 6: Per capita consumption trend amont the two pilot localities

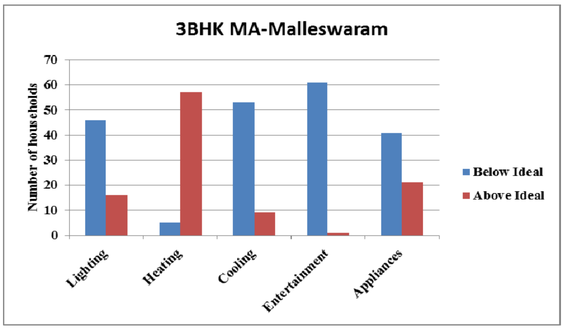

Figure 7: Usage wise consumption in Malleswaram against Ideal model

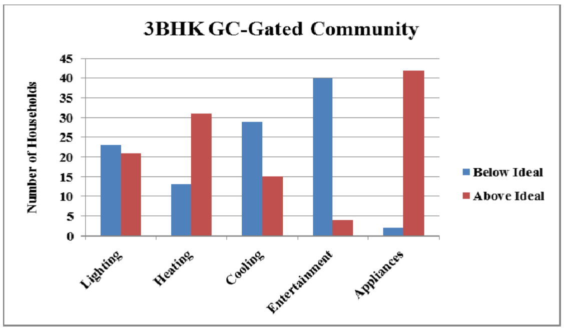

Figure 8: Usage wise consumption in Gated commu ity against ideal model

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- **VR has influenced shifting consumption behaviour**

While analysing the historic trend in consumption for the participants, it was found that about 10% of the participants (42 numbers) appear to have shifted their historical behaviour of increasing consumption year by year to reducing consumption since signing up for VR, as shown in Figure 9.

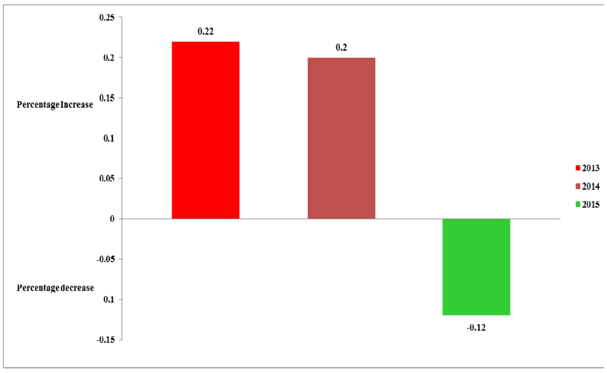

Figure 9: VR participants shifting consumption behaviour

- **VR may help to beat the trend in increasing consumption**

Though a steady rise in electricity consumption is expected and predicted for a developing country like India, VR shows an interesting possibility of arresting that trend, particularly with urban high end consumers. Figure 10 illustrates what should have been the consumption as per NITI AAYOG's prediction, and what actually was seen with VR participants.

In follow ups after Phase I after 6 months, it was found that about half of the participants are continuing in the same category of consumption (Energy saver or champion) which indicates lock-in. This however needs validation over a period of time.

A control group comparison is also being planned to validate direct impact due to the program.

CHALLENGES AND LEARNING

Closing feedback loop remains a challenge in VR in terms of understanding what led to the actual saving. The upcoming mobile app can capture this to some extent allowing the user to input such details.

It is expected that at the start of the program, a fair amount of savings may be achievable through behaviour change or low cost investments. But for the savings to sustain in spite of growing aspirations and rising tariffs, it would be essential to push participants to invest in energy efficient appliances and renewable energy solutions. Also constant engagement will be required till conservation habits are formed.

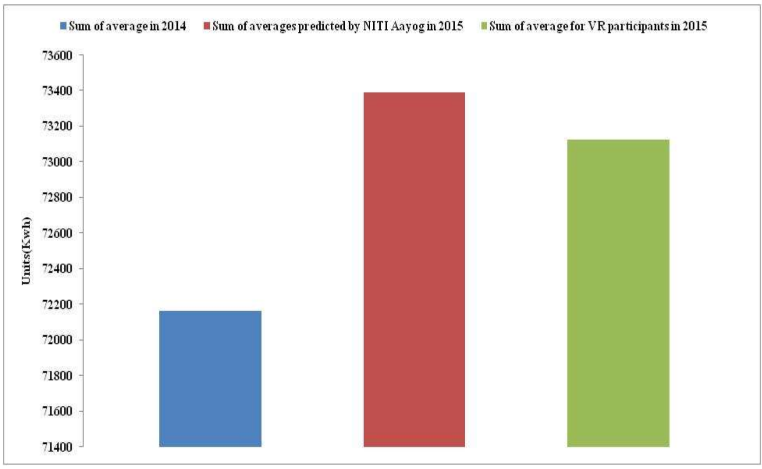

Figure 10: VR participants deflecting NITI Aayog predicted rise

IMPACT

VR's unique strengths are in building capacity in local communities through one- on- one customized engagement and leveraging social / community influences, ideas recommended for electricity conservation through behaviour economics.

By creating awareness and providing knowledge at individual and community level, VR is bridging the invisibility aspect of electricity consumption. Repeated communication over long period reinforces low plasticity behaviours thus attempting a sustainable change.

While implemented as a non-utility driven program, VR has sought active collaboration from the utility service provider. The exchange of data and knowledge will further strengthen the DSM initiatives BEE is advocating through ESCOMs.

While the program goals are focused on electricity conservation, the execution methodology has many other social dimensions as detailed below.

- The stewards deployed in the program are from the under privileged section who are provided training, including life skills which are helping them in aspiring and securing a good career in an urban set up.
- Introduction of VR to schools has helped create awareness among children while roping in those households as participants.

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POLICY IMPLICATIONS

For several decades, energy efficiency program designers have relied on awareness generation and information campaigns to change consumer attitudes towards energy conservation and energy efficiency. However changing attitude does not necessarily lead to changing behaviour. Understanding behaviour of different categories of energy consumers is the key to determining options for shifting consumer behaviour in the desired direction.

Policy interventions based on behaviour: Fredericks et al. (2015) comprehensively reviewed the behavioural psychology of energy consumers and found that consumer behaviour is irrational but predictable despite the economically viable choices offered. They concluded that there are policy implications from this research and lessons learned that can be applied to identifying scalable, practical and cost-effective solutions for encouraging clean energy choices. They identified several policy recommendations from behaviour focussed program interventions, some of which emerged from VR also.

Simplification- As the complexity of information given to them increases, the likelihood of consumers to optimal decisions reduces. Consumers then tend to make satisfactory or ''good enough'' decisions for meeting minimum requirements. This may lead to perverse outcomes or avoiding action all together. Simple programs that reduce time in making decisions, minimize physical and psychological demands and perceived uncertainty will help achieve better results.. In VR, customized recommendations provided to each participating household helped build familiarity and ownership with the program.

Social influence- Social normative information that tells consumers that people similar to them are using less energy or taking energy saving actions has been found to improve efficacy of energy conservation programs. In VR also consumers were presented with data comparing their electricity bill with their neighbours or peers which resulted in energy savings.

Shifting from the status quo- Consumers tend to stick with the status quo than make decisions that otherwise make economic sense. VR provides several impetus to shift the behaviour and it has succeeded also.

Community engagement- Engaging neighbourhoods in highlighting collective outcomes of energy conservation programs instils a sense of ownership. Acknowledging the efforts of individual consumers motivates and encourages people to do more. In VR, communicating the results of their participation helped build trust in communities.

Role of utility: VR demonstrates that DSM programs need not always be utility driven or expensive to do. But scalability of VR interventions improves with utility involvement. We are exploring options with the uitiltiy for monitoring, validation and particularly on-time feedback, say along with the bill itself .

In India, residential energy consumption data is not collected systematically and is limited to insights gathered through utility commissioned load analysis studies. While such studies help utilities estimate quantity and timing of demand, they do not offer advice on specific end-uses to target. Data collected under VR provides recommendations on hitherto less-understood characteristics of end-uses dependent on consumer behaviour. Combination of quantitative data on consumption parameters and qualitative data on behaviour can be an asset for utilities to design Demand Response programs.

We expect that results from phase 2 of VR will provide additional policy recommendations.

WAY FORWARD

Phase II of VR is already under execution with goals to

- Expand the foot print of VR I to a large set of participants across communities and across cities
- Demonstrate sustained savings with participants through follow up and support for implementations, particularly in EE and RE.
- Automate data analysis and report generation to minimise errors and improve efficiency. A mobile app is also being developed to deliver live reports to participants and give access to knowledge resources.
- Eco system sensitization and capacity building through awareness and training programs.

We will also be looking to grow our association with

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the Utility service provider and use VR data to suggest consumer engagement strategies driving demand side management.

CONCLUSION

VR builds on the premise that that energy conservation is a prerequisite for energy efficiency. It corroborates and provides evidence on understanding and addressing consumer behaviour in DSM programs. It has laid the foundation for policy and regulatory support through involvement of utilities.

Programs like VR that provide insights into behaviour towards electricity use are helpful in designing policy and program based solutions that focus on messaging and designing the right type of incentives to shift human behaviour.

Finally we want to highlight the fact that the unchecked electricity consumption in the residential sector cannot be ignored from a climate and resilience perspective.

ACKNOWLEDGEMENT

Authors would like to acknowledge funding and resource support from World Resource Institute – India and Societe Generale Global Solution Centre, Bangalore. Authors are thankful to the Bangalore Electricity Supply Company (BESCOM) for providing data and guidance in support of VidyutRakshaka.

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TRANSFORMING ENERGY EFFICIENCY MARKET – NECESSITY OF PARTIAL RISK SHARING FACILITY (PRSF)

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Keywords: ESCO, ESPC, energy savings, GHG, emissions reductions, partial risk

ABSTRACT

Despite some growth in Energy Service Companies (ESCO) segment, the financing for ESCOs is nearly nonexistent and Indian Energy Savings Performance Contract (ESPC) markets are yet to take off on a large scale. In comparison, China has the world's largest market at more than USD 13.3 billion in revenue from ESPCs in 2015, followed by the United States at USD 6.3 billion (Navigant Research, 2015).

ESCOs establish credibility through an ESPC that guarantees the client savings from the identified EE measures, thereby transferring project risk to the ESCO. ESCOs essentially flourish in markets where long term "project-based" financing can be accessed on a local, affordable and reliable basis (IFC, 2011). The "Partial Risk Sharing Facility (PRSF)" for Energy Efficiency project being implemented by Small Industries Development Bank of India (SIDBI) specifically addresses this issue and intends to create a favourable banking ecosystem for ESCO projects. The project intends to devise innovative mechanism to provide partial risk cover to Commercial Banks and Financial Institutes (FIs) for the loans given by them to ESCO implemented projects. The project is expected to provide partial risk cover to more than 500 projects implemented through ESCO model, which would mobilize financing to the tune of around USD 138 million. By supporting ESCO projects, PRSF is expected to result into significant energy savings to the tune of 1,000 GWh and mitigation of CO_2 emissions reductions to the tune of 0.734 million tons.

INTRODUCTION

India is the fourth largest consumer of energy in the world after USA, China and Russia but it is not endowed with abundant energy resources. Meeting the energy needs of achieving 8-9% economic growth and meeting energy requirements of the population at affordable prices presents a major challenge. It calls for a sustained effort at increasing energy efficiency to contain the growth in demand for energy while increasing domestic production as much as possible to keep import dependence at a reasonable level.

On the other hand, the Government of India (GoI) estimates that its overall Energy Efficiency (EE) market has an investment potential of INR 1.6 lakh crores and could save up to 178 billion kilowatt hours (kWh) and 150 million tons of CO_2 per annum. The above energy saving potential translates to 18-20% of the current levels of India annual electricity consumption (PBI, 2016). Over 25 percent of these estimated savings are expected to be achieved in the industrial sector. Much of this potential lies within Micro, Small & Medium Enterprises (MSMEs), as they comprise more than 80 percent of the country's industrial enterprises and lag behind in technology modernization and other energy efficiency measures (World Bank, 2011). The other sector, "buildings sector", can reduce almost 20% of current energy usage through energy efficiency measures.

IMPLEMENTATION CHALLENGES TO REALIZE EE POTENTIAL

Despite India's enabling regulatory environment and fairly mature financial markets, many consumers with energy savings opportunities, including middle- tier large industries (including those covered by Perform-Achieve-Trade (PAT)), buildings, MSMEs, and municipalities, are unable to implement EE projects, as they lack the technical capacity, have limited ability to obtain financing for EE projects, or face other barriers.

There are other implementation challenges faced by EE markets in general and those apply to India as well – small size and higher transaction costs, multiple stakeholders and ecosystem problems, and ambiguity on asset creation / ownership - which exacerbates the barriers to EE investments on a larger scale.

ESCO'S AND EE POTENTIAL REALISATION

ESCOs establish credibility through an ESPC that guarantees the client savings from the identified EE measures, thereby transferring project risk to the

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ESCO. Implementation of the EE measures can be financed through a "guaranteed savings" model, in which the client finances the project or a "shared savings" model, in which the ESCO finances the project, thereby owning the projects credit risk, and gets repaid through a portion of the client's future savings.

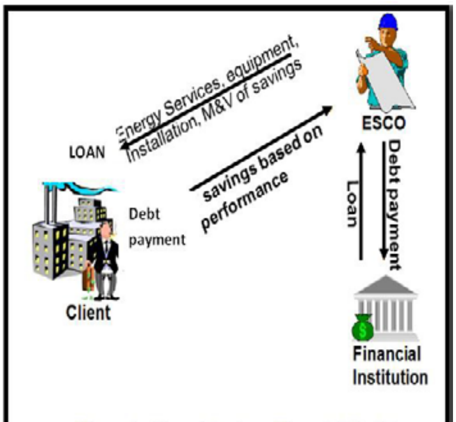

Figure 1: Shared-Savings Financial Model

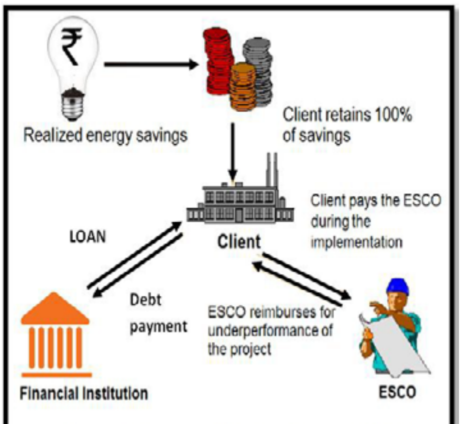

Figure 2: Guaranteed Savings Financial Model

A typical ESCO project includes the following elements:

- Investment grade energy audit;
- Identification of possible energy saving and efficiency improving actions;
- Comprehensive engineering and project design and specifications;
- Guarantee of the results by proper contract clauses
- Code compliance verification and guarantee;
- Procurement and installation of equipment;
- Project management and commissioning;
- Facility and equipment operation & maintenance for the contract period;
- Measurement and verifications of the savings results; and
- Project financing

GLOBAL ESCO MARKET

The ESCO performance contracting adopted in various countries show promising results towards helping address the EE market barriers and scaling up EE investments. The global ESCO market was valued at about USD 24 billion in 2015. China has the world's largest market at more than USD 13.3 billion in revenue from ESPCs in 2015, followed by the United States at USD 6.3 billion. The ESCO market in the European Union generated USD 2.7 billion in the same year (Navigant Research, 2015).

In China, ESCOs have been critical not only to achieving energy savings for the economy as a whole but also as a sector of the economy in their own right. In 2015, 5,426 ESCOs exist, employing 607,000 people. Over the previous five years, the number of ESCOs increased sevenfold (in 2010, only 787 ESCOs were registered). At the same time, ESPCs signed grew by 7% in 2015.

In South Korea, various favourable measures including tax credits, long term & low interest loans, etc. witnessed funding to ESCO projects in 2012 were approximately USD 502 million, resulting in saving of 550 kilo tons of oil equivalent (IEA, 2014).

In Canada, ESCO projects have been undertaken covering 7,500 buildings saving over USD 40 million in energy costs and reducing energy intensity by 20%. Japan has recently completed 50 ESPC projects producing 12% reduction in energy intensity (World Bank, 2015).

CURRENT INDIAN ESCO MARKET

India has evolved from having only three ESCOs registered with the BEE in the 1990s to 139 presently. Despite some growth, the Indian ESPC and EE markets have yet to take off on a large scale. Financing for smaller ESCOs is nearly nonexistent. India's ESCOs are generally limited to original equipment manufacturers that operate as vendor- ESCOs and use guaranteed savings models. No project repository is available to track the ESCO transactions. Nonexistence of any association to promote ESCO market is another barrier faced by the sector. Recently, Energy Efficiency Services Limited (EESL) has been performing a role of super-ESCO for implementing LED streetlight projects in various

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municipalities of the country by entering into a long term ESPCs.

BARRIERS TO INDIAN ESCO MARKET

Most commercial Banks have limited understanding of EE business and ESCOs energy savings performance-contracting business model, in which loans are backed by shared benefits from future cost savings rather than traditional collateral and plans to increase revenue. They also distrust smaller ESCOs creditworthiness – but without the ability to get financing, these ESCOs are unable to resolve this distrust. In addition, the methodologies adopted by Banks in terms of lending and appraisal are not flexible to accommodate energy saving profiles. Despite ESCOs utilizing their own internal funds taking much of the risks, Banks insist upon guarantees and security deposits. (IFC, 2011). In some instances, although the hosts may be credit worthy, because of various reasons including their limited awareness on Energy Efficiency, they end up not investing in EE measures.

A lack of process standardization and standards involved in ESPCs is also a significant impediment to EE market transformation through ESCOs. However, in India, currently there are neither widely accepted codes nor standards or associated legal provisions for these ESPC documents. As a result, many projects often devise their own contract templates, which many market participants perceive as risky.

Measurement & Verification (M&V) is another major barrier to India's ESCO industry. Establishing the baseline is given too much emphasis compared to M&V. ESCOs sometimes agree to adopt approximation and simpler methods instead of a more theoretically accurate M&V approach such as the internationally practiced protocols. There is a wrong industry perception that M&V is a considerable investment, disregarding its value as a contractual issue. However, establishment of a proper M&V protocol goes a long way in the success of a ESCO project.

A final barrier is lack of client demand for ESCO services, which to a large degree results from the other barriers. Many potential clients are simply unaware of the potential gains from EE projects and the benefits of using an ESCO to implement them (though the GoI's Perform-Achieve-Trade (PAT) scheme addresses the former barrier, at least among large industrial clients). In most cases, lack of client demand for ESCOs means that many EE projects, even those with significant potential savings and high financial returns, go unimplemented.

Building an ESCO market incrementally involves: i) developing and promoting simple ESCO business models, ii) facilitating ESCO financing, iii) implementing supportive legislative, regulatory and policy initiatives and iv) creating a stable demand for ESCOs, especially public sector demand. (World Bank, 2016 & IFC 2011)

PRSF – A GAME CHANGER

Introduction

ESCO industries essentially flourish in markets where long term "project-based" financing can be accessed on a local, affordable and reliable basis (IFC, 2011). With a view to support GoI's efforts to transform the EE market in India particularly through energy service performance contracting (ESPC) delivered through Energy Service Companies (ESCO), SIDBI is implementing World Bank supported project, viz. "Partial Risk Sharing Facility for Energy Efficiency (PRSF)" along with Energy Efficiency Services Limited (EESL).

The Indian financial sector boasts of strong and mature financial institutions (FIs) with considerable liquidity in the market. However, there are perceived risks in the mind of FIs which impede investments towards EE opportunities in general, and to lending to ESCOs in particular.

Demonstration of ESCO-based EE transactions through this proposed pilot-scale operation – Partial Risk Sharing Facility (PRSF) for Energy Efficiency project – would help alleviate the perceived risks, assist the market actors like ESCOs to have better access to finance, mobilize commercial financing for EE investments across various demand side sectors and thereby trigger large-scale EE market transformation.

World Bank's past projects like the Commercializing Energy Efficiency Finance (CEEF) Program in Eastern Europe, the China Utility Energy Efficiency Program (CHUEE), and the China Energy Conservation II Program have been highly successful. The latter project supported 148 ESCO projects worth USD 142 million (World Bank, 2016).

Following the implementation of CHUEE and Energy Conservation II, the ESCO industry in China has grown many manifolds. The EE market in India is in many ways similar to that of China and the lessons learned from experiences have been applied in PRSF project design. It is envisaged that PRSF would kick start the Indian ESCO market.

Project Objective

The total project outlay is around Rs. 292 Crore (USD 43 million) consisting of a Guarantee Fund corpus of around Rs. 251 Crore (USD 37 million) and technical assistance of Rs. 41 Crore (USD 6 million). The project intends to provide partial risk cover (up to 75%) to Banks and FIs for the loans given by them to ESCO-implemented projects.

Project Eligibility Criteria

Energy Efficiency Projects implemented through performance contracting route are only supported under PRSF. The projects can be implemented at Large industries, Buildings, Municipalities and MSMEs. Loans starting from Rs.10 lakh upto Rs. 15 crore can be covered under PRSF provided the borrower is a MSME, as per GoI norms (MSMED Act 2006). Even non-BEE empanelled ESCOs are also eligible, provided they get an ESCO grading from any rating agency such as CRISIL (Credit Rating and Information Services of India Limited), CARE (Credit Analysis and Research), ICRA (Investment Information and Credit Rating Agency of India Limited), etc. This grading is similar to the exercise carried out under BEE ESCO empanelment. This arrangement gives an opportunity for all ESCOs to participate under the PRSF even if they have missed out the BEE empanelment process.

Building a Ecosystem for ESCO financing

One of the important objectives of the project is to create a bouquet of Banks / Non-Banking Financial Company (NBFCs) which are active in ESCO financing. As on date, five Memorandum of Understanding (MoU) have been signed with interested and eligible Banks / NBFCs to participate under PRSF, i.e. ESCO financing with PRSF guarantee support. With these agreements, it is clear that with a supportive structure in place, the Indian Banking system can adapt to evolving EE financing landscape such as ESCO financing.

To create awareness among the ESCOs and to sensitize the Banks, Financial Institutions and Non Banking Financial Companies (NBFCs) about the project, SIDBI has already organized more than 20 awareness workshops / training programs thus far benefitting more than 600 officers.

Supported ESCO Projects

The project till date has supported several ESCOs based EE projects with a total project cost of around Rs. 35 crores. The types of projects that have been supported under PRSF include the following:

- LED Street lighting in Municipalities
- LED lighting in Commercial Building
- Waste Heat Recovery in Dairy industry
- Variable Frequency Drives (VFDs) in Large Sponge Iron Industry
- Various EE measures in Hospital

PRSF is trying to support projects all across India. The geographical spread of the supported projects is given below:

- North - 57%
- South - 29%
- Pan India - 14%

These projects will result in an energy savings of around 23,000 MWh annually and reducing around 21,500 tons CO_2 emissions.

Recent Initiatives

One of the major tasks undertaken under the PRSF is market development. In order to have impactful discussions and fruitful outcomes, sectoral approach is being followed in market development activities. Recently, SIDBI had organized Awareness workshops and B2B (Business-to-Business) meetings targeting building sector stakeholders, ESCOs and Banks/FIs at Hyderabad, New Delhi, Bengaluru and Mumbai. More than 250 participants cutting across all sectors took part in these workshops. These activities are resulting in unearthing of new ESCOs and developing a strong pipeline of ESCO projects.

This is being subsequently followed with Awareness workshops for Municipalities and introducing the concepts and benefits of ESCO markets.

Standard Templates & PRSF Website

Under the Project standardized transaction documents for such projects have been developed and hosted on the project website (http://prsf.sidbi.in) for the benefit of ESCOs. Various project guidelines, standard templates for Energy Saving Performance Contract (ESPC), format of detailed Project Report

(DPR), Implementation Completion Report (ICR), etc. have been created and made available in the dedicated website. As a part of the ESCO market development, an interactive platform has been developed at PRSF website, wherein, ESCOs, various financial institutions and hosts can participate.

CONCLUSION

The project is expected to provide partial risk cover to more than 500 ESCO implemented EE projects which would mobilize financing to the tune of around Rs. 864 Crore (USD 127 million). Further, the project is expected to result into significant energy savings to the tune of 1,000 GWh and mitigation of CO_2 emissions reductions to the tune of 0.734 million tons.

With effective & innovative marketing and awareness creation activities, it is strongly envisaged that the targets would be met and exceeded and will bring about a paradigm change in the Indian ESCO market.

ACKNOWLEDGEMENT

Authors express their gratitude to Senior Management of Small Industries Development Bank of India (SIDBI) for providing this opportunity and their continuous encouragement.

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HOW TO HAVE YOUR CODE AND IMPLEMENT IT TOO-BUILDING EFFICIENCY CODE ADOPTION AND COMPLIANCE PILOT IN HYDERABAD

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Keywords: ECBC, Compliance, Hyderabad, Third Party Assessor

ABSTRACT

Building energy efficiency codes specify minimum energy performance levels for building design and construction. States and cities across the world – including in India – have adopted building energy codes to save energy, create healthier cities, and combat climate change. Yet, compliance remains a challenge. Based on initial results from a pilot project in the states of Telangana and Andhra Pradesh, this paper offers recommendations for adopting energy efficiency building codes and developing a code implementation framework, highlighting specific challenges and solutions.

The neighbouring southern states of Telangana and Andhra Pradesh adopted mandatory efficiency codes for commercial buildings in 2014, applicable to both states after bifurcation. Because much of the government leadership and construction activity is in the capital city of Hyderabad, the pilot project focuses on Telangana while developing an online compliance framework for Andhra Pradesh as well.

To accelerate efficient building construction, the State of Telangana and the Greater Hyderabad Municipal Corporation partnered with the Administrative Staff College of India (ASCI) and the Natural Resources Defense Council (NRDC) among key experts to engage with key stakeholders to adopt energy efficiency building codes and create a compliance framework. While working in Telangana, ASCI and NRDC also continued to engage leadership and stakeholders in Andhra Pradesh. Key stakeholders included real estate developers, architects, engineers, and key Indian and international experts. Through continual engagement, Telangana, piloted in Hyderabad, has developed an online energy code compliance framework that is an effective model for achieving India's energy efficiency goals and is potentially replicable in other cities and states.

INTRODUCTION

Building Energy Efficiency in India

Buildings, especially commercial buildings, are developing at a rapid clip in India and are already a major energy consumer. Accelerating energy-saving measures into the building sector is essential to low-carbon, climate resilient development. Clean energy development, such as energy efficiency, is especially important in emerging economies since a majority of the country's urban infrastructure is yet to be built. Energy efficiency is one of the most cost-effective ways to lock in energy savings for decades to come. Building energy codes are proven policy solutions that ensure minimum standards for energy efficiency in the construction and operation of buildings. Effective code implementation and compliance at the city, state and national levels can result in significant energy and financial savings for citizens, according to the Government of India. Implementing energy efficiency codes is critical to achieving India's goals to increase energy supply, energy access and energy security, while also improving air quality and combating climate change. Recognizing this opportunity, energy efficiency is a central strategy to reducing emissions intensity by more than 30 percent from 2005 levels by 2030, as part of India's climate commitment under the 2015 Paris Agreement (UNFCCC 2015).

The Energy Conservation Code and Code Adoption in Andhra Pradesh and Telangana

In 2001, the Indian Parliament passed the Energy Conservation Act, establishing India's Bureau of Energy Efficiency (BEE) as the nodal institution to spearhead energy conservation policies. With state and national government agencies as well as local and international experts, BEE developed the Energy Conservation Building Code (ECBC) for commercial buildings in 2007 and amended in 2009. The ECBC sets minimum efficiency standards for new commercial buildings and is a model for states to modify, adopt and implement the code as state law.

The ECBC is estimated to save 25 to 40 percent of energy use in buildings (Yu et al 2014, Tulsyan et al. 2013). Based on scenarios (high, medium and low) for code compliance, NRDC and ASCI estimated that with a combination of ECBC compliance and voluntary rating programs, India can potentially save more than 3,000 terawatt-hour (TWh) of cumulative electricity by 2030. The saved electricity is sufficient to power more than 350 million Indian homes annually between 2014 and 2030 (NRDC 2014).

Recognizing the energy and cost savings of efficient buildings and to address growing energy needs, the State of Andhra Pradesh (before state bifurcation into Telangana and Andhra Pradesh) enacted legislation to make the ECBC mandatory in December 2014. ASCI and NRDC were key knowledge partners in working with the state to modify and adopt the code into law.

The Telangana State ECBC (TS ECBC), like the Andhra Pradesh ECBC, applies to any commercial building or building complex that has a plot area of 1,000 square meters or more or a built-up area of 2,000 square meters or more. Buildings of a certain type, such as multiplexes, hospitals, hotels, and convention centres, must comply with the code, irrespective of their built-up area.

Origins of the Implementation Framework

After adopting the code, government officials and stakeholders remained committed to code implementation in large part because of the chronic power-blackouts that Hyderabad and the region experienced. Political will at the highest level in the two states emphasized energy efficiency in buildings as a central energy solution.

A technical committee in Hyderabad constituting key stakeholders was formed during the code adoption period to guide the implementation process. The technical committee continues to provided critical inputs for the pilot project's overall goals, described below. While Andhra Pradesh continues to make significant strides in implementing the framework, especially with construction in the new capital city Amaravati, the origins of the pilot are based in Telangana and Hyderabad since the code was originally adopted there in 2014.

PROGRAM AND PAPER OBJECTIVES

The overall goal of the pilot project was to develop an online compliance framework for building energy efficiency codes in India. The specific objectives were: to increase awareness about the energy savings potential from code implementation; to create buy-in from real estate developers, architects, engineers and other key stakeholders; to develop a collaborative process of code implementation bringing along all the stakeholder; to develop technical resources to facilitate compliance; and to develop an online compliance model that is fast, transparent, and replicable to other cities.

Available literature offers extensive evidence on the energy and money savings potential of building energy codes (NRDC 2011, 2012). Yet, few studies describe implementation and compliance strategies. With a view to outline a compliance model, this paper offers experiences from the code implementation process in the state of Telangana and Andhra Pradesh. The Hyderabad pilot for code compliance offers a simple and effective solution for energy efficiency code implementation in cities across India and globally.

The goals of this paper are to provide a narrative of the project, offer details on the first energy code implementation framework in India, describe the main challenges encountered, outline future activities, and highlight elements of the project that may be replicable. The Methods section outlines the approach to the project's development and implementation. The Results section present the project's activities and findings. The Discussion section reviews the findings in light of the published literature and implications for similar efforts in other cities and states.

METHODS

The project has seven overlapping but distinct phases. The first focused on planning and conceptual model development in which goals and objectives were clarified, leading to a roadmap for the pilot framework. The second phase focused on needs assessment with key stakeholders, communities, and organizations and the third on coalition building and outreach. The fourth phase developed the actual online compliance system. The fifth phase focused on building local capacity for implementation. The sixth phase focused on developing supporting infrastructure including technical resources for code implementation. The seventh phase is currently ongoing with a focus on guiding select building projects through the online implementation system. We describe the first six of these completed phases in the following section.

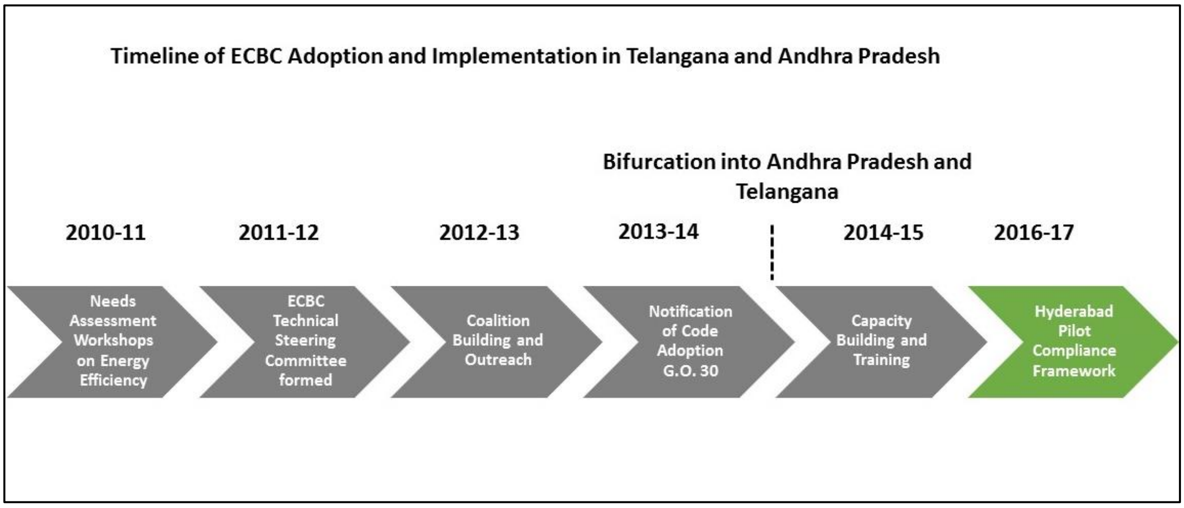

***Figure 1: Timeline of ECBC Adoption and Implementation in Telangana and Andhra Pradesh.* (Source: NRDC and ASCI)**

Throughout the phases, deep stakeholder engagement remained a key element. The timeline for the code adoption and development of the pilot framework are described in Figure 1.

1. Planning and Conceptual Model Development and Needs Assessment

The planning and conceptual model phase was undertaken via semi-structured, facilitated face-to-face meetings involving team members and important local partners, stakeholder representatives, and international experts. The goal was to integrate the best evidence regarding energy efficiency and programming preferences. The series of meetings included several workshops, involving over 40 energy experts, scientists, policy makers, government officials, and local stakeholders from India and the United States.

The needs assessment activities included characterization of the existing energy efficiency policies, building compliance system, the building stock, and stakeholder perspectives, focused on real estate developers. These assessments were done in parallel, using a variety of methodological approaches including roundtable discussions, surveys, technical workshops, and interviews.

This work was supplemented with other qualitative work, including a series of workshops and trainings with energy efficiency experts, real estate developers, government officials, media and community leaders. Comparative research was conducted on building code compliance in leading cities in Europe, the United States, China and elsewhere.

2. Coalition Building and Outreach

The coalition building and outreach phase focused on local government officials and real estate developers. Local government officials in charge of urban development, planning and energy are critical to adopting the code as well as compliance and enforcement. Real estate developers are essential to operationalizing and implementing the code requirements into building construction. Stakeholders, including architects, building consultants are also important to effective code adoption and compliance.

As an initial step, to engage market leaders and government officials, ASCI and NRDC published a series of papers and case studies in India. The purpose of the meetings, papers and case studies was to demonstrate that energy efficiency measures work in India, and to create a roadmap toward code adoption and implementation. (NRDC, 2012, 2013, 2014, 2015.)

Developer associations, in particular, the Confederation of Real Estate Developers' Association of India, the Andhra Pradesh Real Estate Developers Association and the Telangana State Real Estate Developers Association were vital in shaping the roadmap. Developers were invited to technical committee meetings as well as specially organized consultative workshops. The inclusive and collaborative multi-stakeholder consultation process helped raise genuine concerns and was instrumental in developing practical, mutually acceptable solutions while also building trust amongst stakeholders.

Local media was a key asset in developing the pilot framework and highlighting its importance. News articles in English and Telugu elevated the need for

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energy efficiency measures to save energy in the face of power outages and pollution. The city government also issued advertisements in local newspapers and trade publications inviting applications for third-party assessors training and certification.

3. Technical Steering Committee and Code Adoption

development authority areas and urban local bodies (ULBs) together with gram panchayat areas which are covered in master plans and general town planning schemes. The notification included direct support of the Municipal Administration and Development Department, Ministry of Energy, the Chief Secretary and a detailed technical Committee report on adoption of ECBC.

SIMPLE ADDITION TO BUILDING APPROVAL FORM INTEGRATING ECBC

C	DETAILS OF BUILDER / LICENSED PERSONNEL			
S. No.	Name	Address	License No.	Validity
1	.... Builder / Developer			
2	.... Architect/Engineer/Surveyor			
3	.... Structural Engineer			
4	.... ECBC Empanelled TPA			

Figure 2: Amending Building Approval Forms **(Source: NRDC 2016)**

To improve inter-agency coordination and facilitate expedited decision-making toward code adoption, Andhra Pradesh (prior to bifurcation), incorporated a technical steering committee in 2012 (G.O. 1328). The technical committee included representatives from the Municipal Corporation, Town and Country Planning Department, Department of Municipal Administration and Urban Development, Energy Department, Roads and Buildings Department, Public Health Department, New and Renewable Energy Development Corporation, Bureau of Energy Efficiency, and real estate developer associations, in collaboration with ASCI, NRDC, and other partners.

The technical committee prepared a roadmap for adoption of the ECBC into the state's existing legal framework, based on the analysis, benchmarking with best practices and expert recommendations.

In 2014, the state of Andhra Pradesh (prior to bifurcation) issued a legal notification and adopted the ECBC into state law by amending the state building rules. (G.O. 30). The notification applies to all urban

In 2014, the state of Andhra Pradesh, separated into two states. The north-western portion was bifurcated to form India's 29th state of Telangana. Hyderabad, the capital city of over 8.5 million people was transferred to Telangana, but recognized as a joint capital for ten years. While Hyderabad continues to move forward with code implementation, the newly formed Andhra Pradesh capital, Amaravati, has a tremendous focus on efficient construction as well.

All laws passed prior to bifurcation are effective in both states, including the ECBC. The bifurcation process slowed code implementation initially, however, the pressing need to save energy in the region and the political support built through the years has motivated code implementation in both states.

4. Online Code Compliance Framework

Once the ECBC was adopted, the Telangana government through the technical committee focused on developing an online compliance framework for ECBC code compliance with a pilot program in Hyderabad. The online compliance framework is an

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administrative tool that integrates energy efficiency and streamlines the approval process for building construction permits. The online compliance framework is designed to increase transparency and improve the timeline for the building permitting process.

Meeting on a quarterly basis, the technical committee served twin purposes – collaborative decision making and monitoring progress on ECBC compliance which ensured continued momentum as well as a stakeholder feedback process.

A technical team was created within the technical steering committee that reviewed existing forms used for the building permission application and identified effective measures to integrate ECBC compliance requirements.

For building permits, the Telangana government is transitioning to an online platform for building applications, the Development Permission Management System (DPMS). Andhra Pradesh has also developed and adopted a similar DPMS. The development of the online DPMS provided a timely opportunity to integrate ECBC code compliance requirements into the online process. The DPMS expedites the building permission process and makes it transparent and accountable.

In efforts to streamline energy efficiency measures, ECBC compliance requirements were added to the official forms that were being migrated to the online platform. The forms and steps for the ECBC were developed with extensive stakeholder input, including real estate developers, architects, and third-party assessors.

Strengthening Local Capacity

The Telangana government, based on recommendations from the technical steering committee used several methods to strengthen technical capacity, starting with the pilot project in Hyderabad. Empanelling third party assessors and creating a two-tiered approach (design and construction phrase) to code compliance were critical.

Third party assessors are key to the system since they provide the technical expertise to developers, and alleviate the burden on government experts. Third party assessors are empanelled by the state and review

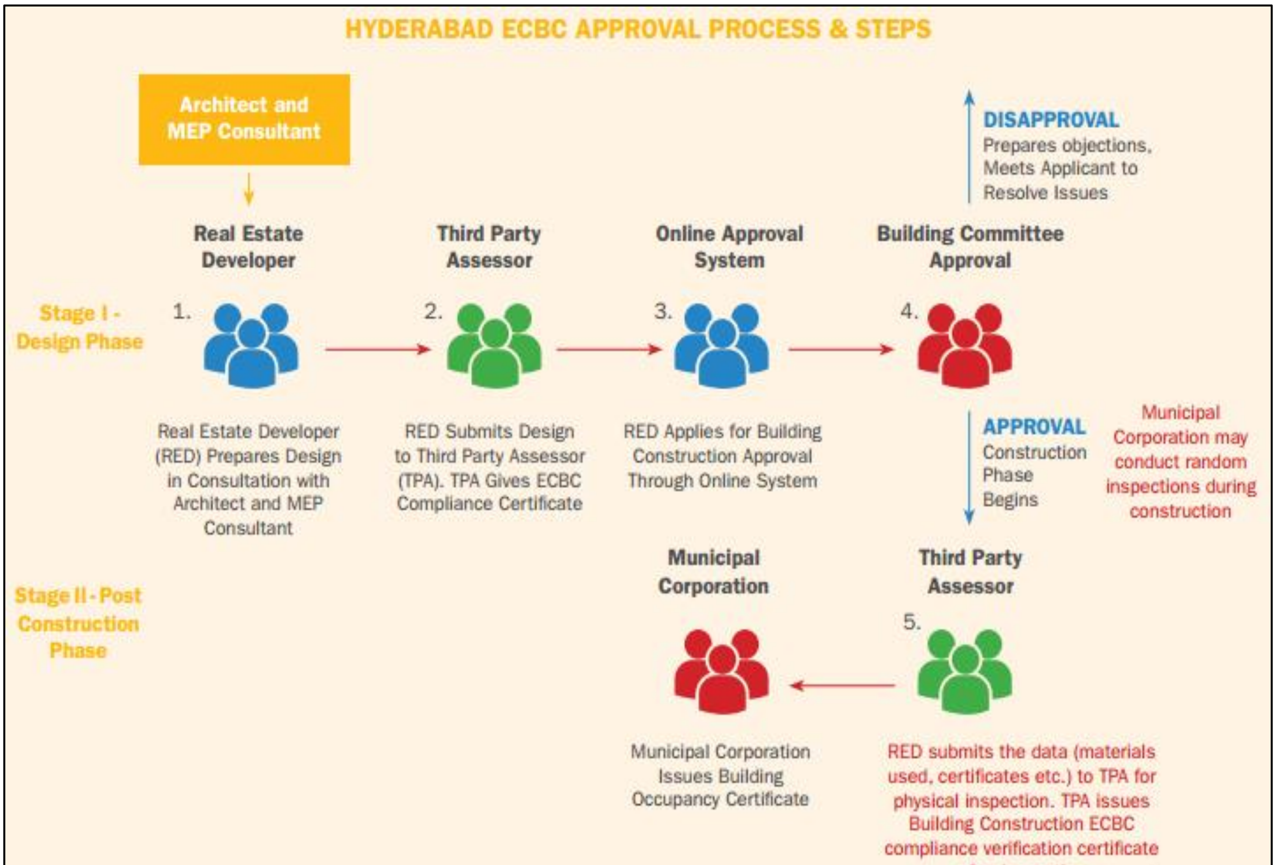

Figure 3: TPA Model for TS ECBC Compliance (Source: NRDC 2016)

and certify the building for ECBC compliance both before and after the construction stage.

As shown in Figure 4, third-party assessors, trained and empanelled with the government, inspect the building in two stages to ensure effective compliance.

i. Stage I – Design Phase: Third-party assessors review the drawings and specifications and then issue an ECBC compliance certificate.
ii. Stage II – Post-Construction Phase: Third-party assessors review the ECBC compliance forms and conduct a physical inspection of the building to ensure ECBC compliance with the submitted plans and simulation report.

The third-party assessor approach creates a scalable market for ECBC trained and empanelled professionals. The two-step process ensures that the building is constructed according to the design. To further ensure compliance, municipal officials conduct building inspections on a random sample basis.

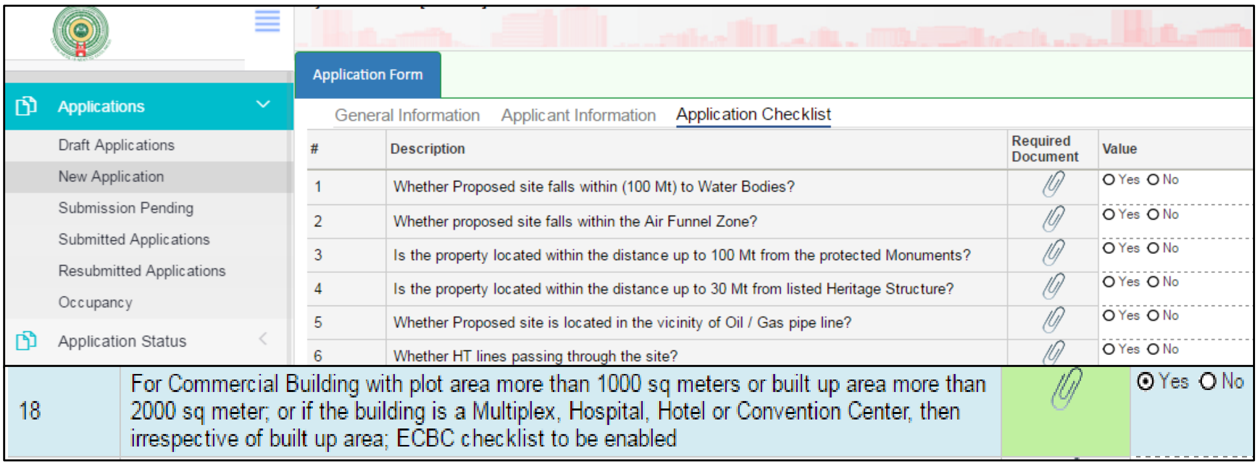

Figure 4: Integrating ECBC Requirements in Online System **(Source: NRDC 2016)**

In a large-scale capacity building exercise, supported by BEE and United Nations Development Program (UNDP), more than 700 architects, engineers, and experts received training on the ECBC in both Telangana and Andhra Pradesh. The State of Telangana, with ASCI, NRDC, and technical experts at the International Institute of Information Technology (IIIT) Hyderabad, conducted workshops to enhance capacity among builders, designers, engineers, architects, and other stakeholders on the code compliance process. Additionally, the Telangana government launched a program to certify a pool of 100 ECBC experts as third-party assessors in Telangana to augment the technical capacity around code compliance.

5. Facilitating Compliance

The Telangana government has developed specific resources to alleviate concerns about code complexity and to provide easy to understand and practical compliance guidelines. The pilot focused on Hyderabad for developing resources.

To enable the use of the online compliance system and provide answers on the technical aspects of the code, the Telangana State government developed a list of Frequently Asked Questions (FAQs). The FAQs address queries in three main sections related to the applicability of the code, its technical provisions, and the online compliance process, to help building owners and developers navigate the process of securing compliance for the TS ECBC. Since most states' building energy codes are adapted from the same national code, the technical guidelines in the FAQs can be useful for users beyond Telangana and serve as a model for other states and cities to develop their own versions. The state of Andhra Pradesh is currently in the process of developing similar FAQs for the Andhra Pradesh ECBC.

And since the ECBC was originally developed as an adaptation of ASHRAE Standard 90.1, which is also the case for the national energy codes of many other countries, the Telangana system has relevance wherever the ASHRAE Standard is used.

Based on real estate developer and stakeholder feedback that specific portions of the TS ECBC needed clarification, the Telangana government along with IIIT, ASCI and NRDC developed handbook with a set of draft guidelines for compliance. The handbook with draft guidelines provides easy-to-understand provisions that clarify and interpret portions of the TS

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ECBC and integrating it with the online compliance system. The guidelines also further adapted the code to the local context and climate. Examples include the removal of requirements for cold and moderate climate zones that are not relevant for the warmer state of Telangana.

The guidelines provide practical means of compliance, such as by providing consistent units of insulation (retaining U-value instead of both R-value and U-value for wall and roof insulation), and introducing and referencing test procedures wherever applicable.

As of writing of this paper, the guidelines are posted on the Telangana State Renewable Energy Development Corporation's (TSREDCO) website for public comments, and the technical FAQs are also available for stakeholders use at Greater Hyderabad Municipal Corporation and TSREDCO websites (NRDC et al 2017). The guidelines aim to strengthen Telangana's building energy code and facilitate greater compliance, all the while keeping the cost of compliance reasonable—both for building owners and developers on the one hand and urban local bodies on the other.

To further assist early building projects, both Telangana and Andhra Pradesh have established an ECBC Technical Cell, in their respective capitals, to provide technical support and expertise on specific aspects of the code, will manage the FAQs and develop new resources as required.

PILOT PROJECT RESULTS AND FINDINGS

The online implementation system is a part of the larger building permission system in Hyderabad which is currently partly operational. New building applications are submitted digitally via the online system and, based on the building particulars in the application, the online system checks for ECBC applicability and, for eligible buildings, prompts applicants to enter the details of the third-party assessor in the web form. Users can upload the supporting technical documents, which will then be reviewed by the Town and Country Planning Office in Hyderabad.

Both Hyderabad and Amaravati have identified initial, demonstration projects for the online system. These include private developments as well as new government buildings.

As the database of ECBC documents builds up with the local government, it allows for future policy tools such as benchmarking energy performance of buildings and creating operational and asset ratings (Goldstein and Eley 2014).

DISCUSSION

Despite the high energy saving potential, enacting energy efficiency codes into law is low in India, and operationalizing codes through effective implementation frameworks is even lower.

According to the Indian government, as of December 2015, 300 commercial buildings in India are ECBC compliant (UNFCCC 2015). With thousands of commercial buildings constructed since the launch of ECBC, compliance remains significantly lower than what was projected at the time of launch in 2007 – 35 percent code compliance by 2015 and 64 percent by 2017 (UNDP 2011).

Low code compliance levels can be attributed to several reasons. First, even after ten years of the launch of the ECBC, the code remains concentrated in only a few states. So far, only 10 out of the 29 Indian states have adopted the ECBC as law. Secondly, in the states that have notified the ECBC, the process to incorporate the code in local building bye-laws is laborious and has not been fully established. Finally, where notified, and included in the bye-laws, there is a slow uptake of the code due to lack of awareness and buy-in from the builder community and inadequate capacity of urban local bodies to implement the code.

Working closely with the states of Andhra Pradesh and Telangana on code adoption and compliance, NRDC and ASCI conducted a series of stakeholder consultations. Through these consultations, we identified the following common barriers and recommendations:

Lack of awareness

Green buildings have gained increased prominence in India over the last several years and the country has one of the largest areas of green certified floor space in the world. However, while voluntary labels such as those offered by the Indian Green Building Council (IGBC) and Green Rating for Integrated Habitat Assessment (GRIHA) are recognized, and sought, building energy codes are not as well known. ULBs

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do not have the resources to build the kind of awareness that private organizations have and because of this lack of awareness among buyers and users, ECBC compliance is generally not discussed in real estate transactions at all.

In Andhra Pradesh and Telangana, extensive and collaborative stakeholder engagement focused on awareness is a key recommendation. Broad stakeholder engagement, including individual meetings and roundtables to discuss barriers and solutions works to increase awareness. Case studies, reports, factsheets, and presentations from local and international experts work to increase awareness. Engaging the media and trade associations in local languages in addition to Hindi and English is also vital to increasing awareness.

Government officials

Government officials at multiple levels are critical to code adoption and compliance. The decision to adopt the ECBC is ultimately taken at the highest level within the state. Operationalizing the code is mandated to urban local bodies and planning departments that have many competing priorities.

In Andhra Pradesh and Telangana, leadership by the Chief Secretary and engaging key ministries proved effective in creating government support. Creating the technical steering committee through a government order has helped momentum in piloting the code compliance framework and online system in Hyderabad.

Real estate developers

Building energy codes have specific technical requirements that real estate developers perceive to be complex, time-consuming and costly. Some developers are therefore hesitant to commit to code compliance, treating it as an additional cost, without incremental benefits.

In Andhra Pradesh and Telangana, neither ECBC adoption nor the pilot code compliance framework would have been possible without active engagement by real estate developers. Ensuring the developer inputs are part of the code and framework is essential to making them work. In particular, real estate developer associations can be forward-thinking and can help create solutions, such as incentive programs.

Architects, engineers, and technical consultants

The designers and technical consultants to the building project are the actual ‘users’ of the code incorporating provisions into the building design and construction. However, many professionals are either not well versed with the code provisions or find it challenging to meet the code requirements - especially building materials, testing, and modelling of mechanical systems – highlighting them as impractical to integrate with local building practices.

In Andhra Pradesh and Telangana, capacity building and training programs with architects, engineers and technical consultants were part of strengthening knowledge among users. Focusing on Hyderabad and key cities, introductory ECBC programs and training increased information for users. Building on these trainings, programs to empanel third party assessors also increase user knowledge.

Limited capacity for enforcement

Urban local bodies in India, and elsewhere, are often under-resourced. Until recently, most government building approval processes were based on submission and scrutiny of physical documents with little and often tedious flow of bi-directional communication. The ECBC offers two pathways for compliance - prescriptive, in which specific requirements are to be met; and whole building performance, which requires modelling results to demonstrate that the building design leads to lower energy consumption than a stipulated base case. In either scenario, there are mandatory provisions to be complied with. ULBs do not have the technical expertise to inspect code provisions or interpret modelling results making it extremely difficult to enforce. ECBC notification in a state also requires amendments to existing bye-laws, which, in turn, mandates various departments to make decisions about changes to entrenched processes and revisions to official documents. Government decision making can take time - often due to lack of coordination and effective communication, and sometimes change of administrative personnel.

In Andhra Pradesh and Telangana, developing an online compliance system with the trained third party assessor model is key to overcoming the limited enforcement capacity. First, requiring online submissions for building permits that incorporate energy efficiency measures streamlines the overall process. Second, ensuring that applications are verified through third party assessors reduces the number of trained government experts needed to approve applications. Finally, random inspections

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during the building design and construction phase help increase the enforcement capacity and overall compliance.

IMPLICATIONS

Many Indian states are currently in the process of adopting the ECBC under their state and city bye-laws. In 2017, the Bureau of Energy Efficiency extensively reviewed and updated the code, ECBC-2017, which is scheduled for amendment into the Energy Conservation Action in early 2018. Both Andhra Pradesh and Telangana are working on integrating ECBC 2017. Updating the ECBC and adopting it into state laws is critical. Strong code compliance is vital to achieve the full energy savings potential of the ECBC.

The Telangana ECBC implementation framework piloted in Hyderabad has been designed specifically for the building construction and approval processes in local, urban bodies in India based on extensive ground-up experience addressing typical barriers to policy implementation. The government of Telangana is the first in the country to incorporate energy code provisions in its online building approval system, and other states are following similar digitization and can benefit from the Hyderabad pilot.

Andhra Pradesh is in the process of integrating ECBC into its advanced online building permission system and ensuring that the new capital Amaravati is developed as one of the most energy efficient cities in India.

The initial results from this pilot project in Telangana and Andhra Pradesh can be used by other regions to adopt energy efficiency codes and develop effective compliance frameworks. Advancing energy efficient construction across India's cities is critical to saving energy, increasing energy access, combating pollution and strengthening prosperity.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the Greater Hyderabad Municipal Corporation, the Government of Telangana State, and the Government of Andhra Pradesh for their leadership and support on the pilot project. This project has been carried out in conjunction with ECBC adoption and implementation efforts at the national level spearheaded by the Bureau of Energy Efficiency (BEE), Ministry of Power. We are grateful to Dr Ajay Mathur and Mr Sanjay Seth, both formerly at BEE, for their leadership on energy efficiency in India. We also thank the Confederation of Real Estate Developers of India and real estate developer associations in Telangana and Hyderabad as well as the Confederation of Indian Industries-Indian Green Building Council and the Green Buildings Rating System India.

We thank Mr S. Srinivas and Dr Satish Kumar for contributing their expertise. We also thank former ASCI colleagues Mr Pavan Parnandi and Pallavi Nadimpalli and NRDC colleagues Ms Meredith Connolly, Dr Radhika Khosla and Ms Shravya Reddy for their work on the early stages of the Hyderabad pilot. Finally, a special thanks to our NRDC colleagues, Mr Karan Chouksey, Mr Bhaskar Deol, Mr Sayantan Sarkar, Ms Laasya Bhagavatula, Ms Kriti Sehgal and Dr Kim Knowlton as well as colleagues from NRDC's China Program for their valuable inputs on developing this paper.

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DEMONSTRATING LEADERSHIP OF CITIES ON EFFICIENT BUILDINGS- LESSONS FROM THE BUILDING EFFICIENCY ACCELERATOR

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Keywords: Building efficiency Accelerator, cities, policies, actions, local governments

ABSTRACT

Buildings are responsible for about one-third of the energy demand and one-fourth of all GHG emissions globally. Implementation of known energy efficiency best practices in this sector can reduce energy demand by 30% by 2050. It is now well acknowledged that the major barriers to efficient buildings are institutional and behavioural rather than technical or financial.

The Global Building Efficiency Accelerator (BEA), is one of the six efficiency accelerators under the United Nations Sustainable Energy for All (SE4All) initiative. The Accelerator works with cities to help local government bodies create enabling conditions for building efficiency. The BEA provides cities a platform to engage with private sector and offers support on (1) assessing and prioritizing locally suitable policies and actions (2) implementing actions through provision of expertise, resources and tools and finally (3) tracking actions and reporting progress and sharing lessons learned with BEA partner cities. 23 cities are a part of the BEA which comprises of over a network of 70 institutions, NGOs, civil society groups and businesses.

Strong commitment and leadership has been shown by BEA partner cities. Our paper describes the experiences working in these cities and lessons learned in implementing the partnership over the last two years.

INTRODUCTION

Urban buildings today are the single most energy and emissions intensive entities. In 2013, buildings were responsible for about 30% of total final energy consumption or half of global electricity (IEA 2016). An estimated two-thirds of the 9.5 billion people in 2050 will be living in cities (IEA 2016) accounting for 84% of global GDP. Consequently floor area in cities is projected to reach 254 billion m^2, and more than 75% of this growth will come from non-OECD countries like India and China.

The implementation of energy efficiency policies and deployment of best available technologies can result in energy savings more than 50EJ by 2050, which was equivalent to combined building energy use in China, France, Germany, Russia and the US in 2012 (IEA 2016a). Energy efficient buildings also present enormous opportunities in reducing emissions and improving overall quality of life of occupants. In addition to reducing energy costs for building occupants, efficient buildings are also more comfortable and add value to the property. Recognizing the importance of energy efficiency in achieving SDG 7, the United Nations Sustainable Energy for All (SE4All) launched the global energy efficiency accelerator platform in 2014. The Platform consists of six individual accelerators to target buildings, lighting, appliances, district energy systems, industry and transportation. Each accelerator is working towards achieving the SE4All objective of doubling the rate of improvement in energy efficiency. The Building Efficiency Accelerator (BEA) is one of these six accelerators. The BEA assists sub-national governments in speeding up the process of adoption of best-practice policies and implementation of building efficiency projects, with the goal of doubling the rate of energy efficiency improvement in the building sector by 2030.

BACKGROUND

BUILDING EFFICIENCY

The efficiency of a building is the result of how productively resources—such as energy, water and materials—are used in the construction, operation and maintenance of that building. Efficient buildings allow for the same or greater comfort, economic activity and human productivity with fewer resources. They can produce cost savings and other local economic benefits, improved human health, and reduced environmental pollution. Efficiency is one essential characteristic of what are commonly known as “green buildings”.

The building sector contribution to a below 2°C pathway requires avoiding at least 50% of projected energy use growth by 2030 and an investment of USD 220 billion annually in energy efficiency by 2020 (GABC 2016). Global energy efficiency investment in buildings was USD 90 billion in 2014 and comprised mostly of programs on improvements and implementation of building efficiency codes and standards (IEA 2016a). While globally energy

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consumption of buildings has declined from an annual average of more than 230 kWh/m2 in 1990 to 160 kWh/m2 in 2013, further energy savings potential exists. Developing and emerging economies contribute to more than half of this potential (IEA 2016a). The implementation of energy efficiency policies and deployment of best available technologies can result in energy savings more than 50EJ by 2050, which was equivalent to combined building energy use in China, France, Germany, Russia and the US in 2012 (IEA 2016). Yet today, two-thirds of the buildings stock that exist has no codes or standards applied to it (IEA 2016).

In India, population living in cities will increase from 33% in 2013 to 50% in 2050 (IEA 2016) with a corresponding increase in floor area by 400% to reach 35 billion m^2 in 2050 (GBPN 2013). As income levels rise and electricity becomes more reliable, residential electricity consumption is expected to increase manifolds. National programs like 100 Smart Cities, National Mission for Sustainable Habitat, AMRUT and Housing for all by 2022 are expected to drive this increase in building sector electricity consumption. In 2050 India is expected to have the largest building stock in the world. To avoid getting locked-in to inefficient buildings India needs to act quickly to maximize energy savings from this sector. In a 2012 analysis (Urge-Vorsatz et al 2012) the unexploited energy efficiency potential from the buildings sector was estimated to be around 2988MW of generation capacity or half of the peak deficit in 2015-16. Through aggressive implementation of policies to improve efficiency of heating and cooling appliances, electricity consumption by buildings can be reduced by up to 30% in 2050 compared to 2005 (GBPN 2013). If left unaddressed, an estimated 1.2 Gt of CO2 emissions will be locked into buildings alone (GBPN 2013).

BUILDING EFFICIENCY ACCELERATOR

Components: The BEA comprises of three key components- (1) The BEA partnership (2) Technical Assistance and (3) Deep-dive engagements.

Figure 1: Components of the BEA

The BEA is a partnership of sub-national jurisdictions, non-government organizations, civil society development and organizations and the private sector. Recognizing that cities are the scale of implementation of most building efficiency policies and programs, BEA works only with cities and similar subnational jurisdictions (e.g. municipal corporations). The global BEA is currently a partnership between over 35 businesses, NGOs and multilaterals assisting 28 subnational governments in 18 countries to act to improve their buildings.

Technical assistance is provided by BEA global organizational partners to participating cities (Table 1). The partners bring contribute their expertise and networks to build a strong foundation for accelerating building efficiency in participating subnational jurisdictions. The range of technical competencies provided by global partners has led to the creation of six thematic working groups that complies resources, develops and delivers training programs and on-site technical assistance to cities in each thematic area. There are BEA working groups on (1) Building Energy Codes (2) Above code and certifications (3) Finance (4) Public procurement (5) Retrofitting existing buildings (6) tracking progress, each group is headed by a different global partner. Webinars are organized regularly by working groups inviting participation from cities and local stakeholders to share experiences.

Table 1: BEA global organizational partners as of March 2017

NGOs/Associations/Multilateral Organizations	
100 Resilient Cities	International Finance Corporation – EDGE
Architecture 2030	Investor Confidence Project
Buildings Performance Institute Europe	Natural Resources Defense Council

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Business Council for Sustainable Energy	UN Development Programme
C40 Cities Climate Leadership Group	UN Environment Programme
Clean Energy Solutions Center	United Nations Foundation
Copenhagen Centre on Energy Efficiency	US Green Building Council
Global Buildings Performance Network	World Bank Group – ESMAP
Global Environment Facility	World Business Council for Sustainable Development
Global Green Growth Forum	Partnering for the Green Global Goals 2030 (P4G)
ICLEI - Local Governments for Sustainability	World Green Building Council
International Energy Agency	World Resources Institute
Service Providers/Companies:	
✓ Accenture	✓ Ingersoll Rand
✓ Alstom	✓ Johnson Controls
✓ The Carbon Trust	✓ Philips
✓ China Energy Conservation and Environmental Protection Group	✓ Saint-Gobain
✓ Saint-Gobain	✓
✓ Danfoss	✓ TECNALIA

The strong technical expertise of BEA global partners is a robust resource available to partner cities at will. Participating cities can reach out to global partners specializing in specific topics and seek support.

All the 30 cities are provided tools, trainings and resources to plan, implement and track actions. From the 30 cities in the BEA partnership, a smaller set of 6 cities were selected by the BEA Steering Committee as ‘’deep-dive’’ cities. Each of the deep-dive cities was provided technical assistance in form of local staffing for an initial period of 18 months. Several criteria were used to select deep dive cities- (1) high-level political commitment by city (2) no local elections in 2 years after the selection of city as deep-dive (3) strong local presence of a BEA partner organization that could lead and facilitate on ground action (4) geographic diversity (5) an assessment of challenges and opportunities of the city and plan for addressing them (6) possibility of replicating the work across other cities.

BEA Process: The BEA process of engagement in a city includes support for**:**

- Assessing and prioritizing locally-appropriate policies and actions
- Implementing actions, through matching needs with expertise, resources and tools
- Tracking action and documenting progress, and sharing lessons learned

BEA engages with cities through a menu of policy options and key actions (Table #) based on the needs of the city and the activities that the partnership can provide in each location. Cities will prioritize policies and activities, and the partnership will connect them to resources and engagement around those priorities

Cities or subnational governments that join the BEA are asked to make three specific commitments to gain assistance from the partnership:

1. Implement one enabling policy
2. Implement one demonstration project
3. Create a baseline of building energy performance, track and report annual progress, and share experiences and best-practices with other governments.

Subnational jurisdictions participating as ‘’deep dive’’ cities, must commit to assigning a point of contact for activities identified in the agreed work plan.

The BEA global partners play an important role in seeking interest from cities/subnational jurisdictions to participate in BEA. Each BEA partner brings its offer and geographical market knowledge to the benefit of the team and to the cities where the BEA partnership collectively works. ICLEI, WRI, GBPN, WBCSD, C40, and the Green Building Councils are all non-governmental organizations that also have relationships or staff in multiple emerging economies and rapidly growing urban areas, enabling the development of customized engagements that match the needs of local stakeholders and competencies of partners.

Local presence of BEA partners has been helpful in soliciting participation of 30 cities in a span of less than 2 years. These BEA partners then serve as local partners in the city and engage with policy makers as BEA partnership. There is no restriction with respect to the type of organizations that can play the role of local partners. Private sector partner like Johnson

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Control can also perform the role of the local convenor and technical advisor.

New partners can be added to the partnership through the signing of a BEA partnership agreement. Partners are encouraged to not only play a local role but regional role in engaging with civil society and private sector partners. Organizational partners must assign a point of contact for activities and work towards advancing the goals of SE4All and partner cities.

The BEA city engagement model: The BEA steering committee has developed a standardized process for engagement with cities and relevant stakeholders. The 5-stage BEA process gives partner cities clarity on defining goals and timelines. The BEA replicates the model in cities that join the partnership. The 5 stages in the BEA process are (1) Commitment (2) Assessment (3) Development (4) Implementation and (5) Improvement.

Figure 2 describes the typical duration and goals for each stage in the BEA process. The ultimate objective being achieving the BEA 2030 vision of doubling energy efficiency improvement in the city.

A framework for tracking progress of each stage has also been developed that helps cities identify measurable indicators for the goals at each stage.

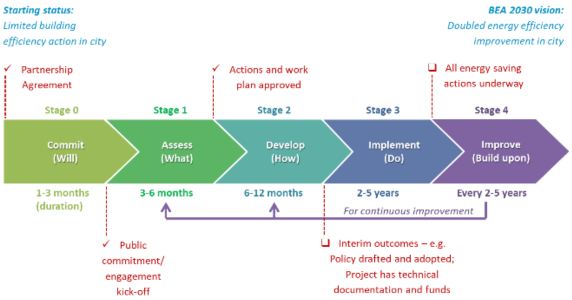

Figure 2: BEA city engagement model

BEA phase 1: The first phase of the BEA for the time period 2015-17 comprised of call for seeking participation of at least 50 cities. A subset of those cities, at least 30 joined the BEA in 2016-17 committing one building efficiency policy, one project, tracking progress and sharing best practices.

BEA assistance to all cities: To meet the three commitments BEA cities are offered several types of resources. These are include operational resources like guidance documents like tool kits, templates, worksheets for gathering input from stakeholders and for prioritizing policies and projects, reporting frameworks for tracking progress and technical resources like trainings, and webinars. This support is provided to each city to improve their capacity to act and create a deeper engagement with interested parties.

For ''deep-dive'' cities the BEA engagement extends beyond just provision of these resources. Such cities are offered technical assistance on- the-ground to assess, develop and implement priority policies and projects and given help with monitoring and reporting progress against baseline assessments. Figure 3 shows the location of BEA 1.0 cities including deep-dive cities, one of which Rajkot, is in India.

There is no fee to participate in BEA and city projects are not provided direct funding. The partnership instead helps identify fungible project and creates conditions that indicate the preparedness of cities for private/public or donor financing. Partners organize stakeholder workshops, seminars and other similar events to promote projects and attract potential investors. Communications of policy and project progress through different forms of media plays an important role in gaining interest from funders.

It has been observed that participating cities are in different stages of the BEA process and do not require assistance at every stage of the BEA process. Besides, the BEA and its partners do not have the resources to support a deep engagement with every city. There is therefore differentiated levels of support provided to BEA partner cities and the deep-dive cities. Network cities have been found to move along the BEA process with some technical support from BEA resources and tools. When needed network cities can reach out to the BEA thematic working groups or BEA partner organizations and work on a mutually convenient way to leverage support. Some of this takes the form of remote technical assistance or peer to peer-exchange of experiences and lessons learned from other partner cities.

BEA assistance to deep dive cities: For the deep dive cities, a detailed work plan is prepared by the focal BEA partner that describes the complete set of activities for implementation. Local partners work with city government stakeholders to develop the

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work plan and provide man power to steer the BEA process.

- *Figure 3: The BEA network of cities*

BEA progress: BEA uses an outcomes, activities and indicators framework to continually measure its impact. Each outcome is mapped to a set of activities. Indicators help assess progress on those activities. In the ongoing phase of BEA also called BEA phase 1 or BEA 1.0 (2015-2017), engagement with most deep-dive cities started in early 2016. Within a span of 18 months some cities have made remarkable progress in securing local government commitments and identifying policy priorities. Table 2 describes the commitments and progress made in the 6 deep-dive cities.

Progress in the remaining network cities has been difficult to achieve in the absence of well-resourced local partners. The only exception is the city of Dubai, the World Green Building Council's UAE counterpart- Emirates Green Building Council has been working with the Dubai Supreme Council of Energy to undertake a benchmarking project of 100 buildings in Dubai on energy performance. Hotels, malls and schools have been invited to participate in the benchmarking process.

Table 2: The six deep-dive cities, their commitments and progress as on May 2017

Deep-dive city and date of joining	Commitments	Progress
Mexico City, Mexico	Policy: Adopt and implement energy code for private buildings Project: Retrofit of 4+ municipal buildings	Stage 5
Eskeshir, Turkey, February 2016	Policy- National level mandates for energy performance certificates for all large buildings Project- Incorporate building efficiency measures in one-or more planned district-scale urban transformation projects	Stage 2
Rajkot, India, April 2016	Policy: Develop a green building policy for Rajkot city Project: Public building retrofits	Stage 2
Belgrade, Serbia, April 2016	Policy: Develop standard procedures for building retrofits, including consumption based billing Project: Conduct an energy retrofit on one or more public buildings	Stage 2
Bogota, Columbia, April 2016	Policy- Integrate a national regulation for building construction into local plans Project- Apply best practices for new efficient buildings in a district scale regeneration project	Stage 2
Da Nang, Vietnam, January 2016	Policy: Develop a directive to implement efficiency measures in large buildings Project: Implement energy efficiency solutions for a hotel demonstration project	Stage 2

Example of BEA working: Mexico City

Mexico City was one of the first few cities to join the BEA platform at the UN Climate Summit in September 2014. The city made quick strides on the BEA process (Figure 4):

<u>Stage 0- Commitment</u>- The Secretary of Environment, Mexico City, the local city jurisdiction partner committed to 1 policy action- implementation of a building energy code and 1 project action- retrofitting a set of public buildings. The local BEA partner organization WRI Mexico leveraged its existing relationships with the city government to engage them and other global BEA partners in the BEA process.

<u>Stage 1- Assessment</u>: A kick-off workshop organized in March 2015 convened close to 100 policy makers,

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business leaders and CSO representatives to seek agreement on the common vision and devise a work plan for meeting the commitments. Attendance from high-level officials of national and local government demonstrated leadership support for BEA's core objectives on accelerating building efficiency. Soon after, the local government integrated the BEA project into the Mexico City's Climate Action Program furthering BEA's contribution to the city's climate mitigation targets. The workshop served as the foundation for public and private sector partnership in Mexico City. This partnership now exists as an advisory group and four multi-stakeholder working groups on (1) local building energy codes (2) finance (3) retrofits and (4) administrative actions. The advisory group provides inputs and advice to ongoing BEA activities, meeting milestones and timelines. The working groups are responsible for identifying specific actions and goals, developing a locally-appropriate work plan and providing technical support for implementing the plan.

Figure 4: BEA process in Mexico City

Stage 3: Development- The working groups continued to meet between March and September 2015 to discuss and finalize recommendations for the government on the committed policy (energy codes) and project (retrofits). These were presented to the Secretary of Environment, Mexico City in October 2015. Finally, the recommendations were approved by the Ministry of Environment on December 3, 2015 at the COP21 where the Mayor of Mexico City announced a plan for energy code implementation in Mexico City.

Stage 4: Implementation- The BEA work plan for Mexico City steered ahead between January and October 2016. In March 2016, Mexico's Energy Conservation Building Code was officially launched while the adaptation and adoption of the new building code commenced in June 2016. Subsequently, code implementation officials have been given training.

Stage 5: Improvement- Additional plans for improvement have been identified. These include setting an audit and retrofit target for the cities full portfolio of municipal buildings, and a city division to manage the program. A building challenge to get large property owners to set targets for energy performance improvement of their buildings has been designed. The plan also comprises of regular reviews and revisions of the energy components of the city's construction regulations and its implementation process in the city.

BEA deep-dive engagement in Rajkot, India

In Rajkot, the Rajkot Municipal Corporation (RMC) is the local jurisdiction partner and receives technical support from ICLEI to develop and implement activities. BEA activities in Rajkot were initiated in July 2016 and a kick-off workshop convening different stakeholders was conducted in November 2016.

RMC's BEA commitments are (1) a green buildings policy for Rajkot city and (2) energy efficiency retrofits of at least 1 public building owned by the corporation. A draft of the policy is being reviewed by local stakeholders like builders, architects and industry associations to solicit feedback and inputs on incentive structures that will support policy implementation.

Strong leadership and participation demonstrated by the RMC Commissioner has helped in ensuring the timeliness of BEA activities despite changing political scenarios. Technical assistance provided by ICLEI to the Corporation is steering the BEA process in Rajkot. Presence of other bilateral capacity building projects in Rajkot e.g. The Swiss Development Corporation's (SDC) Indo-Swiss BEEP and CAPACITIES project that have building efficiency components have helped sustain the momentum and explore synergies effectively.

Building efficiency programs globally:

There is growing momentum by cities to commit to emissions reductions and contribute to a global solution to climate change. The Compact of Mayors and other subnational government associations and partnerships continue to pledge ambitious action – over 400 commitments by mayors were logged by the Compact at the UNFCCC COP 21.

These cities want to ensure that their actions to reduce emissions also contribute to their economic and social

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development goals—such as competitiveness, infrastructure, housing, inclusion. Many are embracing building efficiency because it can provide these multiple benefits.

There are building efficiency initiatives exclusively focussing on accelerating building efficiency globally and increasing the building sector's contribution to climate goals. Most of these are networks or alliances of civil society, private sector, local and national governments. A description of some of these initiatives is given in table 3**.** The BEA relies heavily on the work and engagement with a variety of efforts. These include:

- Policy analysis and the technology roadmaps conducted by IEA and the World Bank's ESMAP program,
- Experiences from C40 and ICLEI creating cross-city learning networks,
- Private sector engagements such as WBCSD's EEB 2.0 which brings businesses together in a "lab" engagement process

The strength of the BEA lies in its structure, which is a combination of all these initiatives and programs. The BEA is focused on delivering city level efficiency. It is a network, an alliance, a platform for engaging multiple stakeholders, providing technical assistance and stimulating local action in cities. The phase 2 of BEA would be also looking at strengthening partnership with national governments and stakeholders, addressing a critical gap that has been identified by the BEA steering committee.

Table 3: International building efficiency initiatives.

Program	Description
C40 cities Private Building Efficiency Network (PBEN)	Network of 13 cities (as on December 2015). Focus areas: (1) Policy development- Understanding what policies and programs cities have in place (2) Data insights- how cities are collecting and using building energy data and (3) stakeholder engagement- engaging with owners, landlords and tenants to take action Process: Limited public knowledge on network's engagement. Sydney and Tokyo are network leads
WBCSD Energy Efficient Buildings (EEB) initiative	The project involved the development of a model for engaging with multiple stakeholders to drive action in local markets. The model involves identifying and bringing together public and private sector stakeholders from the buildings sector who then participate in a 3-day EEB lab to identify priority issues, discuss, build trust and a shared vision. After the lab, long term action is driven by the creation of a local EEB platform. Since 2014, EEB labs have taken place in 10 cities and EEB platforms have been established in 5 cities.
2030 Challenge	Architecture 2030 launched 2030 Challenge inviting participation from global architecture and building community to adopt energy reduction, GHG emissions reduction targets and achieve carbon neutrality by 2030.
Global Alliance for Building Construction (GABC)	Alliance of 24 countries and 72 non-state organisations (sub-national, non-governmental organisations and private sector). Focus areas: (1) Education and Awareness (2) Public Polices (3) Market transformation (4) Finance (5) Measurement, data and accountability Process- Each focus area led by individuals to advance GABC commitments on (1) communicating opportunities and impacts in buildings and construction sector, defining sectoral climate goals and promoting transparency and information exchange (2) Collaborating with stakeholders to support enabling public policies and market transformations for achieving climate commitments and (3) Offering solutions for putting buildings sector on a below 2 °C trajectory.

BEA good practices: BEA's success in achieving traction on participating cities' commitments on policy and project action are explained by the 5 pillars of the BEA model:

- <u>Visible, public commitments</u> – Publicly announced targets provide international recognition, facilitate accountability, and encourage ambition. In Rajkot, leadership of the Rajkot Municipal Corporation Commissioner has helped fast track the process.
- <u>Local action prioritization process</u> – Local collaborative development of a broadly shared community vision leads to selection of jointly developed, locally-relevant action priorities. This

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has been especially true for deep-dive cities where, local stakeholder engagement through regular meetings has helped maintain momentum in identifying and focussing on priorities.

- Public-private collaboration – Neutrally convened dialogue between government and business helps match needs to expertise, and enables co-creation of workable solutions.
- Tools, expertise and solutions – Planning and implementation of selected actions is informed by local and global experts, best practices, peer learning and capacity building. Regular webinars and training sessions are conducted for BEA cities on using the tools and templates
- Connecting projects to finance – Creating project pipelines through efficiency programs and policies, and facilitating funding for implementation from global and national investors.

WAY FORWARD

The second phase of BEA (2018-2022), will build on the experiences, success and lessons learned from BEA phase 1. Discussions with members of the steering committee and partner cities have highlighted the following four areas of impact for phase 2:

- *Expanding private sector engagement*- With cities putting together their action plans and commitments in place, there is an increased interest from private sector now to assist in the mobilization of financial resources for the implementation of priority policies and projects identified in the action plan. The second phase of BEA will develop replicable models for better engagement of private sector in cities and at national scales
- *Coordination between national and local policies and actions to achieve scale*- The locally developed and implemented action plans must find a way to engage with national scale policy and programs. The second phase of BEA will be evaluating the linkages between local action and national commitments like NDCs through streamlined engagement process with selected BEA partner city governments.
- *Stronger outreach on standardized offer for cities*- The tools and templates developed in phase 1 of the BEA will be used to create a standardized offer for cities to (1) quantify costs and benefits of different policy/project options and (2) track impacts. This will enable more cities to advance efficiency.
- *Facilitating project financing*- Deep dive cities have identified projects for implementation in phase 1. BEA phase 2 will work with existing deep dive cities, a few additional deep dive cities (selected from current BEA cities), and selected national governments to expand from project implementation at the project or city level to the development of aggregated national project pipelines.

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AN EVALUATION FRAMEWORK FOR ASSESSING STATE-LEVEL PROGRESS IN ENERGY EFFICIENCY IN INDIA

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Key Words: Energy efficiency, targets, assessment, energy efficiency policy, policy

ABSTRACT

India has made good strides in energy efficiency over the last 15 years from the enactment of the ground-breaking Energy Conservation (EC) Act in 2001 to the ratification of the Paris Agreement in 2016. The EC Act was instrumental in the formation of the Bureau of Energy Efficiency at the centre and State Designated Agencies (SDAs) in the states thus creating an institutional framework for energy efficiency policies development and implementation. The World Bank recently came out with a report on India's state level energy efficiency implementation readiness focusing on policy and incentives, market maturity and institutional capacity.

The authors postulate that although states have a key role in India's energy efficiency policy implementation framework, the same is not currently reflected in terms of priority accorded to energy efficiency, as reflected in the meagre budget and low capacity in states, and the absence of sustained high-level support for energy efficiency programmes. In a top-down approach, all major policy formulation takes place at the central level and with certain exceptions, even implementation mechanisms are put in place in an ad-hoc fashion with limited thought and planning.

The authors highlight the importance of policy implementation by developing an evaluation framework to assess the progress made at the state level. This can provide crucial inputs for evidence-based policy formulation and evaluation, helping position energy efficiency as the first fuel for India. The framework for assessing progress in states is presented, which is based on outcomes such as energy savings achieved and government initiatives.

INTRODUCTION

Energy Efficiency (EE) is a vital pillar in sustaining the current growth of the Indian economy while also achieving development related goals. The Government of India (GOI) post the enactment of the Energy Conservation Act in 2001 has taken a lot of worthy initiatives; but many of them face challenges in terms of implementation at the State level. The complex nature of energy policy in India is reflected in the fact that several ministries (Ministry of Power, Ministry of Coal, Ministry of New and Renewable Energy, Ministry of Petroleum and Natural Gas), each with partial responsibility for different aspects of energy policy operate within a federal system of governance where many subjects including electricity fall under the jurisdiction of both the Centre and the State. The implementation efforts at the state level are also inversely affected due to the limited number of State government officials dedicated to work in energy efficiency. The capacity constraints in India are not very uncommon to developing economies and are highlighted with regards to building energy efficiency efforts in India by various think tanks (Khosla, Sagar and Mathur 2017). The authors believe that for India to achieve its targets in energy efficiency, the capacity of State officials, especially SDAs, needs significant ramp up.

National and State Level Energy Efficiency Governance Structure in India

The Energy Conservation (EC) Act, notified in 2001, laid the foundation for many subsequent policy interventions by the Government of India to instil efficient use of energy and its conservation in India. The EC Act defines specific powers and functions for both the Centre as well as the States to regulate and enforce energy efficiency in India. The Bureau of Energy Efficiency (BEE) came into existence on 1st March 2002 under the provisions of the EC Act to assist policy development and implement provisions of the EC Act at the National level. The EC Act empowers BEE to notify and coordinate with Designated Consumers to abide by specified norms of energy intensity across sectors. Electricity is a concurrent subject as per the seventh schedule of the Constitution of India, which essentially means that the Central and the State governments are to act together on all electricity related matters. The EC Act empowers the States to notify Designated Agencies as an extension of BEE in the states to coordinate, regulate and enforce its provisions. The specific powers conferred to states under the EC Act may be broadly classified as notification of the provisions of Act in the states, establishment of State Energy Conservation Funds and the power to inspect the compliance with specified energy consumption standards. (GOI, EC Act 2001)

National Mission for Enhanced Energy Efficiency (NMEEE)

The Government of India announced its National Action Plan on Climate Change (NAPCC) including eight different missions in 2008. One of these eight missions, the National Mission on Enhanced Energy Efficiency (NMEEE) was subsequently launched in June, 2010 which was re-emphasised in India's commitment and subsequent ratification of the Paris Agreement highlighting energy conservation as a key mitigation strategy. NMEEE spelt out four major initiatives to enhance energy efficiency - Perform Achieve Trade (PAT), Energy Efficiency Financing Platform (EEFP), Market Transformation for Energy Efficiency (MTEE), and Framework for Energy Efficient Economic Development (FEEED) - to unlock the market for energy efficiency and help achieve total avoided capacity addition of 19,598 MW and fuel savings of around 23 million tonnes per year at its full implementation stage. (GOI, BEE 2010)

Important National Energy Efficiency Programs

Energy Efficiency Services Limited (EESL) has championed a host of innovative nation-wide energy efficiency programmes including its flagship domestic LED distribution programme (UJALA) and national LED street lighting programmes where it worked with the electricity Distribution Companies (DISCOMs) and the Municipalities, respectively for large scale penetration that not only enabled significant energy savings but also brought down the price of LEDs considerably through demand aggregation. EESL's other successful initiatives include the existing buildings retrofit program, agriculture Demand Side Management (DSM) and super-efficient air conditioners (AC) for domestic and commercial (e.g. bank ATM kiosks) applications. BEE has been leading many major programmes since its inception including the Standards and Labelling (S&L) programme for appliances; Energy Conservation Building Code (ECBC) for instilling energy efficiency in new construction; and Perform, Achieve, and Trade (PAT) for large energy-intensive industries among many other initiatives including capacity building of DISCOMs on DSM.

Existing National and International Energy Efficiency Related Evaluation Frameworks

The World Bank recently released the State-level Energy Efficiency Implementation Readiness report, which presents a framework for the evaluation of States' readiness for energy efficiency implementation (Sarkar, et al. 2016). The study presents an index-based evaluation of individual states, primarily based upon data available in the public domain, to benchmark their readiness to measure, monitor, and evaluate the energy efficiency implementation readiness. Regulatory Indicators for Sustainable Energy (RISE), another World Bank initiative, presents a host of indicators that assesses countries' (111 countries) policy and regulatory framework for three major pillars of sustainable energy — energy access, energy efficiency and renewable energy (Banerjee, et al. 2017). The American Council for an Energy-Efficient Economy (ACEEE) has published ten editions of the US State Energy Efficiency Scorecard and extended the same to city and international energy efficiency scorecards as well which also includes India (Berg, et al. 2016). The periodic release of these scorecards encourages improvements in states' efforts year after year, promotes healthy competition between states and helps to assess annual progress of individual states. A significant aspect of these scorecards is that they use data vetted by the state energy officials.

Expected Outcome of the Evaluation Framework

None of the frameworks available in India specify outcome-based indicators like actual energy savings achieved through energy efficiency measures and policies across sectors. The authors' attempt to develop this unique framework in India, called State Energy Efficiency Index, is inspired by the US State Energy Efficiency Scorecards. The intent of the State Energy Efficiency Index is to assess the impact & effectiveness of State initiatives, which when performed on a periodic basis (annual/biennial) shall provide guidance for evidence-based policy formulation and help drive energy efficiency policies and programme implementation at the State level. The exercise done on a periodic basis shall highlight best practices and encourage healthy competition among Indian States.

RATIONALE

In developing the State Energy Efficiency Index, the authors have considered energy demand sectors, i.e. buildings, industry, municipalities, transport and agriculture; as well as utilities, i.e. DISCOMs, as the main components of the evaluation framework. Though DISCOMs are not a 'demand' sector they are instrumental in driving Energy Efficiency through DSM programmes. The authors have reviewed each of the demand sectors and the DISCOMs with respect to energy consumption, the potential for energy savings and the role or influence of the States in these sectors.

Energy Consumption

Figure 1 and Figure 2, respectively, show the total energy consumption (ktoe) and electricity consumption (GWh) for demand sectors (MOSPI 2016). Industry, buildings and agriculture are the largest consumers of electricity.

Energy Savings Potential

Figure 3 indicates the energy demand and savings potential per year under different energy demand Scenarios - Level 1 & Level 2 - assuming the Indian economy grows at a Compound Annual Growth Rate (CAGR) of 7.4% in the period 2012-2047 (NITI Aayog 2015). Level 1 indicates the least effort scenario, with minimal adoption of EE measures, e.g. mandatory building codes, EE appliances and equipment, public transport, etc. Level 2 indicates the 'determined effort scenario' with moderate adoption of EE measures, leading to an 18% lower energy demand than in the Level 1 scenario.

States' Role in Energy Conservation

The Energy Conservation Act 2001 recognises the role of States in driving Energy Efficiency and stipulates the powers of the States to "facilitate and enforce efficient use of energy and its conservation". (GOI, EC Act 2001)

Buildings: States may amend and notify the Energy Conservation Building Code (ECBC) to suit local conditions, direct designated consumers to conduct energy audits and furnish energy consumption information, and regulate energy consumption standards for equipment and appliances.

Industry: States may regulate the norms for process and energy consumption standards in any industry, and the energy consumption standards for equipment and appliances. However, the notification of specific large industries as designated consumers and the administration of central programmes such as Perform Achieve Trade (PAT) fall under the purview of the Centre, with States' Designated Agencies (SDA) providing support as needed.

Municipalities: Though municipalities are not mentioned in the EC Act 2001, they fall under the purview of States since local government is a State exclusive subject. Therefore, States could have a significant role in influencing the adoption of Energy Efficiency measures by municipalities.

Transport: The EC Act 2001 specifies the transport sector (industries and services) as designated consumer, thereby empowering the State to direct energy efficiency and conservation in this sector as in the case of other designated consumers. Roads and inland waterways come under the joint purview of the State and Centre, but rail and air transport come under the purview of the Centre alone.

Agriculture: While the EC Act 2001 does not explicitly specify agriculture, it is a significant demand sector, especially with regard to electricity consumption for irrigation pumping. Agriculture is under the purview of the State government.

DISCOMs: The EC Act 2001 specifies DISCOMs as designated consumers, empowering States to facilitate and enforce energy efficiency and conservation with regard to designated consumers. DISCOMs have been notified as Designated Consumer under PAT Cycle II, which specifies Transmission & Distribution (T&D) loss as the sole criteria to assess their performance (GOI, Notification for PAT cycle II 2016). Further, the Electricity Act (EA) 2003 stipulates the formation of a committee in each district to promote energy efficiency and its conservation. (GOI, EA 2003)

The EC Act 2001 stipulates that States may direct a designated consumer to permit an inspection officer to inspect production processes, equipment and appliances to ascertain energy consumption norms and standards. States may take measures to create awareness on energy efficiency and conservation, encourage preferential treatment for use of energy efficient equipment and appliances, and constitute State Energy Conservation Funds (GOI, EC Act 2001).

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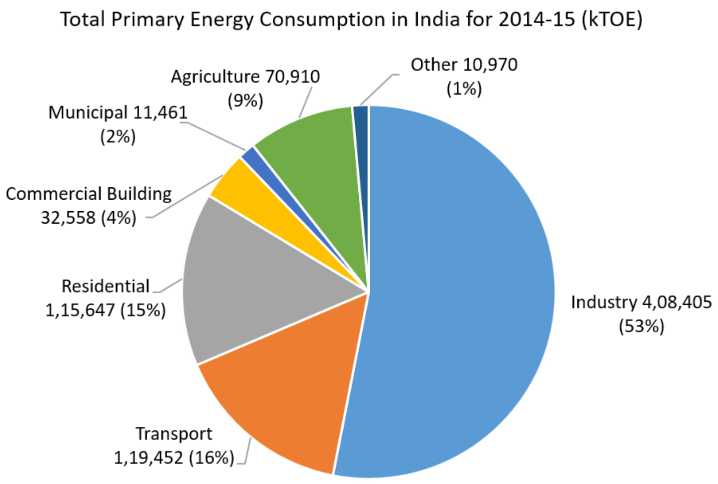

***Figure 1. Total Primary Energy Consumption (derived from** (MOSPI 2016))*

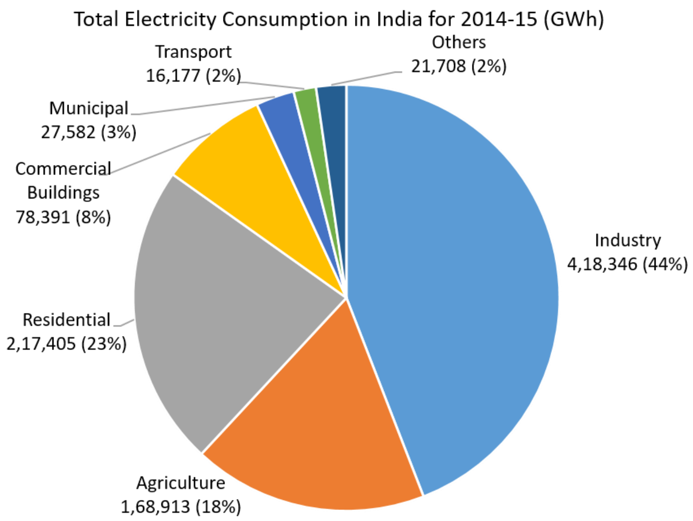

***Figure 2. Total Electricity Consumption (derived from** (MOSPI 2016))*

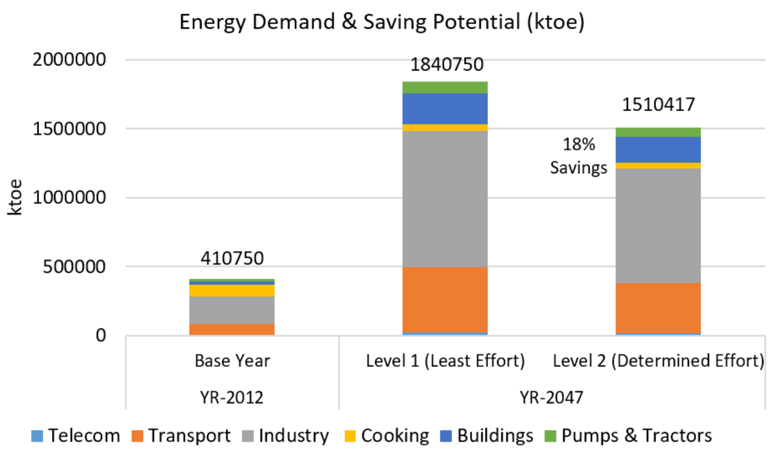

***Figure 3. Energy Demand and Saving Potential** (NITI Aayog 2015)*

Weightage of Demand Sectors in Index

Given the differences in energy consumption, potential for energy savings and States' influence in the different demand sectors it's important to develop the EE evaluation framework giving due weightage and importance to the demand sectors based on the above three parameters.

Since DISCOMs are not included in the energy consumption and energy savings data, they have been apportioned a weightage based upon electricity consumption in the demand sectors.

The main contributor of energy consumption in the Agriculture sector is electricity used for irrigation. Given that EE measures in agriculture comprise DSM programmes, the EE indicators for agriculture have been clubbed with those for DISCOMs.

The weightage assigned to each demand sector and DISCOMs in the State EE Index is based on the quantum of their energy consumption, energy savings potential and States' influence in that sector; with a weightage factor of 35% for energy consumption, 20% for energy savings potential and 45% for States' role. The weightage assigned to individual indicators would take into account existing policies and inputs from SDA's and BEE, and will likely evolve over time.

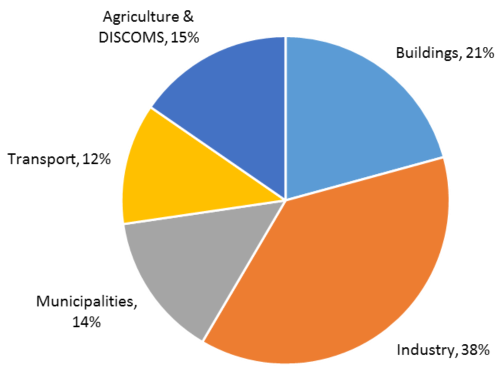

Figure 4. Weightage Assigned to Sectors

Categorisation of EE Indicators

The State EE Index is comprised of indicators that relate to States' capacity to facilitate, drive and enforce Energy Efficiency, and outcome-based indicators that indicate energy savings.

1. **Policies and Regulation**
   Policies are the first step to effecting change by setting direction for Energy Efficiency, and devising programmes to enhance adoption of EE. Regulations enable States to enforce compliance to EE mandates, e.g. mandatory building codes, energy consumption standards for equipment and appliances.

2. **Financing Mechanisms**
   In cases where the initial cost of EE measures is a barrier, financing mechanisms such as subsidies, soft loans, tax rebates, etc. help stimulate the market for EE products and services, thereby driving the implementation of EE.

3. **Institutional Capacity**
   States require dedicated resources – people, systems & processes – to facilitate and enforce Energy Efficiency. These include trained energy auditors, entities to ensure compliance with EE codes and mandates, energy data management systems.

4. **Adoption of EE Measures**
   These indicators signify the level of implementation of EE measures, e.g. penetration of EE appliances and equipment, implementation of energy conservation measures in industry, penetration of fuel-efficient vehicles, etc.

5. **Energy Savings**
   These indicators are a measure of the actual energy saved and/or the reduction in energy intensity due to the implementation of EE measures.

ENERGY EFFICIENCY INDICATORS

Energy Efficiency (EE) indicators are presented for each demand sector and the DISCOM sector. In each sector indicators have been selected based on their impact in driving Energy Efficiency implementation in States. The outcome-based indicators have been selected to signify energy savings and/or reduction in energy intensity.

Units for qualitative indicators are either binary (Yes/No) or a checklist (List), such as a list of financing mechanisms or programmes for EE appliances.

Units for quantitative indicators are currency (INR), kWh, energy intensity (e.g. kWh/m^2) and % of an appropriate population.

EE Indicators for Buildings

Buildings include residential, commercial and public buildings. Indicators have been developed based on their impact in enabling, driving and enforcing Energy Efficiency measures. For example, mandating Energy Conservation Building Code (ECBC) ensures that new buildings comply with Energy Efficiency norms, having a direct impact on the energy consumption in those buildings. Likewise, energy audits and energy performance reporting enable tracking of EE measures and help identify buildings that could be potential targets for EE retrofits. Programmes and financing mechanisms to increase the penetration of EE lighting and appliances also have a direct impact on energy consumption. Outcome-based indicators measure the adoption of EE measures in buildings, penetration of EE appliances and actual energy savings.

Policies and Regulation (Buildings)	
Indicator	**Unit**
Mandatory Energy Conservation Building Code (ECBC)	Yes/No
Incorporation of ECBC in municipal building bye-laws	Yes/No
Mandatory Energy Audits & Reporting	Yes/No
% of buildings complying with mandatory energy audits	%
Adoption of BEE star rating or green building rating systems for public buildings	Yes/No List
EE Lighting programmes	List
EE appliance programmes	List
Programmes for EE cooking fuel	List

Financing Mechanisms (Buildings)	
Indicator	**Unit**
Subsidy for building energy audit	Yes/No
Funds allocated & utilised for building energy audit	INR
Financing mechanisms for ECBC-compliant construction / retrofits	List
Funds allocated & utilised for ECBC-compliant construction / retrofits	INR
Financing mechanisms for EE appliances	List
Funds allocated & utilised for EE appliances programmes	INR

Institutional Capacity (Buildings)	
Indicator	**Unit**
Entity assigned for enforcing and certifying ECBC compliance	Yes/No
Entity assigned for checking compliance of mandatory energy audits and reporting	Yes/No

Adoption of EE Measures (Buildings)	
Indicator	**Unit**
Demonstration of ECBC-compliant public buildings	List
% of new buildings that are ECBC-compliant	%
Certified green buildings	List

Energy Savings (Buildings)	
Indicator	**Unit**
Energy Savings	kWh
Reduction in energy intensity	kWh/m^2

EE Indicators for Industry

These include indicators for large industry and Micro, Small & Medium Enterprises (MSME). The level of State influence is much higher in MSME when compared to large industry, since large industry is extensively regulated from the Centre. Further, MSME are more widespread in States compared to large industry. In fact, some smaller states may have no large industry at all.

The first step in advancing industrial energy efficiency is to mandate energy audits and set energy saving targets. Financing mechanisms such as tax rebates, soft loans, subsidies, etc. can help in meeting the higher initial costs of EE measures. Developing institutional capacity is a lot more complex for industries, given the diversity and size of the sector. At a minimum, there should be an entity capable of conducting and enforcing energy audits across all types of industry.

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There should be an outcome-based indicator to measure the penetration of EE measures across all industrial units. This can be further detailed for each sub-sector, e.g. ceramic, glass, cement, fertilizer, etc.

Overall energy savings is another outcome-based indicator, which signifies the success of EE programs, and the improvement in the sector. Energy intensity should be defined more specifically for each sub-sector of industry. This is done in the case of large industries in India that fall within the Perform, Achieve, Trade (PAT) scheme, where energy targets are measured in terms of Specific Energy Consumption (SEC) for each type of industry.

Policies and Regulation (Industry)	
Indicator	**Unit**
Energy Saving target(s) for industries Target as % of state industrial energy use	Yes/No %
Mandatory Energy Audits	Yes/No
Proportion of industrial units audited	%
Financing Mechanisms (Industry)	
Indicator	**Unit**
Financing mechanisms for implementing EE measures	List
Funds allocated & utilised	INR
Institutional Capacity (Industry)	
Indicator	**Unit**
Entity assigned to conduct and enforce energy audits	Yes/No
Entity assigned to support PAT implementation in state	Yes/No
Budget allocated for entity to support EE in industry	INR
Adoption of EE Measures (Industry)	
Indicator	**Unit**
Proportion of industrial units that have adopted EE measures	%
Energy Savings (Industry)	
Indicator	**Unit**
Energy Savings as a % of industrial energy use	%
Reduction in energy intensity for PAT industries	SEC
Reduction in energy intensity for other industries	kWh / unit of production toe / unit of production

EE Indicators for Municipalities

Indicators are defined for street lighting, water pumping and sewage treatment. Municipal buildings would be covered under 'Buildings' and urban transport would be covered under the 'Transport' sector.

Policies and Regulation (Municipalities)	
Indicator	**Unit**
Energy savings target Target	Yes/No kWh
Programme for EE LED Street Lighting	Yes/No
Programme for EE Municipal Water Pumping	Yes/No
Programme for EE Sewage Treatment	Yes/No
Financing Mechanisms (Municipalities)	
Indicator	**Unit**
Funds allocated & utilised for EE lighting	INR
Funds allocated & utilised for EE water pumping	INR
Funds allocated & utilised for EE sewage treatment	INR
Institutional Capacity (Municipalities)	
Indicator	**Unit**

Entity assigned for supporting EE measures	Yes/No
Budget allocated for entity	INR
ADOPTION OF EE MEASURES (MUNICIPALITIES)	
Indicator	**Unit**
Penetration of EE street lighting (km covered / total km)	%
Penetration of EE water pumping (proportion of EE stations / all stations)	%
Penetration of EE sewage treatment (proportion of EE plants / all plants)	%
ENERGY SAVINGS (MUNICIPALITIES)	
Indicator	**Unit**
Energy savings from EE street lighting as a % of street lighting kWh	%
Energy savings from EE water pumping as a % of water pumping kWh	%
Energy savings from EE Sewage treatment as a percent of sewage treatment kWh	%
Reduction in energy intensity in street lighting	kWh/km at specific lux level
Reduction in energy intensity in water pumping	kWh/million litres pumped
Reduction in energy intensity in sewage treatment	kWh/m^3

EE Indicators for Transport

Indicators are primarily for road transport, rather than rail or air, since States' have a significant role in road transport, whereas rail and air is under the purview of the central government.

Indicators are defined for fuel efficiency / energy efficiency rather than emission control, and are for passenger vehicles including public transport.

POLICIES AND REGULATION (TRANSPORT)	
Indicator	**Unit**
Fuel efficiency or Fuel saving targets for State Road Transport Corporation (SRTC) public transport	Yes/No
Policy for procurement of fuel-efficient public and government vehicles	Yes/No
FINANCING MECHANISMS (TRANSPORT)	
Indicator	**Unit**
Financing mechanisms for hybrid and electric vehicles	List
Funds allocated & utilised for fuel-efficiency programmes	INR
INSTITUTIONAL CAPACITY (TRANSPORT)	
Indicator	**Unit**
Awareness campaign on fuel saving for SRTC personnel	Yes/No
Specific entity assigned for fuel saving / efficiency in transport sector	Yes/No
Budget allocated for entity to support fuel efficiency efforts in State	INR
ADOPTION OF EE MEASURES (TRANSPORT)	
Indicator	**Unit**
Proportion of public and government passenger vehicles meeting a specific definition of "fuel-efficient" (as a % of all government passenger vehicles)	%
Penetration of hybrid and electric passenger vehicles (as a % of all registered passenger vehicles)	%
Proportion of passengers using public road transport	%
ENERGY SAVINGS (TRANSPORT)	
Indicator	**Unit**

Fuel Savings by SRTC as a % of total SRTC fuel consumption	%
Fuel Savings target achieved by SRTC	%

EE Indicators for Agriculture and DISCOMs

Energy consumption in agriculture is primarily for irrigation pumps. Irrigation directly impacts electricity consumption and is the main target for DSM programs. The EE indicators for agriculture are related to DSM and are therefore included in the DISCOM sector indicators. Indicators are largely based on DSM programs for agriculture and other demand sectors.

Policies and Regulation (AG & DISCOMs)	
Indicator	**Unit**
Notification of DSM regulation	Yes/No
Ag DSM program	Yes/No
Target for Energy savings from Ag DSM as a % of Ag kWh	%
Non-Ag DSM programs	List
Target for energy savings from Non-Ag DSM as a % of kWh sales	%
Target for reducing T&D losses	%
Penalties for non-compliance of DSM mandates	Yes/No
Financing Mechanisms (AG & DISCOMs)	
Indicator	**Unit**
Financing mechanisms for DSM	List
Funds allocated & utilised for DSM measures	INR
Institutional Capacity (AG & DISCOMs)	
Indicator	**Unit**
Dedicated DSM cell	Yes/No
Budget allocated for DSM cell	INR
Adoption of EE Measures (AG & DISCOMs)	
Indicator	**Unit**
Consumer participation in DSM programs in terms of consumers who have opted for DSM programs out of total consumer base (industry, residential, commercial)	%
Energy Savings (AG & DISCOMs)	
Indicator	**Unit**
T&D losses	%
Energy savings from DSM as a % of total kWh sales	%

DATA COLLECTION

A twin pronged approach shall be followed for the data collection exercise. Initially data available in the public domain shall be collected and compiled and then the same shall be shared with respective state departments for verification and further additions.

Second, we will ask SDAs and State departments to provide missing data.

LIMITATIONS

The authors are aware that an index-based approach has some inherent drawbacks that it may encourage undue attention on (scoring well on) indicators which may shift the focus to a numbers-game instead of actual progress. The current selection of indictors which has been done to address this issue diligently, may need to be carefully studied in the future as the EE Index rolls out and the way it is perceived by the states.

In this paper only the more common EE indicators that are relatively well understood in India are included. It does not include indicators for water transport, urban public transport planning and usage, freight, farm equipment, etc.

Clearly any Index is only as good as the data input; if data is incomplete and/or inaccurate it will affect the quality of the Index. We note that collecting even the data listed in the tables above will be challenging, and based on the data that is ultimately collected, some modifications to the indicators are likely. Further, while this paper does not list any quality assurance (QA) measures to ensure data accuracy, we would like to state the necessity of incorporating such QA measures in developing the State EE Index.

CONCLUSION

This evaluation framework, the State EE Index, is a crucial first step in assessing where States stand with regard to energy conservation and efficiency. It would help identify which sectors and/or areas need more focused attention in achieving energy conservation and efficiency within a State. The index would also indicate which programmes are successful, and help in identifying best practices that could be replicated across States. The authors believe that in the short term, identification of potentially successful programmes (based upon learnings from other states) and increased awareness amongst SDAs and other entities would encourage more EE projects ultimately leading to increased budget allocation by state governments and development of the entire eco-system including increased staff dedicated to EE in the States.

In the long run the State EE Index can help institutionalise energy data management and reporting, and thereby, serve as a useful input for developing evidence-based data-driven policies and programmes to drive energy efficiency. It is proposed that the State EE Index be published periodically, at least once in two years, to assess progress in EE. The EE Index indicators shall be continually modified to reflect the evolving landscape of EE in the country.

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INTERNATIONAL EXPERIENCE ON INSTITUTIONAL GOVERNANCE AND FRAMEWORKS FOR ENERGY EFFICIENCY

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Keywords: Energy Efficiency, Institutional Frameworks, Governance Models, Energy Efficiency Programs and Policy, Global Experience

ABSTRACT

The study is aimed for policy makers to suitably establish or modify local Energy Efficiency (EE) governance frameworks learning from countries which have long realized the importance of sound EE governance. These countries have established robust Institutional Framework and Governance Mechanisms (IFGM). They have been successful in launching numerous EE programs and achieving their EE targets.

Five countries were selected for study based on their uniqueness, exclusivity and availability of ready data and information. These are: 1) India, which has a well-established institutional structure for EE governance and is one of the countries where EE is backed by a national law; 2) Japan, which has time and again shown tremendous results in EE, such as after the 2011 earthquake in which Japan lost about 30% of its electricity generation but compensated through EE; 3) Dubai, which has a framework involving multiple interrelations with several organizations; 4) Tunisia, which, since becoming a negative energy balance country in the early 2000s, has achieved great results in energy efficiency and ranks as one of the best countries in terms of EE in the MENA region) and 5) USA, which has the oldest and most successful Energy Efficiency governance in the world.

We have highlighted the key characteristics, pros and cons, what worked and what has not in achieving EE targets, of these IFGMs. Drawing from these country experiences, we have made recommendations of IFGM for EE. We believe our recommendations will be helpful to policy makers in developing or modifying IFGM for achieving the EE targets. Although our experience suggest final choice of IFGM is governed by local political considerations. Nevertheless starting point in policy development is always what is best for us.

INTRODUCTION

To establish a sound IFGM for achieving the EE targets at fast pace, it is beneficial to leverage learning from international experience. As certain countrieshave since long established IFGM. Although any IFGM is required to be tailored to the local specific requirements and should be derived from the local landscape.

For this study we have selected five countries based on their mutual uniqueness, uniqueness and based on ready availability of data and information. These are:

1. India, has a sound institutional structure for EE governance where EE is backed by a national law, The Energy Conservation Act 2001.
2. Japan, which has time and again shown tremendous results in EE, such as after the 2011 earthquake and tsunami in which Japan lost about 30% of its electricity generation but compensated through energy efficiency.
3. Dubai, which has a unique geo-political structure similar to wherein EE responsibility lies with multiple government organizations which then report to one single entity- the Supreme Council.
4. Tunisia, which, since becoming a negative energy balance country in the early 2000s, has achieved tremendous results in energy efficiency and ranks as one of the best countries in terms of EE in the MENA region). Tunisia is a representation of the countries which have or are facing a tilt in their energy balances
5. USA, which has the oldest and most successful IFGM in the world.

Establishment of an IFGM

The increasing concerns about climate change, rapid economic development, energy security challenges and the increasing cost of electricity production, has brought energy efficiency into focus as a low cost and fast implementable solution. EE is a proven and cost-effective measure to address these challenges, particularly in the countries (such as Jordan, Egypt, Bangladesh etc.) where finances are impacted heavily by rising cost of fuel or due to fear of energy resources getting consumed soon. On the other hand, there is a huge potential for improving EE across energy consuming sectors in these countries.

Energy Efficiency IFGM

Implementing an EE focus in a country requires an IFGM to promote combination of technology development, market mechanisms and government policies (governance), which can influence the actions of all the energy consumers. As such, it can be defined as "a combination of legislative frameworks, funding mechanisms, and co-ordination mechanisms, which can guide the implementation of energy efficiency strategies, policies and programmes."

The key elements of IFGM are presented in the Figure 1 below:-

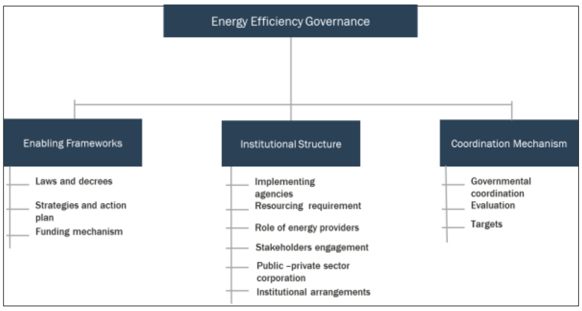

Figure 1: Elements of IFGM

However, to steer EE in any country, series of institution at federal, state or local level needs to be established depending upon size of the country. These institutions can be government, private or mixed. Based on our experience of working in the EE sector across the world, we believe, the contribution of this entity is crucial for success of EE in any country. In the following sections, we will discuss their structures as adopted by the selected five countries as well as their linkages with the larger governance frameworks.

INDIA: BUREAU OF ENERGY EFFECIENCY

The Bureau of Energy Efficiency (BEE) was established at the federal level under The Energy Conservation Act, 2001 (EC Act), which came into force in March 2002. BEE's mission is to develop policy and strategies on energy efficiency with an emphasis on self-regulation and market principles, with the primary objective of reducing the energy intensity of the Indian economy. This is to be achieved with the active participation of all stakeholders, resulting in the accelerated and sustained adoption of energy efficiency in all sectors. BEE is operated by the Ministry of Power. Its organization structure is presented in Figure 2.

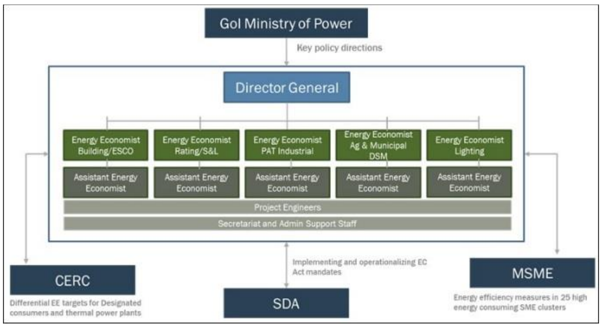

Figure 2: Organizational structure of BEE

BEE is headed by a Director General (a Government of India employee) and has 6 energy economists and 14 supporting secretarial staff. Having six economists on the team reflects a strong reliance on the financial and economic gains of EE programs. To support BEE on the coordination and implementation of EE programs throughout India, each state government was given the task of establishing the state-designated agency (SDA) in their state. BEE coordinates with SDAs, for implementation of EE programs in the respective states of the India

BEE follows a "tree structure" in which the distinction between departments is made on the nature of the work (capacity building, demand-side management, lighting, etc.). This type of institutional structure has the advantage of yielding better program design and development as it is being done centrally, but program implementation can suffer. (Nigel Jollands 2011)

The SDAs are small bodies under state governments and BEE has little control over them. SDAs have difficulty in pushing the utilities which are large entities, on EE policy and program implementation. Also, BEE's staff receive government salaries, which are lower than private sector, and thus finds recruiting qualified and experienced staff to be difficult. BEE is generally helped by consultants deployed to BEE by donor agencies.

Key Characteristic of BEE's Organization Structure

BEE is a dedicated EE agency established under a ministry and supported by a national level law, hence it is better focused on EE. However, there are too many variations in EE program implementation by various implementing agencies (SDAs) under BEE. Hence, coordination, data-sharing, overall management becomes an issue. Since, BEE is a dedicated federal agency it has a better understanding of national priorities and develops EE programs that are in sync with the national priorities. On the other

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hand there is BEE operates through state level agencies (SDA) which results in a poor control of program implementation: as a SDA does not administratively report to BEE (it reports to state government and also holds various portfolios at the same time) and may be executing other state programs. Similarly, program monitoring in such a structure is difficult.

JAPAN: ENERGY CONSERVATION CENTER, JAPAN (ECCJ)

ECCJ was established under the Energy Conservation Law of Japan in 1978. Its mission and objective are to promote the efficient use of energy, protect against global warming, and encourage sustainable development. Figure-3 reflects institutional framework of Japan for EE.

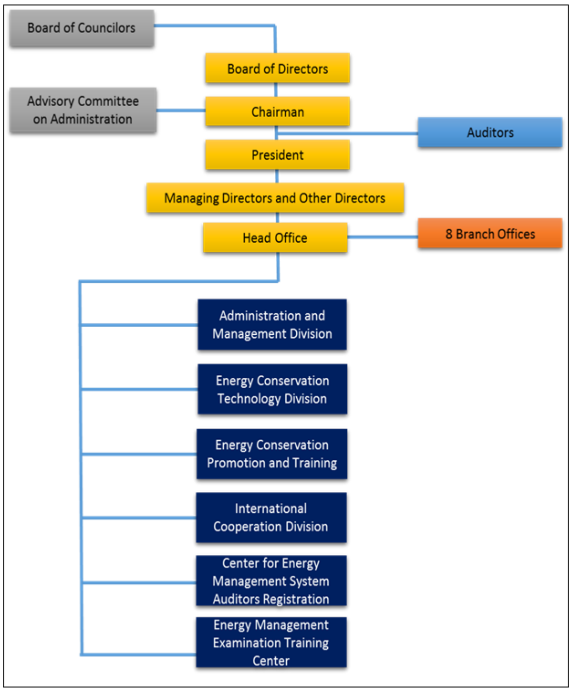

Figure 3: Organization structure for ECCJ

The unit has 91 employees and an operating budget of approximately $10 million. Japan's framework is more like corporate house. The ECCJ is a specialized agency focused exclusively on EE. It runs a wide array of programs such as:

1. Promoting energy-related policies in Japan
   a. Engaging the private sector, households, and communities
   b. Issuing energy manager certifications
2. Capacity building and knowledge transfer
   a. Seminars and training programs
   b. Energy conservation certification program
   c. ISO 50001 evaluation and registration
   d. Energy conservation magazine, books, handbooks, etc.
3. Promotion of international cooperation
   a. Dispatch of energy experts
   b. Acceptance of trainees
   c. Promotion of Japanese energy conservation expertise, etc.

Key Characteristic of Japan's ECCJ's Institutional Framework

ECCJ is responsible for most of the activities related to the design, development, and monitoring of EE programs. The implementation is carried out by relevant agencies stationed in different organizations across Japan. Therefore, different agencies adopt different approaches in implementation, similar to India's BEE. However Japan being not so big as India the control over state agencies is much better. ECCJ is a dedicated federal EE agency, and hence focused solely on EE policies and planning. Although the resources dedicated for ECCJ are high, there are too many variations in program implementation. A key advantage with holding a structure such as that of ECCJ is that such an institution holds a standing with implementing agency because of the top-down nature. Additionally it has a greater access to public fund. Since this agency is solely dedicated for EE, it's easier to attract relevant staff. Similarly since this agency is solely focussing on EE, it is easier to attract dedicated funds from sources such as donor agencies or government funds, On the other hand, since the focus is narrowed down to EE, such institutions holds a lesser clout with the country Governments. ECCJ is guided by national level objectives. For e.g. since the Fukushima disaster in Japan, Japan is highly focussed on EE. However, at a time when things will get stabilized, this focus may falter and ECCJ may lose its relevance to some extent. Thus a better governance is required in terms of relations between Government and ECCJ.

DUBAI: DSM AGENCY

The Dubai Supreme Council of Energy (DSCE) was formed in August 2009; it is the country's apex body for matters pertaining to energy. The Council is headed by the prime minister, with its members comprising the heads of departments dealing with high volumes of energy, including DEWA (the electric and water utility), the Rail and Transport Authority, and Dubai Municipality, which are also members of DSCE's Demand-Side Management Executive Committee (DSM). This committee addresses

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demand-side measures including energy efficiency. The Demand Side Management strategy is the first of its kind in the region. It provides new opportunities for companies working in energy services, sustainability, and efficiency. The strategy has eight programmes to manage energy demand. These include green building regulations, retrofitting of existing buildings, district cooling, wastewater reuse, laws and standards to raise efficiency, and energy-efficient street lighting.

DSM has minimal staff and is largely managed by external consultants. With their help, it has identified eight programs to reduce energy consumption by 30% by 2030 (see Figure 4). For each program DSM has defined targets and identified an existing institution/department as program champion to ensure the targets are achieved. For example, DEWA has been made champion for power and water tariffs, and for the demand response program; its target is to reduce demands by 3% and 6%, respectively, by 2030 (PWC 2012). The champions receive a high-level road map from DSM and are then expected to build their own strategy and implementation mechanisms for their programs. DSM monitors the progress of each program with the help of DSM agency.

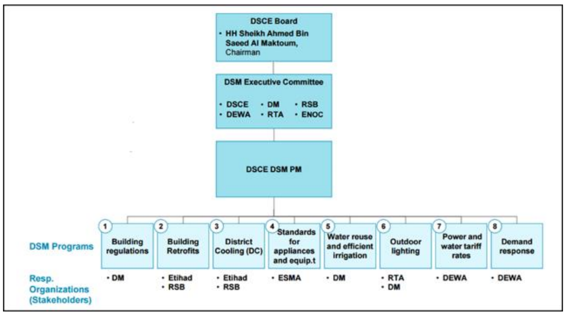

Figure 4: IFGM the Dubai DSM agency

Dubai has an energy efficiency structure that is controlled and monitored at the highest level (prime minister). Program design, development and target setting are done at this level. Utilities are responsible for implementation and progress is regularly monitored by DSM.

Key characteristics of Dubai IFGM

The DSM agency has representatives from all the key executing agencies as well as regulators, and hence, better coordination between management and execution. However, when it comes to actual implementation- it is carried out by many different agencies which results in some unaddressed administrative issues. A top-driven structure as that of Dubai's DSM agency results in a better policy inception as one central agency brings all key stakeholders together. On the other hand the arrangement is more top-down than participatory in nature, i.e. some agencies may limit their focus to EE and some may not involve fully due to their own different priorities. DSM Agency is a government-owned entity with representation from the energy sector regulators, as such it has a much better access to resources. Since, all the stakeholders come together, there is excellent coordination among all departments-at the program inception stage at least. DSM agency is a dedicated agency, hence, highly focussed.

TUNISIA: NATIONAL AGENCY FOR ENERGY CONSERVATION

EE in Tunisia is governed by the Tunisian National Agency for Energy Management (ANME). The National Agency for Energy Management (ANME) was founded in 1985. The unit has 195 employees and is spread across five regions of the country - Five regional departments: Kef, Gabès, Sidi Bouzid, Sfax, Sousse. It is an administratively independent governmental organisation under the supervision of the Ministry of Industry, Energy and Mines. ANME's key tasks comprise translating ministerial policy directives into practice. The IFGM for ANME is presented in Figure 5 (IMED 2010)

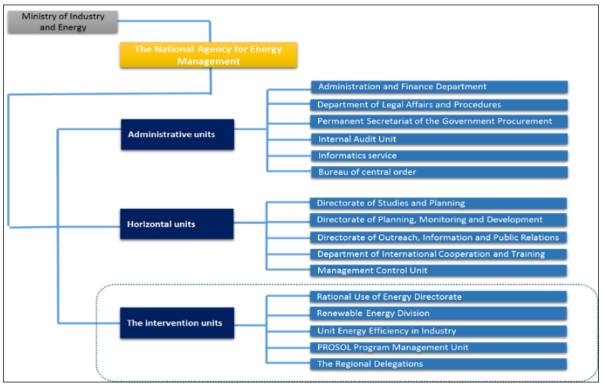

Figure 5: IFGM of Tunisia's ANME

Similar to the BEE in India, ANME draws its powers from the Energy Conservation Law of 1990 (amended 2004). However, a distinctive feature of Tunisia's ANME is that unlike BEE it has overall responsibility for all energy-related issues and is accountable to the Ministry of Industry and Energy. While the BEE in India is central to 29 SDA's, ANME is spread only in 5 regions and as such has a better control over the national and local EE activities.

Another highlight of Tunisia’s ANME is that the unit is highly driven by international cooperation. That is through funds and grants received from bilateral or multilateral agencies. For example during 2010-2013, the German International Cooperation (GIZ) contributed about USD 3.2 Million as technical assistance and donation. Similarly, the Italian Ministry of Environment has contributed about USD 1 Million from 2004- 2014.

Key characteristics of Tunisia's ANME’s IFGM

The ANME is structured in such a way that EE is only one of ANME’s many important activities As a single a single parent agency, it is required to accommodate local and national level country needs on various fronts and hold various divisions governing many sub-units. As such the EE objectives may get diluted. On the other hand since it is a part of larger country level organization, it has a much better access to resources. The EE division in ANME holds a very good coordination among all departments as the central body already has established relationships at a senior level with the local implementing agencies. The decision making in such a large organization is generally cumbersome and slow. Moreover, the top management of the agency is more committed to other functions (energy security, supply side-management, etc.) and sometimes the EE functions are neglected.

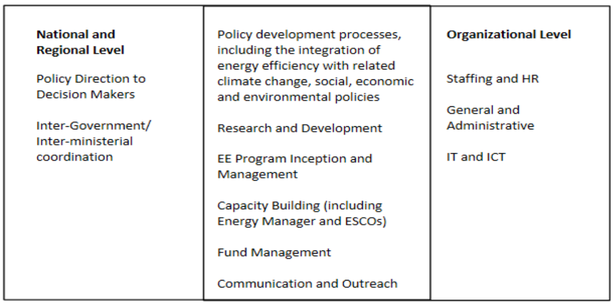

Figure 6: Broad roles and responsibilities of an EEU

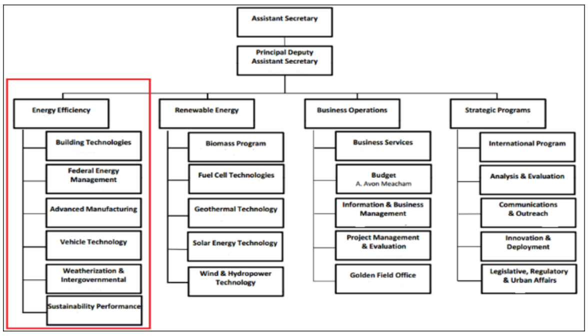

Figure 7: Department of Energy (DOE) -Office of Energy Efficiency and Renewable Energy (EERE) organization structure

UNITED STATES OF AMERICA (USA): DEPARTMENT OF ENERGY (DOE), OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY (EERE)

Similar to Tunisia, The US DOE’s EERE is a national-level energy agency that is responsible for clean energy. Thus, this organization performs multiple functions including EE. Its mission statement is, “The mission of the Office of Energy Efficiency and Renewable Energy (EERE) is to strengthen America’s energy security, environmental quality, and economic vitality in public–private partnerships that enhance energy efficiency and productivity; bring clean, reliable, and affordable energy technologies to the marketplace; and make a difference in the everyday lives of Americans by enhancing their energy choices and their quality of life.” (Nigel Jollands 2011)

As a US Government entity, EERE is funded from the federal budget. Its organization structure is presented in Figure 7 *(USDOE 2016).*

Key characteristics of USA IFGM

US DOE, Being a part of a larger, well-recognized federal agency provides good visibility and credibility to the EE function with its stakeholders. Being a part of a larger organization, organizations such as these have a better access resources within the larger parent organization that may be needed for special assistance. Moreover, the large parent organization is likely to have greater clout in obtaining government funds than a small agency focusing only on EE. However, EE activities can experience a slowdown or a loss of interest as it is difficult to accommodate local needs as a single parent agency will govern many sub-units.

RESULTS AND RECOMMENDATIONS

The IFGM plays a vital role in achieving EE targets at faster pace. IFGM is a complex, and yet critical, part

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of the EE delivery system (IEA 2010). Based on our studies of the five countries as stipulated above, we believe the essential key elements for IFGM are:

1. Clearly defined functions for the organization
2. Clearly defined roles and responsibilities for each staff member
3. Well-defined reporting outline
4. Clearly identified external and internal linkages.

Moreover, an EEU is primarily responsible for the planning and design of an EE program for any jurisdiction, monitoring of the EE programs, suggesting course corrections, if any, and informing all stakeholders of program details and progress (communication and outreach). As such, it is prudent to structure the unit in a way that all the functions that are envisaged are adequately represented.

Key recommendation on establishing an IFGM

External Linkages: Meeting the EE goals and targets requires support from both external and internal stakeholders. As the EE programs will be carried out by multiple stakeholders, a robust linkage mechanism should be established, particularly with external stakeholders. The essential linkages (as depicted in Figure-8) are:

a. Policy Direction: A high level council consisting of representatives from various EE entities across the country should be established. The role of this organization will be to ensure coordination between the EEU and other stakeholders as well as alignment with national level goals; help in establishing linkages with other energy programs to be operated by various ministries, which can be especially in case of funds convergence for common goals
b. Program Implementation Monitoring: The IFGM should designate a government agency monitoring the implementation of all EE programs that are being implemented by the EEU. This agency will be responsible for Periodic reviews of EE program implementation and providing coordination support from all utilities.
c. Regulatory Guidance: Similar to the M&E entity the EEU should designate an entity to provide regulatory guidance to implement various EE programs. This guidance may be in the form of: new regulations or updates in existing regulations or codes for supporting the various EE programs; Public consultations on regulations related to EE programs, including those related to protecting customer interests, amongst other areas.
d. Market Development: The EEU should link itself with a government financing agency (such as EESL in India) or establish a designated arm for market development. The ultimate objective of this will be to make EE programs and activities run on commercial basis without any support from the government or any grant funding. This will require building the capacity of other FIs and banks, developing ESCOs, working with EE product manufacturers, and providing necessary policy support.

2. Senior stakeholder involvement and coordination: Since EE is a far reaching concept and is specialized for different streams, it is important to involve stakeholders from various organizations. Further, since it is important to associate with the other agencies at high level by forming an association or a committee at top level
3. Work Streams: To achieve maximum results, the EEU should be bifurcated into three major streams:
   a. Program and Policy: Since running programs and preparing policies are an integral part of an EEU. This unit should be separated and should focus on the core areas. This unit will conceptualize, manage, analyse and assess key EE programs; provide quality assurance for each of the programs being implemented; provide guidance on program execution or the diagnosis of program performance; manage all aspects of program budgets including forecasting, cost review and validation, etc.
   b. Funding and Outreach: Based on our international experience, its observed funding and outreach play a tremendous role in an EEU's success. As such a dedicated unit for these activities headed by a senior position should be established. The key roles will be: fund

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management: raising and managing finance for EE initiatives for the EEU; communication and outreach: media outreach, program promotion, preparation of marketing materials, etc. and capacity building: running nationwide capacity building programs for energy manager/auditors, consumers, financial institutions, ESCOs and other stakeholders.

4. IT/ICT and Administration: Over the years IT and ICT have taken up an important role in governance, especially if the scale is large. As such a dedicated unit highly trained IT staff with expertise in various software should be established.

A model governance structure is presented in the Figure-8

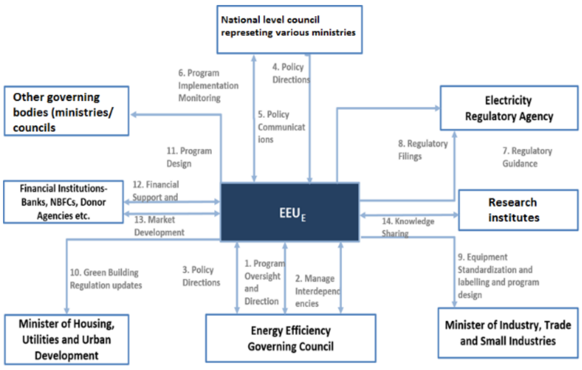

Figure 8: Recommended Governance Structure

Comparison of pros and cons of the Institutional Framework of the five case studies

Table 1: Comparison of pros and cons of the IFGM of the five case studies

INSTITU-TIONAL FRAME-WORK	PROS	CONS	EE AGENCY
Federal agency with broad energy responsibilities (EE is only one sub-sector)	There is greater credibility with stakeholders. Government agencies have access to public funding.	EE must compete with other energy programs for resources and management attention.	USA's DOE

INSTITU-TIONAL FRAME-WORK	PROS	CONS	EE AGENCY
	There is integration of EE within broad sector objectives	Large bureaucracy may impede decision making. It is difficult to retain staff.	
Federal Agency where focus is EE/RE and Energy Conservation	Agency focus is consistent with EE. It is easier to attract dedicated staff. Dedicated "clean energy" agency provides greater voice in sector policy and obtaining resources.	Narrower focus provides less clout. Potential for competition between technologies (EE, RE) within the clean energy umbrella.	Dubai's DSM Agency
Independent Authority with statuary backing from the government	Independence facilitates operational discretion. There is flexibility in accessing outside advice and support. Flexibility in hiring management and staff. There is flexibility to obtain external inputs and funds, including shares flotation.	Agency may not be viewed as mainstream There is potential competition between ISA and public agencies. ISAs have less direct access to public funding. Changing scope may require legislation.	Tunisia's ANME Japan's ECCJ
Agency where	EE programs	Monitoring and	India's BEE

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INSTITU-TIONAL FRAME-WORK	PROS	CONS	EE AGENCY
implementation is largely led at the local level	are better suited to the local needs and thus achieve better results	Evaluation is cumbersome Local targets may not be well aligned with national policies Poor program management local implementation agencies may have different priorities	Dubai's DSM Agency USA's DOE

Learning Key governance issues based on the five case studies

The key governance issues based on the selected five case studies are presented in the Table-2 below

Table 2: Learning on key governance issues

GOVERN-ANCE ISSUES	DESCRIPTION	EXAMPLES
Voluntary and mandatory program participation	A key aspect of EE governance is type of consumer participation (voluntary or mandatory) for EE in an economy. Mandatory participation is effective in economies where the energy prices are low and the energy sector is still developing as the people are not much so much aware. As an example in India, energy intensive industries (Designated Consumers) have to undertake special EE measures. On the other hand, voluntary participation works well in developed countries, where the energy prices are high and consumers are aware. An example of this is Japan's EE schemes which are mostly driven by voluntary participation.	India's PAT scheme Japan's Top Runner Program
Local/ Federal program implementation	EE programs and policies implementation can be taken up at both the federal and the local level depending upon the demographics. For example India's BEE implements its programs at local levels through SDA's and only provides directional support. On the other hand Tunisia's ANME implements its program centrally. The key difference in both these is the control over program implementation.	Tunisia's ANME (federal level implementation) India's BEE (local level implementation)
Program M&E	Program M&E and continual improvement in the EE programs and policies is an essential feature for any EEU. To perform M&E functions, the EEUE must be effective in coordinating with key actors. Some EEU's such as Dubai's DSM agency have successful M&E frameworks and have smooth data exchange due to the presence of a high level energy council in which all the energy stakeholders are present. On the other hand EEU's such as BEE does not have a sound M&E framework.	India's BEE Dubai's DSM Agency US DOE
Market Mechanisms	EE governance should promote the EE entities in becoming self-reliable. As such the governance frameworks should promote and encourage schemes which can generate revenue for the unit. An example of the can be India's PAT scheme where the excess EE savings can be traded	India's PAT scheme
Role of ESCOs and Super ESCOs	Some EEU or governments promote development of Super ESCOS (Super Energy Service Companies). These	Dubai's DSM Agency

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GOVERN-ANCE ISSUES	DESCRIPTION	EXAMPLES
	companies compensates for a lack of government finance. Super ESCOs such as India's EESL are typically successful due to government support and large scale of operation. The development of Energy Services Companies (ESCO) market is severely impacted due to a large share being taken up by the ESCOs	EESL in India
Use of technology (software)	EE entities (EEU) will need strong information and communication technology support to monitor implementation of programs, which are spread over the entire geography under their purview. The EEU will need software for activities such as designing and developing programs, analysing tariffs and policies, and developing management information systems for programs to be communicated to all stakeholders in the country. The governance system should allow for use of technology as much as possible	Use of DSMore in USA's DOE

ACKNOWLEDGEMENT

The contents presented in this research paper are a part of research carried out by Tetra Tech ES India Pvt Ltd in executing a World Bank funded project- Establishment of an Energy Efficiency Unit at the Ministry of Electricity and Renewable Energy in Egypt.

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ENABLING POLICIES TO SUPPORT INDUSTRIAL ENERGY PRODUCTIVITY IN INDIA

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Keywords: Productivity, Policy, Capacity Building

ABSTRACT

This paper explores the policy dimensions of an industrial energy productivity strategy in India. The paper briefly traces the evolution of industrial energy use in the country, discusses the need to include productivity benefits in energy efficiency analysis and evaluates policy options to support an industrial energy productivity strategy. Working on the premise that energy productivity offers a more meaningful and contextual strategy than energy efficiency, the paper provides an analytical framework to develop energy performance indicators for measuring energy productivity of the industrial sector in India.

INTRODUCTION: ENERGY PRODUCTIVITY BASED MODEL FOR INDIA

While India has set clear goals regarding the objective of addressing energy efficiency through the Energy Conservation Act, 2001, the pathway for delivering this needs to be more clearly mapped out. There is a need to use energy productivity as a policy framework and an indicator to address this issue as well as help manage the interplay between energy consumption and sustainable development. Today, with persistent weak economic demand around the world governments are confronting the reality that the growth models of the past must be transformed. This raises the question: what new sustainable development policy narratives can help policy makers in India address current challenges. Energy productivity is both a policy agenda focusing on how energy can best be used to create value in the economy, as well as an indicator that integrates economic growth with energy consumption. At the macroeconomic level, energy productivity describes how much GDP can be produced using a unit energy. It is thus both a reflection of the structural make-up of the economy between energy intensive and non-energy intensive activities, as well as how efficiently energy is used in those activities[1].

Between 1990 and 2015 energy productivity rose in almost all major economies around the world, including India where it grew by 72%. (Figure 1). This increase was in part due to India's economic and industrial reforms of 1991 and rising per capita energy consumption from a relatively low base. However, it was also due to the expansion and modernization of energy-intensive heavy industry reflecting higher levels of energy efficiency. Looking at the global shifts in greater detail it can be seen that China had greater success in improving energy productivity (203% versus 72% for India) coming as it were from almost similar per capita energy consumption in the 1980s. This reflects a period of massive infrastructure expansion, which boosted GDP and helped modernize the economy. Such modernization, which accelerated in India in the mid- 2000s, a decade-and-a-half after China, also improved energy efficiency in the overall capital stock.

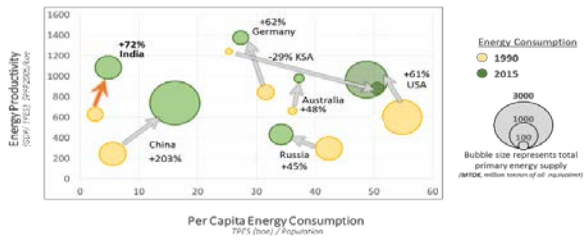

Figure 1: Global shifts in energy productivity: An indicator for diversification and energy efficiency at the national level. *Source: KAPSARC based on IEA and Enerdata*

INDUSTRIAL EVOLUTION AND ENERGY CONSUMPTION IN INDIA

The Indian industrial sector is critical to the country's economic strength as well as standard of living and well-being of its people. In India,40% of the final energy consumption is attributed to the industrial sector and this is expected to exceed 50% by 2050 at

[1] *Source:* Nicholas Howarth, et al , KAPSARC-UNESCWA Report, *Growth through diversification and energy efficiency: Energy Productivity in Saudi Arabia*

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a compounded average annual growth rate of 4.4%; with the energy intensive industries (iron & steel, cement, aluminium, chemicals incl. fertilizers, and pulp and paper) accounting for over 50% of the total industrial energy consumption in the country[2]. The light industries – food processing, textiles, wood products, printing and publishing, metal processing and brickmaking account for the other 50%. Table 1 provides a snap shot of industrial production and energy use for India.

Table 1: Industrial Production and Energy Use in India

Industry sub-sectors	Material production (MT)	Energy use (MToe)	Electricity use (Mtoe)
Iron and Steel	53	38	3.3
Chem & Petrochem		27	
Non-ferrous metals		0.4	
Aluminium	2	2.9	1.6
Non-metallic minerals		11.0	
Cement	170	13	1.1
-Pulp &Paper	13	3.2	0.7
Food and tobacco		10	
Textile and leather		1.3	
Other		66	15
Total industry sector		**150**	**22**

Note*: The table has been compiled from a mixture of top-down and bottom-up sources and so the totals may not match. Iron & steel includes energy use for coke-making and energy data for chemicals and petrochemicals include feedstocks. Sources: World Steel Association (2009); USGS (2009); IAI (2009); IPMA (2010); IEA (2009a and 2009c)*

There is significant, potentially exploitable, energy and emission-saving opportunities in Indian industry. Typically energy efficiency opportunities present themselves in areas of energy use associated with industrial utilities (e.g. boilers, furnaces, captive power plants, etc.), energy transfer (e.g. plant steam distribution) and end-use utilization in processes (e.g.. heating, drying, distillation, etc.) and equipment (motors and motor driven equipment such as fans, pumps, compressors and blowers). The efficient use of energy is a function of good operating and maintenance practices as well as choice of technology. In addition, non-fuel feedstock and its efficient use is driven by a combination of factors such as structural change (i.e. moving towards less energy intensive products), new and improved process technologies (i.e. product and market innovation). While pursuing policies and programs that advance industrial energy efficiency in the immediate term, it is also important to be mindful of the economic diversification possibilities that characterizes efficient use of both energy and non-fuel use in Indian industry. It is imperative to recognize two key drivers; the need for energy security and mitigating the impact of climate change through carbon reduction policies and programs in the country.

Table 2 provides a comparison of specific energy consumption in energy intensive industrial sectors in industrialized and developing countries, and India. Table 2 also benchmarks current best available technologies and the global average achieved.

[2] India Energy Outlook, 2015,

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Table 2 Specific Energy Consumption In Industry – India And The World

Sectors	Units	Industrialized Countries	Developing Countries (incl EIT)	Global Average	Best Available Technology	India
Petroleum refineries (2003)	Energy Efficiency Index (EEI)	0.7-0.8	1.3-3.8	1.25	1	0.9
High value(HVC)	Gj/t HVC	12.6-18.3	17.1-18.3	16.9	10.6	17.1
Ammonia(2007)	Gj/t NH3	33.2-36.2	35.9-46.5	41	23.5	37.5
Methanol(2006)	GJ/tMeOH	33.7-35.8	33.6-40.2	35.1	28.8	40.2
Aluminium smelting (2007)	MWh/t	14.8-15.8	14.6-15	15.5	13.4	16
Alumina Production	Gj/t alumina	10.9-15.5	10.5-24.5	16	7.4	
Iron &steel (2005)	EEI	1.16-1.4	1.4-2.2	1.45	1	1.55
Clinker (2007)	Gj/t clinker	3.3-4.2	3.1-6.2	3.5	2.9	3.1
Cement (2 007)	Gj/t cement	109-134	92-121	109	56	92
Lime	Gj/t lime	3.6-13	5-13	-	-	5.6
Glass (2005)	Gj/t melt	4-10	6.8-7.8	6.5	3.4	6.8
Brickmaking (2000s)	Mj/kg fired brick	1.5-3	0.75-11	-	-	3-11
Pulp and Paper	EEI (heat & electricity)	0.93-1.73	0.43-2.29	1.31	1	
<u>Textiles</u> *Spinning*	Gj/t yarn	Ring yarn: 3.5-3.6 Open end: 2.57	Ring yarn: 3.5-3.6 Other: 0.5-7.5	- -	- -	Ring yarn: 3.57 2.5
Weaving	Gj/t cloth	11-65	5-43	-	-	27-32.4
Cast iron	kWh/t melt	Cupola: 950 Electric: 525-715	780-850		520	780-900
Cast/alloy steel	kWh/t melt	Electric: 525-715	735		500	735
Cast aluminium	kWh/t melt	Fuel-fired: 600-1250 Electric: 440-590	590		570	
Cast copper	kWh/t melt	Electric: 400-1100	590		400	590

Source: Data drawn from Global Industrial Energy Efficiency Benchmarking – An Energy Policy Tool: Working Paper, UNIDO, Nov. 2010

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Analysis of the above pattern of specific energy consumption in key energy intensive sectors in industrialized countries, developing countries and comparisons with India leads to the following conclusions:

i. Energy efficiency opportunities in India can be found in petroleum refining, chemicals & petrochemicals (e.g. ammonia, methanol), aluminum smelting, iron & steel including alloy steel, and foundaries where the average SEC in India is higher than that of industrialized countries. However, in these sectors India compares well with other developing countries and except for high value chemicals, methanol, aluminium smelting, iron & steel and glass manufacture its SEC is lower than the global average.

ii. India has the lowest SEC in clinker and cement manufacture among all industrialized and developing countries including economies in transition. In addition, India is also better than the global average in petroleum refining, and ammonia production, and compares satisfactorily with the global average SEC in iron & steel, glass and textiles (spinning & weaving).

iii. India lags behind in the application of best available technologies in almost all industrial sub-sectors. The gap is most pronounced in chemicals & petrochemicals (e.g. high value chemicals, ammonia and methanol), aluminium smelting, glass, iron & steel and foundaries (e.g. cast iron, alloy steel, cast copper). It is for further critical examination in these sub-sectors whether restructuring and process modernization needs to be undertaken in addition to implementing energy efficiency programs.

ANALYSIS: INTEGRATING ENERGY PRODUCTIVITY IN ENERGY EFFICIENCY ANALYSIS

The basis of all policy design and implementation is a need to understand why energy productivity policies should be introduced and how well they might work to advance the economic gains to society.[3] The energy efficiency potential in the economy and the structure of the economy are two fundamental factors that impact energy productivity. Energy productivity can grow as part of a broader modernization, transformation or restructuring process. The modernization or replacement of old capital stocks can simultaneously improve productivity and competitiveness, product quality, and energy and environmental performance. Improving the energy efficiency of industry without any change in the industrial structure of the economy will serve to improve energy productivity. By the same token, an economic restructuring and product/goods diversification strategy to move up the value chain towards less energy intensive (higher energy productivity) industrial economy including services will also improve energy productivity. For example, the share of India’s steel production based on alternative technologies such as direct reduction iron-making and scrap-using electric arc furnaces (EAF) has grown, accounting for over 65% of the country’s installed steel manufacturing capacity and have replaced the inefficient integrated steel mills using blast furnaces and basic oxygen furnaces.

It follows, therefore, that any attempt at an energy productivity improvement program should consider a pragmatic blend of energy efficiency measures and technologies and industrial product diversification. Energy productivity improvement plans must examine both approaches – the shorter term, less capital intensive industrial energy efficiency measures that could yield high payoff in terms of improved productivity and the longer-term industrial diversification and modernization. In many situations there are economic energy efficiency opportunities that could produce immediate impacts that can slowdown, or even reverse, the growth rates in industrial energy demand without negatively impacting industrial and economic growth. Enhancing industrial energy productivity based on available tools/measures/policies should be the priority. To this end, addressing the “efficiency” gaps and identifying remedial actions is essential in improving industrial energy productivity.

Industrial Energy Productivity Driving Force-State-Response framework

Various frameworks assist in identifying problems, assessing impacts and developing enhanced

[3] *Energy Efficiency Indicators: Essentials for Policy Making.* IEA, 2014.

understanding of the underlying causes and effects. The driving force-state-response (Organization for Economic Co-operation and Development (OECD); UN Commission on Sustainable Development (UN-CSD)[4] is a useful framework in analyzing those relationships. The Industrial Energy Productivity driving force – state –response framework is depicted below in Figure 2.

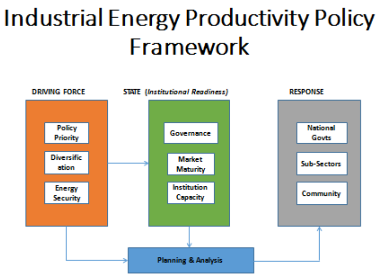

Figure 2

The conceptual framework that defines the scope, approach and methodology of an industrial energy productivity policy instrument would comprise of:

- Information about the nature of the eco-system that promotes energy efficiency and conservation: *the driving forces of Energy Productivity*
- Information about the factors that define the status and performance of energy productivity measures and policies: *the state of preparedness or institutional readiness.*
- Information about policy options and potential impact: *the response that policies should enable.*

The driving force-state-response framework constitutes the formation of an integrated approach that can regularly review and update policies based on their measured performance. This is further amplified in the next section on Energy Productivity Policy indicators.

ENERGY PRODUCTIVITY INDICATORS: DEFINITION AND GOAL

Energy indicators are a key guide for setting targets and supporting decision makers in establishing energy policies and strategies and are essential in tracking EP progress. The IEA uses a pyramid of energy productivity indicators (shown in Figure 3) ranging from Economic Scale indicators (GDP/TFC), through sectoral indicators, sub-sectoral and industry unit energy productivity (plant specific energy consumption). Here we are examining the specific energy consumption of sub-sectors.

EP indicators can be classified under four levels, as follows:

Level 1: Economy level aggregate EP indicators defined as the ratio of GDP to National Energy Consumption (defined as domestic energy production + energy imports – energy exports).

Level 2: Sectoral level EP disaggregated indicators defined as the ratio of sectoral value add to energy consumed by the sector. Its inverse, industry sector energy intensity is defined as the quantity of energy needed to produce a unit of economic output or value.

Level 3: Sub-sectoral level disaggregated EP indicators defined as the ratio of sub sectoral value add to energy consumed by the sub-sector. Its inverse, industry sub-sectoral energy intensity is defined as the quantity of energy needed to produce a unit of economic output or a unit of physical output (Gj/$, Gj/t)

Level 4: Plant level energy efficiency (EE) indicators or the plant’s specific energy consumption defined as the total energy consumed by the plant divided by the physical manufactured output. EE indicators can be further disaggregated to define specific energy consumption by a department or an equipment in the plant.

To understand the energy situation, it is essential to have energy efficiency and energy productivity indicators at various levels; starting from the base (Figure 3): equipment, facility, sub-sector, sector, and national level. Each level has its own indicators based on specific circumstances. At sectoral level, for example, the Energy Productivity indicator in the industrial sector is mainly $ value added per unit of energy consumed and at the plant level it is defined by specific energy consumption or energy intensity, i.e. energy consumption per unit physical production. Table 3 provides an illustrative list of energy productivity performance indicators for energy intensive Indian industry.

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[4] The UN CSD framework for indicators adapts the OECD Pressure –State-Response model. UN CSD uses a driving force, state, and response (DSR) framework.

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Table 3: Energy Efficiency Performance Indicators for Indian Industry

Sector/sub-sector	**Coverage**	**Typical Process Energy End-Use**	**Energy Data**	**Output Data**	**EE Performance Indicator**
All Industry	***Sub-sectors*** Iron & Steel Fertilizers Chemicals & Petrochemicals Cement Aluminum	Heating Lighting Cooling Motive power (pumps, fans, blowers, dryers, compressors, conveyors etc) Electrolysis	Total industry sector energy consumption	Industry value added	**Level 1** Total industry energy consumption per total industry value added
Iron & Steel	Basic Oxygen Process (BOF) Electric Arc Furnace (EAF) Direct Reduction Iron (DRI)	Heating Motive power Lighting	Total sub-sector energy consumption	Sub-sectoral physical output	**Level 2** Sub-sectoral energy consumption per unit of sub-sectoral physical output **Level 3** Process/product energy consumption per unit of physical output
Chemicals & Petrochemicals	Ethylene Benzene, Toluene, Xylene (BTX) Ammonia Methanol Butadiene	Heating (distillation, drying, evaporation) Motive power Lighting Chillers	Total sub-sector energy consumption	Sub-sectoral physical output	**Level 2** Sub-sectoral energy consumption per unit of sub-sectoral physical output **Level 3** Process/product energy consumption per unit of physical output
Cement	Clinker (wet and dry);	Heating (calcination, drying) Motive power Lighting	Total sub-sector energy consumption	Sub-sectoral physical output	**Level 2** Sub-sectoral energy consumption per unit of sub-sectoral physical output **Level 3** Process/product energy consumption per unit of physical output

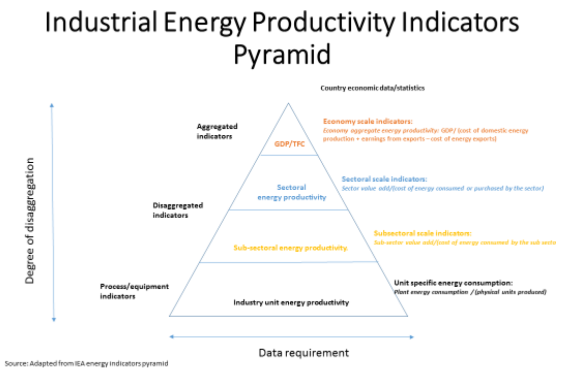

Figure 3

DISCUSSION: POLICIES TO SUPPORT INDUSTRIAL ENERGY EFFICIENCY

As industry accounts for a high proportion of energy use in India having effective policies that assist industrial enterprises to improve levels of energy efficiency (and hence energy productivity) should be a priority. Over the past few decades industrial energy efficiency policy formulation has evolved considerably with program designs reflecting analytical practices that reflect increasing methodological sophistication. Following the 1973 oil crisis Japan was among the first countries to have adopted an industry-wide energy efficiency policy, and since then several developed countries followed suit while adopting and implementing a variety of mechanisms. A number of inter-related factors need to be considered by policy makers and a phased step-by-step program employing analytical and system planning tools and methods is presented in Table 4 as

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the policy pathway to advancing industrial energy productivity in India.

Table 4: Energy Productivity Program Policy Pathway In Indian Industry Sector

Five Phases	Ten Steps	Twenty Actions	Five Tools
Policy Definition	1.Formulate industrial EP regulations in legislative framework	- Analyze legislative framework and regulatory drivers	1.GAP analysis 2.SEC norms
Program Planning	2,Define program role in policy framework	- Analyze policy framework and industrial context	
	3. Design the program	- Define scope and objectives - Define Energy Management System (EnMS)	3. ISO 50001: Energy Mgt. System
	4. Establish Action Plans and mobilize resources	- Establish Management - Information Systems (MIS) - Create Action Plan - Secure resources	
Program Implementation	5. Provide Institutional support	- Conduct energy audits; ESCOs performance contracts - Develop training strategy :institutional and human capacity - Follow-up with companies and assist in implementation	4. Energy audit tools & practices
Monitoring & Evaluation	6. Establish M&E protocols	- Establish verifiable indicators and data sources - Meter & sub-meter facilities - Establish baselines	5. Benchmarking
	7. Assess compliance; feedback & correction	- Use transparent & predefined criteria - Establish rewards or penalty mechanisms	
	8. Evaluate program	- Define evaluation objectives - Select evaluation approach and indicators	
Reporting	9. Promote program	- Address challenges and failures	
	10. Revise and adapt program.	- Adjust program design and consider up-scaling	

Program Planning

The chart below (Figure 4) shows the industrial energy productivity policy planning and implementation process. An important point to note is that policy directives in the form of energy target reduction stipulations or mandating energy audits and reporting is a consequence of and derived from the findings of the gap analysis and target setting exercise at the sectoral, sub-sector and unit levels.

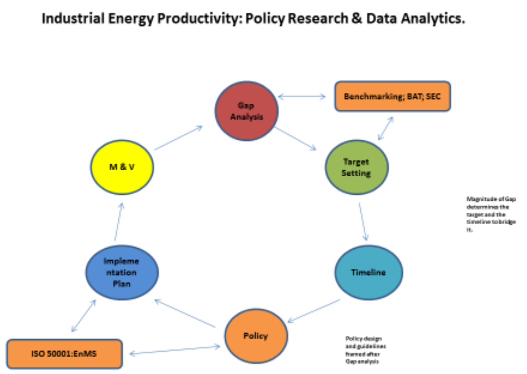

Figure 4

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Once the policies have been formulated, governments need to provide the enabling climate that assist industries in adhering to the policy requirements and plan for sustained energy efficiency/productivity improvements. The implementation plan needs to be technology, market and business driven and draws upon EMS systems (e.g. ISO 50001) that require data analytics and includes institutional development and capacity building as well.

Measuring policy outcomes and the policy cycle

To ensure maximum effectiveness, policy outcomes in all areas need to be measured and reviews of performance need to be built into policies and programmes. Given that the overall objective is to improve energy productivity, i.e. reduce energy input per unit of value added, this measure – the inverse of energy intensity – is a high-level measure of performance, but it has to be normalised for changes in the economic structure of the economy. Shifts towards more services and away from industry will improve energy productivity but not necessarily represent an improvement in underlying energy efficiency. To measure actual energy efficiency in industry, and the success of policies designed to affect it, there needs to be a hierarchy of indicators as shown in Figure 3– ranging from energy per value added per industrial sector to energy per value added for individual enterprises. It is also possible to gather useful information on the adoption of key technologies from monitoring the business activity of the energy efficiency equipment supply industry.

Policies should be monitored and evaluated on a regular basis. In the ideal policy cycle, policies are first formulated, implemented and then put into practice. Following which they are monitored and evaluated and the results fed into a re-formulation or even abolition and replacement of policies. Post-policy evaluation is an essential component of the cycle. However, it is important not to change policies too often, medium to long-term stability of policy is essential for both industry credibility and effectiveness. This is particularly important when seeking to influence investment decisions on projects that take time to develop and by their very nature are long term.

Basic policy options

Industrial energy efficiency policies and programs can include:

- Incentives for improving energy efficiency, which may include financial incentives such as reduced taxes or enhanced capital allowances as well as non-financial incentives e.g. recognition ("carrots").
- Penalties on companies if they do not improve efficiency e.g. fines, additional taxes or exclusion from certain markets ("sticks").
- Regulations to limit choice e.g. only allowing the sale of motors with a certain minimum level of efficiency.
- Programs that seek to build capacity and improve the quality of energy management within enterprises.

Industrial energy efficiency policies can be classified into four main types although in practice specific policies and programs often cut across these boundaries. The types, as defined by Sustainable Energy for All (SE4ALL), are:

- Information-led and capacity building policies.
- Institutional, regulatory and legal policies.
- Fiscal and financial policies.
- Technology innovation acceleration policies.

Information-led and capacity building programmes are focused on providing better information to decision makers about a) the need to invest in energy efficiency b) the potential c) the benefits of energy efficiency and d) specifically how to improve efficiency and increasing capacity in energy management. Capacity building seeks to improve the know-how and capability of industry to develop and implement effective energy efficiency programmes, as well as the capability of other actors including energy service companies, efficiency technology vendors and the financial sector.

Institutional, regulatory and legal policies are centred on regulating activity in energy efficiency by mandating or prohibiting certain courses of action. Laws and regulations seek to define guidelines and responsibilities that impact the form, manner and pattern of energy usage and can include specifying energy savings targets, setting performance standards, establishing codes of practice and choice of energy efficient technology. Standards for energy management and performance benchmarks are important tools for improving industrial energy efficiency and requiring large, energy intensive industries and other industrial energy users to conform to ISO 50001, or incentivising them in some way to adopt the standard. They help to build energy management capacity. Enterprises that consume energy above a certain level can also be required to appoint an energy manager and submit energy efficiency improvement plans with monitoring and reporting of energy use. Benchmarking among industries and their subsectors, possibly implemented through industry associations, and ensuring the sharing of information can be an important tool. As well as regulations of end users, regulatory framework for the energy supply industry can also be used to impact energy efficiency improvement, for example by mandating certain expenditures on efficiency by energy suppliers, or by regulating tariff design.

Fiscal policies use the tax system to encourage improvements in energy efficiency and financial programmes seek to increase the flow of investment into energy efficiency projects including by third party investors and lenders. As well as policies specifically designed for energy efficiency, energy pricing policies, particularly where energy price subsidies are in force, will also affect the attractiveness of energy efficiency. Energy pricing decisions clearly have wider economic and social implications.

Although energy efficiency can be greatly improved simply by adopting existing proven technologies, the innovation of new efficiency technologies also has a role to play and can be a source of economic growth. Policies to accelerate innovations in energy efficiency can be implemented. Key energy productivity options in a few energy intensive Indian industry sub sectors is provided in Table 5.

Table 5: Indian Industry – Energy Productivity Options

Sub-sector	Energy Efficiency Status	Energy Efficiency Options	Fuel and feedstock switching	Recycling and energy recovery
Cement	Efficiency is currently better than world average with large kilns being among the best in the world	Deployment of BATs in smaller cement plants	Expanding the use of clinker substitutes; Expanding the use of biomass and alternative fuels	Waste heat recovery for in-situ power generation
Iron and steel	Largest DRI producer worldwide and one of the few countries that have coal based DRI High consumption of reducing agents in blast furnace owing to lack of suitable metallurgical coke	Deployment of BATs Development of new technologies (e.g. smelting reduction)	Lower use of coal-based DRI	Higher recycling rate
Chemicals and petrochemicals	Ammonia production accounts for more than half of energy use; oil feedstocks play an important role	Deployment of BATs in the short term and new technologies in the long term	Continue to switch away from oil feedstocks; Expand the production of bio- based plastics and chemicals	Improved materials and energy flow management
Aluminium	Average energy intensity in smelting is on par with world average	Implementation of energy efficiency measures in refining and smelting Introduction of new smelting technologies	Increased use of low carbon electricity sources	Higher recycling rates
Pulp and paper	High share of small and medium-sized paper mills (half of total manufacture)	Deployment of BATs (including black liquor and biomass gasification, heat recovery)	Switching to combustible biomass	Increased use of waste paper

Strengthening Institutional Readiness

Strengthening institutional readiness is central to the task of planning, designing and implementing of energy productivity policies and measures. It includes the formulation and implementation of energy productivity strategic goals, promotion of integrated energy resource planning, improving governance and developing incentive frameworks and delivering market driven energy efficiency services. Energy productivity strategic goals are driven by key policy drivers such as i. national energy efficiency laws, ii. energy security and climate change actions, iii. prevailing economic conditions and governance structures, and, iv. rational energy pricing.

Innovations in advancing industrial energy productivity

The productivity challenges of today in Indian industry cannot be addressed in a business-as-usual manner. The country's comparative advantage is as a convenor, interlocutor, and accelerator. To this end it can leverage a range of resources – alliances and partnerships, human capacities and skills, and technological advancements that select, design, develop, test, validate, and scale innovations that address productivity challenges in their regions, including industry.

Innovative development methods and new forms of partnerships are central tools for attaining energy productivity objectives. Innovation refers to novel business or organizational models; operational or production processes; or products or services that lead to substantial improvements in executing against the challenges. Innovations help produce outcomes more effectively, more cheaply, that reach more beneficiaries, and in a shorter period of time. New forms of partnership refers to employing a range of creative platforms and alliances, which bring together diverse organizations, enabling these organizations to leverage each other's resources for identifying and scaling up innovative solutions to productivity challenges.[5]

This strategy suggests that a new approach that catalyzes new processes, business models, technologies, and non-traditional partners can alter the pace and direction of change. Central to this approach is the creation of an Innovation Platform – a network of Indian and global partners working on a common theme of advancing energy productivity by investing in open innovation processes that capture ideas and converts knowledge into solutions; and builds alliances and expertise to take a handful of proven solutions to scale in the country. Figure 6 provides a schematic of an open innovation platform to catalyse development of industrial energy productivity technologies.

It has been universally acknowledged that best-in-class companies are twice as likely as their industry average to have open innovation processes in place[6]. Open innovation[7] processes enable Indian companies to reach out to clients, partners, experts, employees, inventors and suppliers to capture ideas, to broadcast marketing or R&D search themes or challenges and collaborate on developing powerful new concepts to feed the innovation process. All this in a managed and controlled way through the use of IT "search and scouting" software that links the company's fully integrated web portal to source ideas, insights and technology proposals. The result is instantaneous access to a vast new network of external experts along with the automated tools to quickly and effectively sort, manage, and evaluate the volume of ideas and technology proposals generated.

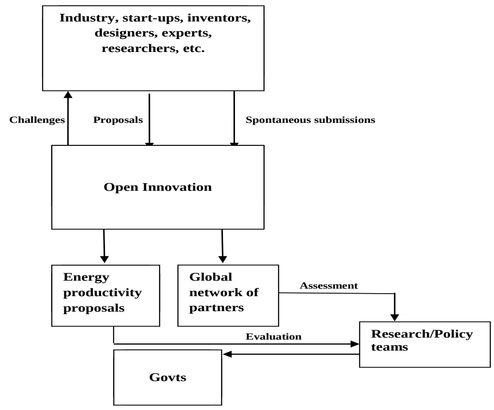

Figure 6: Open Innovation Framework to Advance Industrial Energy Productivity

[5] USAID/India CDCS Paper, 2013

[6] Innovation Framework Technologies, 2011

[7] Open innovation could be effective in SMEs, but might be less relevant in heavy industries (e.g. steel, petrochemicals, cement , etc.) where there is need to modernize and incorporate existing global best practice technologies.

CONCLUSION

Energy productivity policies and programs benefit from the creation of effective institutional capacity and enablers in a variety of areas, including infrastructure development, policy formulation, research, manufacturing and service capacity development, financing, engineering design and systems and market development. This calls for the provision of a strategic pathway for policy makers in India to deliver market-driven energy productivity policies programs and services in the industrial sector.

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ENERGY, EMISSIONS AND ECONOMIC IMPACTS OF APPLIANCE EFFICIENCY MEASURE

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Keywords: Energy Efficiency, Macroeconomic impacts, Co-benfits

ABSTRACT

As India moves towards meeting its Intended Nationally Determined Contributions (INDCs) to emissions reduction, policy makers have to choose among available alternatives. Investment in renewable energy continues to be the primary choice. Energy efficiency is relegated to the second place as savings are not obvious to track and its economy wide impacts are difficult to estimate. The debate on the choice between energy efficiency and renewable energy is far from settled and decisions continue to be made void of empirical evidence.

This paper is a work in progress. Here we estimate the reduction in energy consumption, emissions and economy wide impacts over time from promotion of efficient light bulbs in the Indian context. We then calculate the investment (and associated emissions) required to meet the equivalent energy demand through conventional and renewable sources if the energy efficiency measures were not deployed.

The impacts of these alternative policy scenarios are estimated using a coupled input-output econometric framework of the newly developed E3-India model. The model captures the relationship between Economy, Energy and Emissions, covering 20 economic sectors, 8 energy users and five income quintiles for India's 32 states and union territories. This method used here can be used to quantify the monetary and environmental impacts of efficiency improvement programs as compared to renewable energy options.

INTRODUCTION

As India moves towards meeting its Intended Nationally Determined Contributions (INDCs) to emissions reduction, policy makers have to choose among available alternatives. Investment in renewable energy continues to be the primary choice. Energy efficiency is relegated to the second place as savings are not obvious to track and its economy wide impacts are difficult to estimate. The debate on the choice between energy efficiency and renewable energy is far from settled and decisions continue to be made void of empirical evidence.

India's Intended Nationally Determined Contribution (INDC) includes reduction in the emissions intensity of its GDP by 20-25% by 2020 and, 33 to 35 per cent by 2030 from 2005 level. It also pledges to create a carbon sink of 2.5 to 3 b tonne of CO_2 equivalent through additional forest and tree cover by 2030 (MoEF, 2015).

Total electricity generation capacity in 2016 was 322 GW (CEA 2016). The consumption was 1,031 TWh of which 23% (or 237 TWh) was in the domestic sector. The overall power deficit dropped to less than 1%. About 81% of the households (NSSO, 2016) use electricity as the main source of lighting. Lighting accounts for 28% of the residential electricity use. It is believed that promoting efficient lighting in domestic sector will save 50 b kWh in electricity every year which is equivalent to about 19 GW of avoided generation capacity (EESL, 2014).

Ministry of Power, Government of India launched the Demand side management based Efficient Lighting Program (DELP). DELP was relaunched as Unnat Jyoti by Affordable LEDs for All (UJALA, meaning light in Hindi) in 2014. It is being executed by Energy Efficiency Services Limited (EESL, a super Energy Service Company under the Ministry of Power, Government of India) as possibly the world largest zero subsidy LED program for domestic consumers. The aim of the program is to replace the inefficient 60 W ICL bulbs with energy efficient 8 W LED bulbs. The LED bulbs consume about 85% less energy, gives same amount of light and last 20 times longer.

Under this program, EESL negotiated bulk purchase from LED manufactures and brought the cost down from about Rs. 310 to Rs. 38 /bulb to make it affordable to households. The corresponding retail prices of these bulbs were Rs.

400 and Rs. 65 respectively. The program aims to replace 770 m bulbs during 2014-2019 (EESL, 2014). About 758 m ICL bulbs were sold in 2012 alone (ELCOMA in EESL, 2014) and hence, the overall replacement potential is huge.

Households buy these LED light bulbs as a replacement for their conventional ICL bulbs at the cost of Rs. 50 / bulb under the program. Assuming a usage of 3.5 hours per day for 300 days a year (EESL, 2014), the LED bulbs completely pay for itself in little over 2 months.

RESEARCH QUESTION AND METHODOLOY

This paper estimates the reduction in energy consumption, emissions and economy wide impacts on employment and income over time from promotion of domestic efficient light bulbs in the Indian context. We then estimate the investment required to meet the equivalent energy demand through conventional and renewable sources if the energy efficiency measures were not deployed.

The impacts of these alternative policy scenarios are estimated based on their economy wide impacts using a coupled input-output econometric framework and the future technology transitions module of the newly developed E3-India model. The model captures the relationship between Economy, Energy and Emissions covering 20 economic sectors, and 8 energy users for India's 32 states and union territories.

SIGNIFICANCE OF RESEARCH

This method helps to quantify the additional monetary and environmental benefits of efficiency improvement programs beyond their direct impacts. It also helps to identify any potential negative impact which may be addressed during policy design.

THE E3 INDIA MODEL

E3-India is a simulation model built using the coupled input-output econometric approach linked with the national accounting framework. It is based on globally accepted E3ME model (Cambridge Econometrics, 2014) which has been in existence since the mid-1990’s and builds on the UK MDM- E3 model that has existed since the 1970s. It has been used for official policy analysis in Europe (e.g. Pollitt et al, 2014). The description of E3- India that follows is based on Cambridge Econometrics (2015, 2017).

<<insert Figure 1 here>>

ECONOMIC MODULE

The economic module is a demand based post Keynesian, non-equilibrium model which neither assumes perfectly competitive market nor optimized use of capital and labor. The behavior is instead estimated using historic data. It is based on real-world relationships, rather than an optimization based tool (see European Commission, 2016 for more details). This approach sets it apart from more traditional CGE approach to economic modeling which is heavily reliant on assumptions about optimizing behavior and perfectly available information (Pollitt, 2017).

ENERGY MODULE

The energy system is integrated with the economy within the modelling framework. Five of twenty economic sectors in the model namely Coal, Oil extraction, Gas extraction, Electricity distribution, and Gas distribution are used to establish relationship between the economy and energy sectors. Energy demand by industrial sectors is econometrically estimated in the model as part of the production process.

The model has five carriers of energy (Coal, Oil, Natural gas, Electricity, Biomass) and eight users (Power generation, Other transformations, Manufacturing, Transport, Households, Services, Agriculture, Non-energy use).

POWER GENERATION MODULE

The power generation sector is modelled using the evolutionary theory in the FTT (Future Technology Transitions) tool (Mercure, 2012). FTT consists of 24 energy technologies adopted on the basis of existing market structure and relative technology costs. It uses a diffusion model that estimates learning rates and declining development costs over time. It also recognizes limitations in the energy system like the maximum shares of intermittent generation, or limitations on available sites for certain renewable technologies.

E3 INDIA

E3-India provides a representation of the Indian economy using the E3M framework. The model covers 32 Indian states and union territories, 20 economic sectors, 5 income quintiles, 8 users of 5 different energy carriers, 24 power sector technologies, 10 types of atmospheric emission and annual projections out to 2035. While the general structure of the model allows it to assess general economic policies, the integrated economy-energy linkages make the model an ideal tool for assessing various energy policies (e.g. efficiency programs, energy or carbon taxation).

The model data are derived from official and publicly available sources wherever possible. For most model variables the data are sourced from state-level statistical offices. Limitations in the data are recognized and gaps are filled out using specialized software algorithms. Time series data are collected for all economic, energy and emission related variables (annually from 1995) so that econometric estimation may be carried out.

The estimation approach used is a two-stage least squares error correction model. The exact specification is derived from Hendry et al (1984) and Engle and Granger (1987). It provides both a long-term 'steady-state' outcome as well as looking at the transition period to get to long-term outcomes.

The model can be run for a single state or for India as a whole. The states are linked together through trade linkages and the sectors are linked through input-output relationships. Energy-economy relationships are modelled by combining physical and economic data. Outputs from the model include a full set of national accounts indicators, covering macro-level indicators such as GDP and inflation, but also sectoral output, trade and prices. The sectoral dimension of the model is particularly important for assessing the effects of energy policy as the ways in which sectors use (or provide) energy vary considerably. Cambridge Econometrics (2017) provides detailed description about the model assumptions and structure.

SCENARIO DEFINITION

We make the following simplifying assumptions to model the economy, energy and emissions impacts of the bulb replacement program -

- Total of 770 m LED bulbs replace conventional ICL bulbs equally over the 6 years of the program. The number of bulbs replaced in each state is proportional to the household expense on electricity in that state.
- Households pay for the efficient LED bulbs from their savings without altering their expenditure on other goods.
- As of now we are not aware of study on how LED bulbs may change the usage pattern in the Indian context, and hence the usage patterns under the program are assumed to be same as that under the baseline.
- No market transformation is assumed at the end of the program period. Households revert to their original preferences for bulbs once the program is over. However, they continue to save on electricity bills due to replacements made well beyond the program period as LED bulbs have very long product life.
- The manufacturing sector makes a one-time investment of about Rs. 30 b in 2013 to meet the increased demand of LED bulbs from 2014. The investment in manufacturing is prorated to states based on the number of workers in manufacturing sector in the respective states.
- EESL creates a total of 35,000 temporary jobs (EESL, 2014) during the program period to distribute LED bulbs to households via various electricity distribution companies.

<<insert Figure 2 here>>

Note that the current work ignores the lifecycle cost and benefits of using LED bulbs, program implementation cost, intra-year monetary transactions that happen as part of program implementation, and indirect benefits accrued to power distribution companies.

DIRECT IMPACTS

The direct impacts of the program include household savings in electricity bills, investment in manufacturing to increase domestic production of LED bulbs, reduction in need for new power generation capacity and associated emissions (Table 1). These are estimated using simple multipliers for conversions among energy, emissions and savings. Households spend about Rs.
6.4 m/yr. during the program period on purchase of replacement LED bulbs. By the end of the program period they start saving 42 TWh/yr. of electricity

and Rs. 218 b/yr. in corresponding bills. The direct impacts of the program is equivalent to avoidance of about 12 numbers of new 500 MW coal plant and removal of 34 m tonne of CO_2 every year after 2019.

<<insert Table 1 here>>

MODEL RESULTS

The results presented in this paper are work in progress. The section describes the modeled impact of the efficient bulb replacement program at the end of the program period i.e., 2019 unless otherwise mentioned. The % change values are over the respective business as usual scenario (baseline). All monetary values are specified in Rs. (INR) in 2010 prices.

ECONOMY

There is a reduction of Rs. 256 billion (0.2%) over the baseline in Gross Domestic Product (GDP) by the end of the program (Table 2). The decline is largely due to reduction in investments and household consumption and is marginally offset by reduction in imports. There is negligible change in exports.

<<insert Table 2 , Figure 3 here>>

The impact on GDP is described below.

GDP = Investment + Consumption by households + Government expenditure + (Exports – Imports)

A heavy reduction in electricity demand by households leads to avoidance of new power generation capacity. This translates to a reduction of Rs. 344 b investments in the electricity generation sector in 2019 alone. An overall reduction in **investment** of Rs. 353 billion (1%) is observed. The reduction in investment is the largest contributor to short run reduction in GDP. The cumulative reduction in investment in power generation during the program period is Rs 1,776 b.

The overall reduction in **consumption by households is** of Rs. 113 b, of which there is a reduction of Rs. 287 b (17.4%) on electricity bills, and about Rs. 174 b in increased spending on goods and services including purchase of LED bulbs. The total household consumption dropped even when households saved a considerable amount from electricity bills which they could have spent on other goods. This was due to an overall decrease in real personal disposable income to the tune of Rs. 172 b. This drop in personal disposable income is primarily associated with decreased employment in the power generation and the construction industry.

Part of the reduction in GDP is offset by decrease in **imports** by Rs. 174 b. This was spurred by investment in manufacturing at the beginning of the program period leading a decrease in imports of Rs. 118 b. There was no change in the government expenditure component of GDP as it is exogenously derived in the model.

The total number of jobs marginally decreased by around 261,000 (0.05%). There was 9 % reduction in jobs in the electricity generation (71,000) sector and about 50,000 each in the construction and trade sectors. The reduction in the construction and trade sector can be attributed partly to decrease in construction of new power plants and its spill over impacts on other sectors.

<<insert Figure 4 here>>

In the long run, there is marginal negative impact on the GDP. This reduction is less than the household's reduced expenditure on electricity bills, even beyond 2035 due to sustained savings. LED bulbs have a very long life of around 35,000- 50,000 hour (or 20 or more years) and low failure rates, leading to sustained savings over long term. There is no noticeable negative impact on investment, imports, exports or employment. (Table 2).

ENERGY, ELECTRICITY AND EMISSIONS

The impact on energy, electricity and emissions are summarized in Table 3. They are as follows.

<<insert Table 3, Table 4 here>>

Energy

The total fuel use for energy (by 8 users of energy across 5 carriers) is reduced by 2.6% or about 31 m TOE/yr. in 2019. Maximum reduction in fuel use happens in power generation (5%) and households (2%). The cumulative reduction during the program period is of 110 m TOE. In the long run, there is an overall sustained reduction of about 28 m TOE/yr. of fuel use (Figure 5)

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Electricity consumption

The change in total electricity consumption is almost completely led by savings due to households' use of efficient bulbs (Table 4). Electricity consumption by households is reduced by 17.5% or 3.4 m TOE/yr. (~39.5 TWh/yr.) (Figure 6) at the end of the program period. The cumulative savings in electricity during the program periods is about 142 TWh. The impact of LED bulb replacement is visible in the long run and households continued to save 2.6 m TOE/yr. (~32 TWh/yr.) of electricity even beyond 2035.

<insert Figure 6 here>>

Electricity generation

There is a reduction of 40 TWh (4.2%) in electricity generation in 2019 alone. The investment in new generation capacity drops by 11% or Rs. 344 b by the end of the program period. The total reduction in investment during this period is about Rs 1,722 b. The reduction of investments happens mainly in large hydro, coal and CCGT based plants. The investment returns to the baseline situation after the program ends. New construction of electricity capacity is reduced by 10% every year and cumulatively by 9 GW between 2014 and 2019
(Figure 7).

<<insert Figure 7 here>>

Emissions

The program leads to a CO_2 reduction of 13.9 m tonne of Carbon/yr. (51 m tonne of CO_2/yr.) at its peak in 2019. Almost all of this reduction comes from power generation sector of which two-thirds is from coal fired power plants and one-third from natural gas (

Figure 8). The cumulative reduction in emissions during the program period is equivalent to 182 m tonne of CO_2. The program leads to sustained reduction of about 47 m tonne of CO_2/yr. beyond 2035.

<<insert Figure 8 here>>

SUMMARY OF FINDINGS

In the short-run, there is a minor reduction of 0.2% in GDP by the end of the program period. The decline is largely due to reduction in investments and household consumption, and is marginally offset by reduction in imports. There is negligible change in exports.

The program will lead to cumulative savings of 110 m TOE in fuel use, 142 TWh in electricity consumption, a staggering Rs. 1,722 b in investment during 2014-2019. It will lead to avoided new generation capacity of 9 GW along with a reduction of 182 m tonne of emissions of CO_2 during the same period.

In the long run, there is a negligible reduction in GDP except for the part contributed by the sustained decrease in spending by the household on electricity bills. No other noticeable impacts are there on imports, exports or employment. There is sustained reduction in fuel use of 28 m TOE/yr., 32 TWh/yr. in electricity consumption and 47 m tonne of CO_2/yr. even beyond 2035.

This summarizes the long term benefits of the program with little private investment of Rs. 30 b in the manufacturing sector and a proactive policy to facilitate adoption of efficient bulbs without subsidies or tax incentives.

CONCLUSION

The single most important contribution of program like UJALA, India's domestic efficient lighting program is the sustained reduction in emissions without any adverse impact on the economy in the long run and the need of tax or subsidies.

Using the E3 India model, we find that India will save at least 28 m TOE/yr. in fuels in the long run. This is equivalent to reduction of 47 million tonne of CO_2 every year. And it happens with the government just acting as a catalyst to promote energy efficient lighting without any investment, taxes or subsidies and an initial one time investment of Rs. 30 b in the manufacturing sector. The program will also lead to avoidance of the new generation capacity of 9 GW and save Rs. 1,776 b in investment in power generation.

If the same reduction in emissions is to be achieved using renewable option, India will need an investment of about Rs. 10 b every year during the program period, or Rs. 59 b cumulatively between 2014 and 2019. This is twice the investment required in the manufacturing sector under the efficient lighting policy scenario. Further, the efficient light bulb program frees up investment of

Rs 1,776 b for other economic sectors and welfare. Thus, while both energy efficiency program (like the efficient light program) and renewable energy reduces emissions, EE based measures requires half the investment to achieve the same.

The estimated benefits of the efficient lighting program in this paper are on the conservative side, given that the model currently does not account for market transformation. Currently, we have estimated the impact of replacing 770 m bulbs over 6 years, while 758 m ICL bulbs were sold alone in 2012 (ELCOMA, EESL 2014). Hence the overall potential for transition to efficient lighting is huge. As LED bulbs become widely used beyond the stipulations of the program and in applications such as streetlights, commercial and industrial buildings, the benefits will be many times of what is currently estimated in this paper.

SIGNIFICANCE OF THE WORK

E3-Indlia like models can estimate the economy, energy and environment benefits of efficient light bulb replacement programs well beyond their direct effects.

This is the first attempt to estimate coupled economy, energy and environment benefits of energy efficiency program for appliances in the Indian context to our knowledge. The results also cautions about some adverse impact of the program in short run (like reduction in investments and jobs, particularly in the power generation sector) to better plan for those contingencies and avoid any short term employment and welfare impacts that can derail the policy. These short term negative impacts predicted in the model can be overcome if the investments saved from power generation is used in other sectors or for direct transfer to households. The findings help provide empirical support to policy makers to confidently advocate and adopt energy efficiency as a tool to combat climate change without sacrificing economic growth, or needs of additional investment, taxes or subsidies.

Importantly, we also show that the energy efficiency route to emissions reduction (as in the case of efficient bulb replacement program) requires one-half the investment that is required to achieve the same benefits through a renewable energy technology like solar farms. The argument can be extended to promote other efficient appliance programs like air conditioners, motors and pumps, etc., though it should be noted that these have much higher costs, are less prevalent and provide comparatively lower reduction in consumption as compared to the bulb replacement program. However, to meet India's INDC goals, the option is not going to be either energy efficiency or renewable energy, but both.

LIMITATIONS AND NEXT STEPS

This is 'work in progress' and is based on simplified version of the UJALA like DELP program. The model is also being continuously improved. Hence, the impacts and the results presented here should be used as preliminary estimates only. Currently aggregated national level results are shared here for brevity of presentation. The comparison with investment in RE is preliminary. We hope to perform comparable analysis of the renewable energy route to emission reduction.

It is important to note that the current estimates of benefits are on the conservative side. To estimate the full benefit of the program, the following will have to be considered - market transformation and associated investments including the use of LED bulbs outside the program i.e., in industry, streetlights, commercial buildings; and their use as new fixtures ; detailed modeling of renewable energy investments and associated impacts on economy and emissions; issues related to power supply constraint, shortage and access; alternative use of investment saved in power generation and its economy wide impacts; and comparison of our results with other similar studies globally

We hope to address these in next iteration of the model. Some of the relatively more difficult, nonetheless important drivers include impact on households in different income quintiles to understand the distributive impact of the policy; shifts in consumer preferences for LED bulbs; behavioral interventions (Allcott & Mullainathan, 2010); and associated health, education and productivity benefits.

ACKNOWLEDGEMENTS

We thank the support from the Regulatory Assistance Project (RAP) - Ranjit Bharvirkar, Surabhi Joshi, Riley Allen; Cambridge

Econometrics – Unnada Chewpreecha, Hector Pollitt ; Prayas Energy Group - Aditya Chunekar; and Vidya Bhamidi, ps Collective

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Nomenclature

m millions
b billions
T tonne
th Thousand
Rs. Rupees (INR)
yr Year
TOE tonne of Oil Equivalent
MW Megawatts
GW Gigawatts

FIGURES AND TABLES

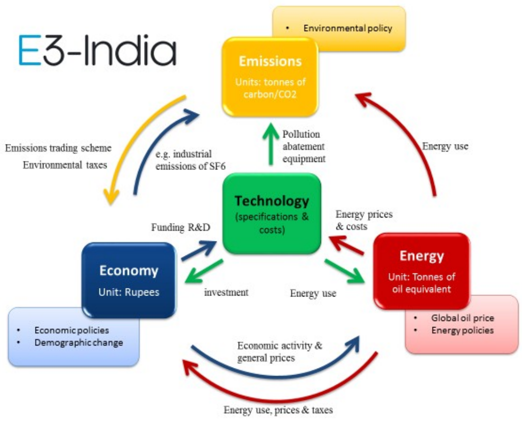
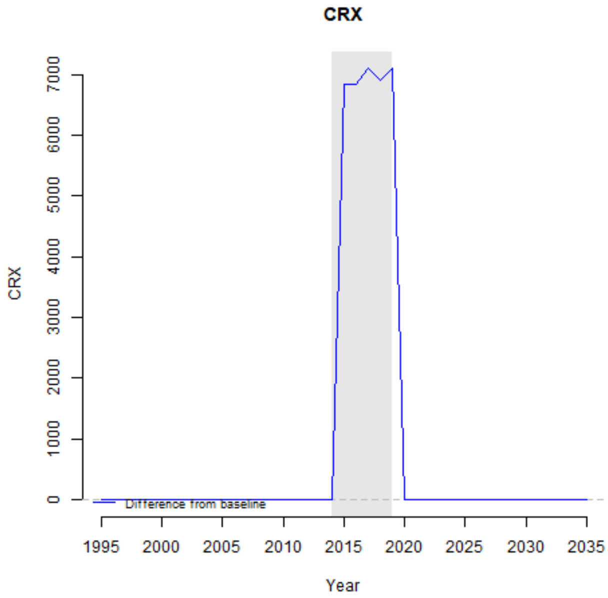
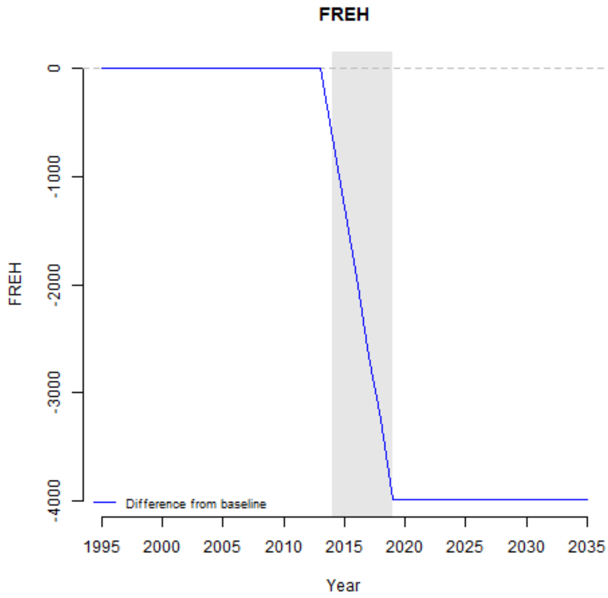


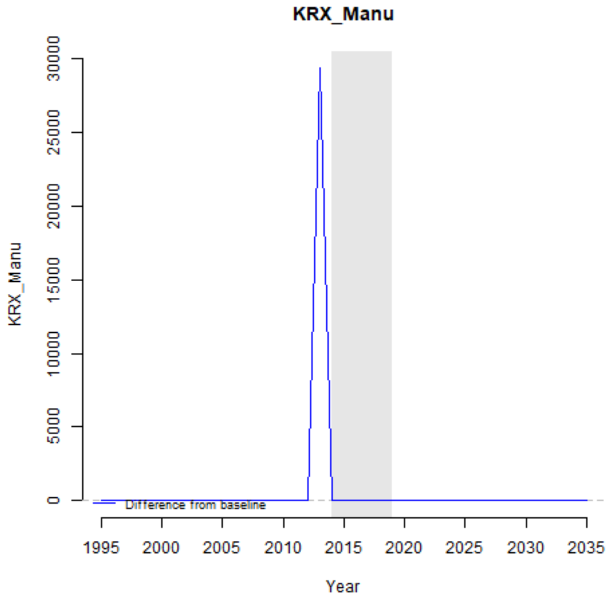
Figure 1: Model structure (Cambridge Econometrics, 2017)



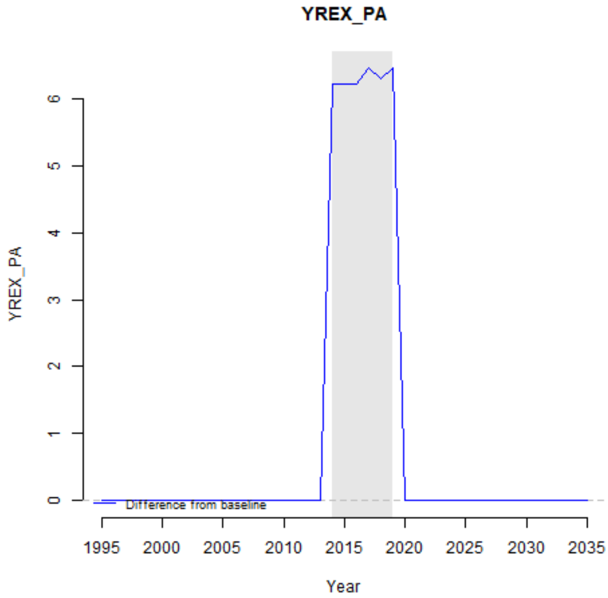
a. Household's exogenous expenditure on bulbs (m Rs): Households buy LED bulbs during the program period. This expenditure is program induced and hence, applied exogenously to their expenditure.



b. Household's exogenous expenditure on electricity (m Rs): Households expenditure on electricity falls linearly during the program period. After 2019, households continue to save from replaced bulbs but the scenario assumes that no new replacements takes place



c. Investment in Manufacturing (m Rs): The scenario includes one-time exogenous investment in the manufacturing sectorjust before the start of the program to meet the increased demand for LED bulbs



d. Temporary jobs for bulb distribution (thousands): EESL creates temporary jobs during the program period to facilitate the distribution of LED bulbs across different states

Figure 2: Scenario definition / Inputs to the model

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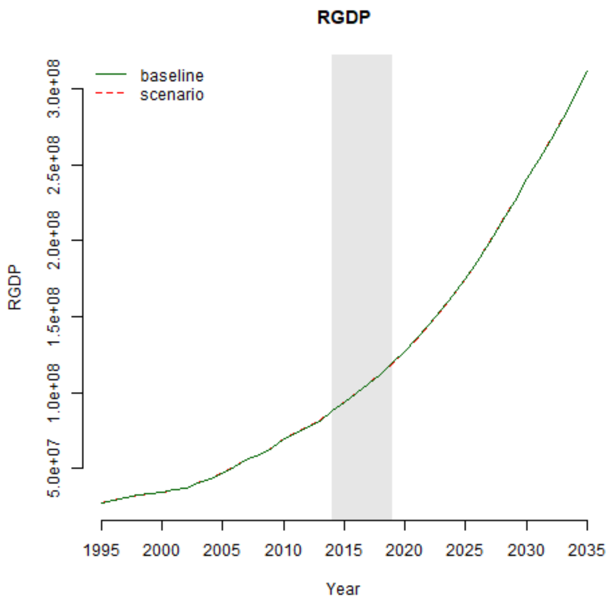
Year	Number of bulbs purchased (m)	Total HH expenditure on bulbs (m Rs)	Reduction in electricity consumption (GWh)	Reduction in electricity consumption (th TOE)	Reduction in HH expenditure on electricity bill (m Rs)	Reduction in new plant capacity (MW)	Emissions Reduction in Carbon (th tonne)	Emissions Reduction in C02 (th tonne)
2014	128.33	6,417	7,007	602	36,436	1,067	1,547	5,676
2015	128.33	6,417	14,014	1,205	72,873	1,067	3,093	11,351
2016	128.33	6,417	21,021	1,807	109,309	1,067	4,640	17,027
2017	128.33	6,417	28,028	2,410	145,746	1,067	6,186	22,703
2018	128.33	6,417	35,035	3,012	182,182	1,067	7,733	28,378
2019	**128.33**	**6,417**	**42,042**	**3,615**	**218,618**	**1,067**	**9,279**	**34,054**
Sum	**770**	**38,500**	**147,147**	**12,652**	**765,164**	**6,399**	**32,477**	**119,189**
2035		-	42,042	3,615	218,618	-	9,279	34,054

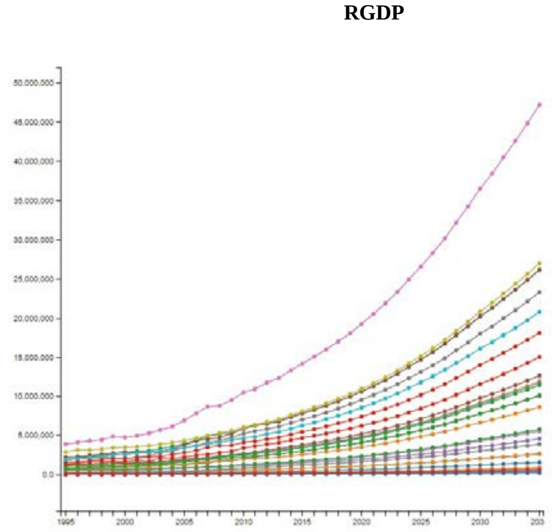
Table 1: Direct impacts

			GDP (m Rs)	Investment (m Rs)	HH Consumption (m Rs)	Government expenditure (m Rs)	Exports (m Rs)	Imports (m Rs)	Real personal disposable income (m Rs)	Total employment '000s
aseline	2,014	annual	87,964,925	26,981,811	56,623,800	16,552,779	52,023,051	54,860,436	56,642,014	437,801
Baseline	2,019	annual	119,576,099	36,590,017	77,566,905	21,126,002	68,632,031	72,624,543	81,275,028	499,465
Scenario	2,019	annual	119,320,043	36,236,358	77,453,778	21,126,002	68,615,748	72,450,438	81,102,782	499,204
Short run impacts	2019 Scenario - 2019 Baseline	**value**	**-256,056**	**-353,660**	**-113,127**		**-16,283**	**-174,104**	**-172,246**	**-261**
		% over baseline	**-0.21**	**-0.97**	**-0.15**		**-0.02**	**-0.24**	**-0.21**	**-0.05**
		cumulative change 2014:19	-1,037,844	-1,776,173	-370,694		-33,069	-893,199	-587,859	-1,714
Long run baseline	2035	annual	311,625,280	95,125,339	192,734,830	46,115,382	165,932,187	175,214,093	247,349,150	743468.977
Long run scenario	2035	annual	311,449,026	95,099,982	192,581,579	46,115,382	165,899,510	175,199,138	247,135,707	743356.681
Long run impacts	2035 Scenario - 2035 Baseline	**value**	**-176,254**	**-25,358**	**-153,251**		**-32,677**	**-14,955**	**-213,442**	**-112**
		% over baseline	**-0.06**	**-0.03**	**-0.08**		**-0.02**	**-0.01**	**-0.09**	**-0.02**

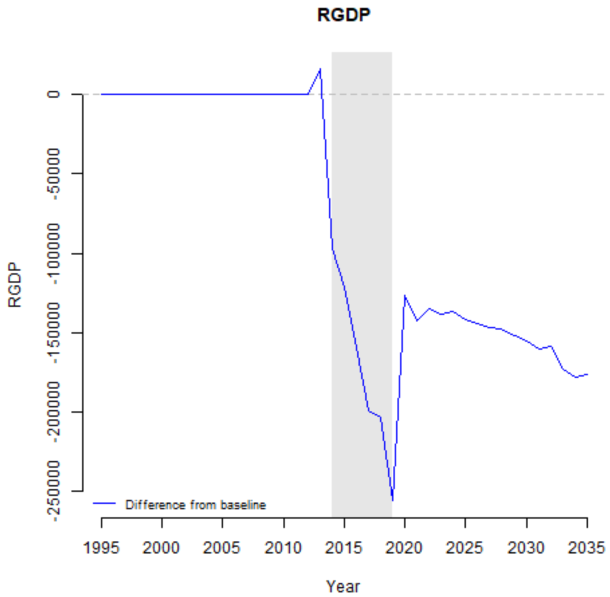
Table 2: Impact on the economy (2010 prices)



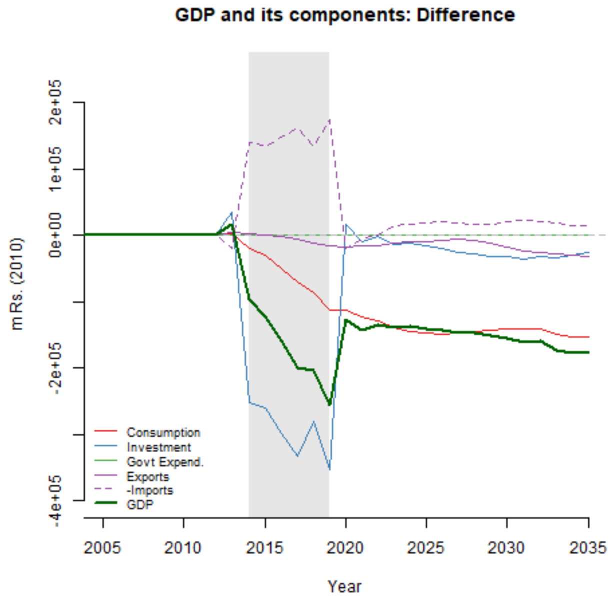
a. GDP



b. GDP for different states and UTs



c. Change in GDP



d. Changes in different components of GDP

Figure 3: Impact on GDP (m Rs 2010 prices)

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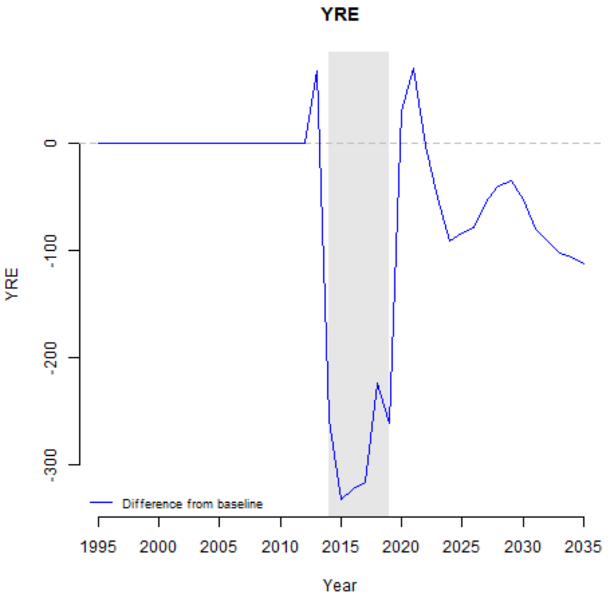


Figure 4: Change in total employment (thousands)

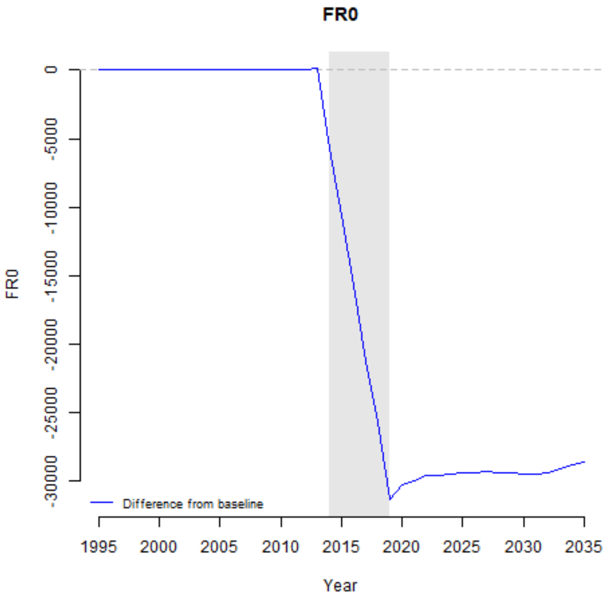
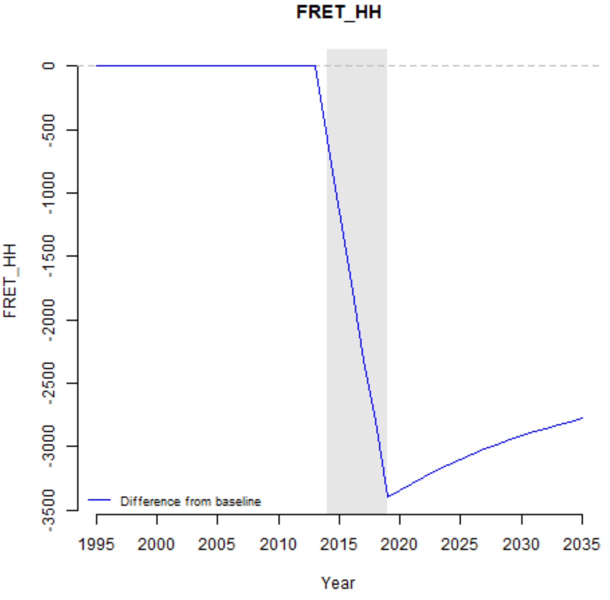


Figure 5: Fuel use for energy (th TOE)

a. Electricity use by households



b. Reduction in electricity use by households

Figure 6: Electricity used by households (th TOE)

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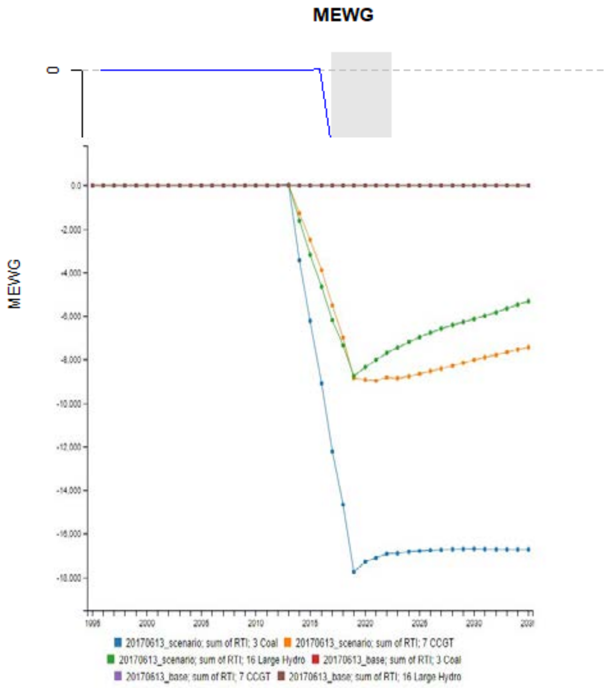
			Electricity generation (GWh)	Investment in new generation capacity (m Rs)	New construction of electricity capacity (GW)	Emissions, C02 (th tonne)	Total fuel use (th TOE)
Baseline	2,014	annual	751,638	2,266,645	15	2,371,488	1,015,979
Baseline	2,019	annual	970,361	3,056,989	17	2,897,958	1,211,329
Scenario	2,019	annual	929,964	2,712,259	15	2,846,932	1,179,911
Short run impacts	2019 Scenario - 2019 Baseline	**value**	**-40,397**	**-344,730**	**-2**	**-51,026**	**-31,418**
		% over baseline	**-4.16**	**-11.28**	**-10.00**		**-2.59**
		cumulative change 2014:19	-142,748	-1,722,370	-9	-182,504	-110,596
Long run baseline	2035	annual	2,236,093	7,614,389	33.8		2335468
Long run scenario	2035	annual	2,203,541	7,597,398	33.7		2306857
Long run impacts	2035 Scenario - 2035 Baseline	**value**	-32,551	-16,991	0	-46,728	-28,610
		% over baseline	**-1.46**	**-0.22**	**-0.25**		

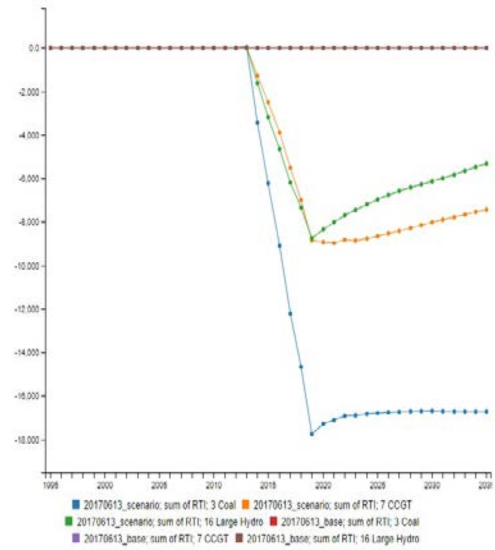
Table 3: Energy, electricity and emissions

			HH expenditure on electricity bill (m Rs)	Total Fuel use by HH (th TOE)	Total Fuel use by HH (GWh)	Electricity consumption by HH (th TOE)	Electricity consumption by HH (GWh)
Baseline	2,014	annual	1,397,925	181,647		16,331	189,924
Baseline	2,019	annual	1,657,702	190,726		19,412	225,757
Scenario	2,019	annual	1,370,087	186,998		16,011	186,205
Short run impacts	2019 Scenario - 2019 Baseline	**value**	**-287,615**	**-3,728**	**-43,356**	**-3,401**	**-39,552**
	% over baseline		**-17.35**	**-1.95**		**-17.52**	**-17.52**
	cumulative change 2014:19		-1,011,777	-12,832	-149,232	-11,954	-139,022
Long run baseline	2035	annual	3,265,168	222329.208		38,475	447,464
Long run scenario	2035	annual	3,031,301	218146.882		35,697	415,157
Long run impacts	2035 Scenario - 2035 Baseline	**value**	**-233,868**	**-4,182**		**-2,778**	**-32,307**
	% over baseline		**-7.16**	**-1.88**		**-7.22**	**-7.22**

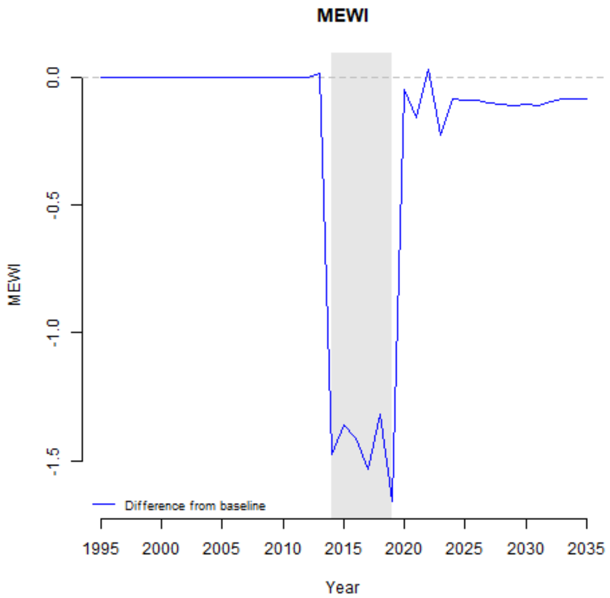
Table 4: Impact on Households



a. Reduction in electricity generation (GWh)



b. Reduction in electricity generation (GWh)



c. Reduction in New construction of electricity capacity (GW)

d. Investment in power generation (m Rs. 2010 prices)

Figure 7: Power generation

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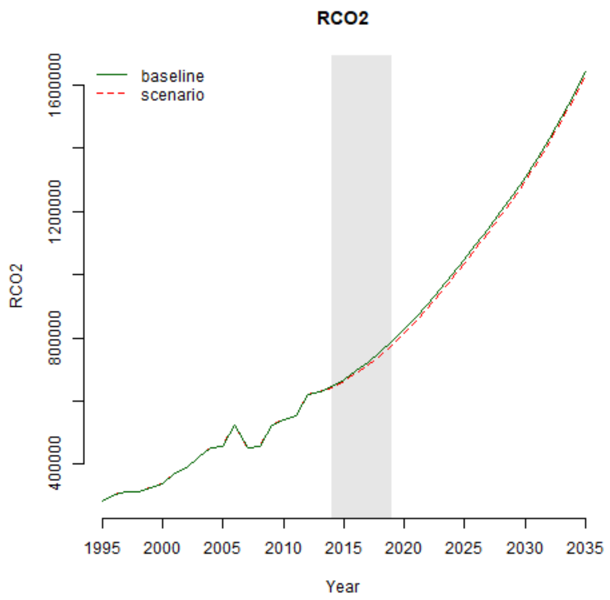

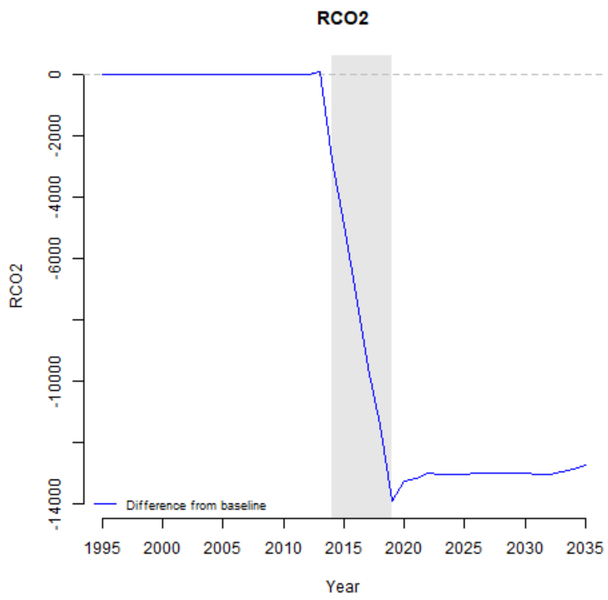

a. Total emissions (CO_2)

b. Total reduction in CO_2 over baseline

Figure 8: Emissions (th tonne of Carbon)

BUILDING ENERGY DISCLOSURE POLICY FOR INDIAN CITIES AND STATES

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Keywords: Cities, Building Energy Disclosure

ABSTRACT

Building energy use disclosure laws and benchmarking programs help reduce the information asymmetries in the marketplace, identify opportunities to cut energy waste, spur energy efficiency investments, create green jobs, and enable cities to reduce their energy footprint. While such policies are not yet a factor in India, development and climate trends in Indian cities make it important that their adoption and potential impact– both from technical and institutional perspectives – are considered carefully. In this paper, we propose some preliminary consideration for designing and adopting benchmarking and disclosure laws for Indian cities to reduce emissions from buildings. We proceed as follows: First, we develop a broad understanding of building disclosure and benchmarking laws through review of scholarly literature, policy documents, early reports on efficacy of programs existing outside India, most notably in the US. This helps us separate regulatory and incentive based approaches, as well as identify how these programs vary by type of buildings, size of the community, and nature of agency in charge of enforcing or managing such programs. Next, we conduct some key informant interviews on parameters and performances of such laws or programs in multiple US cities where such programs have existed for some time. We learn, for example, that such programs are most useful only for buildings beyond a certain minimum size, making percentage gains higher and management easier. We also learn that designing tools that make reporting easier can significantly enhance user experience and adoption. Finally, we stakeholders about the pros and cons of adopting similar approaches, both from technical and from governance perspectives, for Indian cities. Our findings suggest that benchmarking and disclosure laws can be a viable, low-cost approach for Indian cities for reducing building emissions.

INTRODUCTION

interview select Indian Buildings use more energy than any other sector in the world and account for roughly 40% of the global greenhouse gas emissions. The IEA's report 'Capturing the multiple benefits of energy efficiency' shows that the potential benefits from improved energy efficiency address a range of political, social, economic and environmental issues. Energy efficiency measures in the building sector have resulted in positive impacts on the economy and labour market, health and well-being, environmental impact, poverty, industrial competitiveness and the value of buildings as assets[1].

AIM

This project aims to initiate a discussion around building energy benchmarking and disclosure laws and thereby, set path towards measured emission reduction from buildings in Indian cities. To the best of our knowledge, this is the first formal exploration on building energy disclosure policy for India. While the ideas presented here are preliminary and need substantial deliberation before they can be considered as recommendations for program implementation, we hope that our work will help establish new partnerships with organizations and efforts that are working towards similar goals globally and invite them to partner on similar work in India.

METHODOLOGY

First, we analyse existing building disclosure and benchmarking laws in the US focusing on topics like

[1] Commission staff working document impact assessment accompanying the document Proposal for a Directive of the European Parliament and of the Council amending Directive 2010/31/EU on the energy performance of buildings access from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD:2016:414:FIN

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organizational and implementation structure, policies, technological challenges; data privacy and protection issues, aggregation and comparison techniques. This is followed up with interviews from experts representing various stakeholders.

Next, we brainstormed various models for Indian cities through interviews with a few Indian stakeholders representing real estate organizations, facility managers, cities, state designated agencies, policy experts, architects and building professionals etc. The discussions focused on various issues of policy conceptualization including merits of alternative models of implementation, phasing, policy implementation agency (e.g. Cities, Utilities, State, Private sector, etc.), potential opportunities and challenges, integration with existing policies and government agenda, etc. in the Indian context.

Finally, we present a conceptual structure of building energy disclosure policy and ideas for implementation for the Indian context. The study builds on the team's experience in policy research, data analysis, building energy efficiency, benchmarking and performance labelling and advocating for a low carbon future.

BENCHMARKING AND DISCLOSURE POLICY

Building energy benchmarking and disclosure has the potential to be a low cost high impact tool for significantly reducing emissions. It allows comparison of energy performance of similar buildings thereby reducing the information asymmetries in the market-place. It has the potential to compel building owners and operators to looks for opportunities that can cut energy waste. Employed systematically through well designed programs and policies, this has the potential to induce behavioural changes and market transformation that are scalable across cities and sectors.

Benchmarking and disclosure promotes market transformation through performance contracting, valuation of energy efficiency in real estate transaction, and facilitates energy efficiency services (e.g. facility management, ESCO). It also supports existing policies and green building labelling programs. Many regions and cities in the US, Canada, China, Europe, and Australia have mandated disclosure laws. These efforts are often aligned with their goals to transitioning towards a low carbon society and are supported by organizations like the Global Building Performance Network (GBPN), Institute for Market Transformation (IMT), Natural Resource Defence Council (NRDC), C40, ICLEI. International, Inter-organization and public-private collaborations have helped in developing stronger partnerships, experience sharing, knowledge transfer, and meeting needs for financial, technological and organizational infrastructure.

Figure 1 shows how the disclosure process works on the building owner side and Figure 2 shows some activities that a city agency may perform in the process. Table 1 lists the typical data required for disclosing energy consumptions. It includes information about buildings and energy systems in addition to energy use.

Some benefits of benchmarking and disclosure policy for different stakeholders are listed below -

- **Real estate developers**: Developers of efficient buildings would be able to demand a premium based on demonstrably superior performance.
- **Building owners**: Building owners would be able to find opportunities to save money by reducing energy consumption through behavioural or operational changes, retrofitting, retro commissioning etc. and may see an increase in the property value of energy efficient buildings.
- **Facility managers**: The disclosure policy may encourage performance based contracts and create incentives for good operations and management.
- **Professionals**: The policy may create various kinds of green jobs including increased demand for auditing, retro commissioning, retrofitting as well as specialized services at the time of building design and construction.
- **Utility**: Energy efficiency may help mitigate problems associated with growing demand of energy and power resources for the Utility and may help target demand side management (DSM) projects or create customized packages for various building clusters.
- **City**: The city would be able to spur investments in conservation, both behavioural and technology related. It will also help them to identify and adopt other related energy efficiency policies based on empirical data. Efficient cites will also see an improvement in their economy through increase in green jobs, services and businesses. The disclosure policy will provide infrastructure for continuous data collection that forms the

backbone of ‘Big Data’ in Smart Cities discussions. Finally, cities will be able to contribute to meeting national and internationally agreed targets towards emission reduction.

LESSONS FROM US CASES

AN OVERVIEW OF US POLICIES

In the absence of a coordinated federal policy, many local governments in the US such as Seattle, Austin, Kansas, Chicago, Atlanta, Washington DC, Philadelphia, and New York City, and states such as, Oklahoma, Utah, Alabama, Ohio, and Michigan, have adopted their own building energy benchmarking and disclosure programs. Figure 3 identifies some of these locations. These policies may require -

- Regular disclosure of building performance rating and energy consumption.
- Disclosure prior to real estate transactions such as sale.
- Requiring lending agencies to consider total cost of ownership for mortgage terms.
- Building retrofits requirements for egregious energy inefficiencies.
- Disclosing energy costs to prospective tenants in multi-family apartments and commercial buildings.
- Minimum energy standards for government buildings and leases.

In this study we examined the experiences of three cities, Chicago, New York and San Francisco so that we can adapt them to the Indian context. In Chicago, building sector accounts for 71% of total greenhouse gas emissions. Chicago Energy Benchmarking Ordinance (2013) phased in municipal and commercial buildings over 2014 and 2015 and residential buildings over 2015 and 2016. The city requires disclosure of energy information for buildings over 50 thousand sq. ft. The law captures 3,500 buildings accounting for 900 million sq. ft. Even though that covers less than 1% of Chicago’s buildings but accounts for about 20% of total energy used by all buildings.2 In New York City, building sector accounts for 70% of total greenhouse gas emissions. LL84 : Benchmarking and Disclosure Law (2009) requires all privately-owned properties with individual buildings more than 50 thousand sq. ft. and properties with multiple buildings with a combined gross floor area more than 100 thousand sq. ft. to comply. Together they amount to roughly 2% of New York’s million buildings, but account for over half the overall square footage3. Mayor’s Office of Long-Term Planning and Sustainability (OLTPS) is in charge of implementation and NYC Department of Buildings imposes fines for non- compliance.

In San Francisco, building sector accounts for 52% of total greenhouse gas emissions. The law covers more than 100 million sq. ft. of building area in the 50 thousand plus sq. ft. category (since 2011) and about 15 million sq. ft. of building area in each of the 25-50 thousand sq. ft. (since 2012) and 10-25 thousand sq. ft. categories (since 2013)[4]. The San Francisco Existing Commercial Buildings Ordinance (2011) categorised commercial buildings based on size and phased out compliance from 2011-2013. SF Department of Environment is in charge of implementation but they do not impose fines for non- compliance. The OpenData platform[5] discloses aggregate data.

A SUMMARY OF US EXPERIENCES

Our interviews and literature review found that understanding of building energy consumption remain limited. This problem is more acute in large buildings with multiple tenants where the utility costs are shared between the owner and the tenant. The split incentive issues, where the cost of energy efficiency upgrades to the buildings are borne by the owner whereas the gains are accrued to the tenant is a major market barrier in owners investing in building systems upgrade. If the market participants can command premium for energy efficient buildings then product differentiation will spur further investments in high performance buildings reducing the total energy consumption.

An analysis of NYC’s program found that benchmarking disclosures have more impact on energy consumption than the more costly formal building audits.6 The laws are effective because the energy information can be obtained from a relatively

[2] cityofchicago.org and wegowise.com

[3] http://metered.urbangreencouncil.org

[4] San Francisco Existing Commercial Buildings Performance Report 2010-2014

[5] data.sfgov.org

[6] http://dx.doi.org/10.1016/j.enpol.2013.08.094

small number of fuel providers and utility companies in the US. In order to correct information asymmetries, the data need to be accurate, timely, reliable and valid. Hence the thrust of the programs is to make sure that the data that is captured is useful to various stakeholders.

The cities we studied had different approaches to disclosure and benchmarking yet they share some similarities -

- Disclosures are mandatory only for large buildings (over 50,000 sq. ft.).
- Program requirements are phased in over multiple years
- The cities also publish annual compliance and achievement reports.
- None of the cities studied have retro-commissioning requirements, only disclosure and benchmarking requirements.
- The cities use property tax records databases to identify the buildings that are covered by the laws and notify the building owners. The utilities are required to maintain meter information associated with each building address rather than the owner business address.

The program staffs also have extensive training themselves and provide assistance to building managers to comply with the programs.

While all of the programs we reviewed use Energy Star Portfolio Manager for comparison and tracking, they require different levels of effort on part of the building owners to maintain and track the information. In San Francisco, the staff worked with the utility to directly access information, while the NYC building owners have to request the information from various utilities by email and then manually enter them in the Portfolio Manager. This could be due to the differences in the structure of the utilities. Portfolio Manager was launched in year 2000 to track energy usage and maintenance of certification. This program has significantly increased adoption of energy efficiency practices since 2006 (Figure 4) and has been shown in various studies to increase rent premiums, sale prices and reduce vacancy rates (Figure 5)

When it comes to disclosing building energy data to others, policies do differ from city to city as to how, when, and to whom benchmarking information is made available. They take into consideration impact effectiveness, cost effectiveness and fairness. Cities require a strong legal foundation for public disclosure that specifies what data should be disclosed, with what frequency, to whom, on what platform, and how it should be formatted to enable comparison between buildings.

The impacts of policies evolve over time. The only immediate impact of disclosure is awareness of stakeholders about the efficiency of the building stock and how individual buildings fare against others with similar weather, occupancy, area etc. The short term impact is that owners identify opportunities for energy savings, or incorporate energy performance into decision making during sale / renovation / construction / lease etc. The intermediate to long term impact is capitalization of energy investments into property values, energy saving behaviour, and availability of more green real estate.

CONCEPTUALIZING THE POLICY FOR THE INDIAN CONTEXT

The key guiding principle for implementing the building energy disclosure policy in the Indian context should be based on wide acceptability among stakeholders, low enforcement and compliance costs, consistency, and transparency. It should focus on inducing behavioural change among stakeholders eventually leading to market transformation. In the long run, the goal should be to an enabling environment to move towards a target oriented, sustained and measurable reduction in emissions due to energy consumption by buildings.

NODAL AGENCY

There are multiple agencies that could possibly be responsible for promotion, design, and implementation of building energy disclosure policy in India. They include the Urban local government in cities; State Designated Agencies (SDAs) like the Gujarat Energy Development Agency (GEDA) at the state level; Central government ministries like Ministry of Urban Development or Ministry of Power to name a few; Utilities; Non-government agency and various green building rating programs; Market based initiative led by the real estate sector; etc.

Hybrid models like that in California, has a state level policy along with provisions for city to go beyond the minimum state laws to further reduce emissions due to activities from within their jurisdictions. San Francisco has much more stringent disclosure laws that supersede the state laws. Buildings that comply with San Francisco laws are exempted from meeting California laws to reduce double compliance for its citizens and administrative expenses.

In our view, a hybrid structure would be well suited for India cities. Hence, we recommend that the final program design and implementation be a two way approach, with the city leading the policy design and the state responsible creating the enabling legislations and supporting inter-agency coordination. However, these have to be seen in specific local and state context and may vary from case to case. There is also no reason for cities to wait for these laws to be in place before they spring into action.

Involvement of state will ensure longevity, scalability and coordination among key government agencies. They include the utility (through the electricity regulatory commission) for easy access to energy data, and various ministries in power and development. Still, top down approach run the risks of alienating stakeholders and cities with reciprocal local initiative.

PHASING, ELIGIBILITY, COVERAGE AND EXCEPTIONS

A gradual scripting and roll out of the policy are our recommended strategy for design of the disclosure policy. We propose starting with a voluntary compliance for a specific type of building and gradually moving towards making it mandatory as stakeholders see the benefit and cities develop efficient compliance mechanisms. While the compliance is made mandatory for the first type of building, it may be expanded to other building types that have easy access to information required and resources for disclosure (e.g. large buildings). This would encourage higher adoption rates and reduce risk of failure.

Complex cases such as multi-tenant buildings, multi-use buildings should be carefully brought under the policy only once the implementation agency has gained good experience and established credibility. It will involve the city's cadastral managers to work closely with the utility to identify various sub meters at a particular address and generate aggregate energy consumption data for the building.

At any stage, there should be adequate provision of granting exemptions to certain buildings. For example, buildings which are newly occupied may be exempted for one to two years till their energy use is stabilized and sufficient data is available for benchmarking. Similarly, under occupied buildings too may be exempted. Owners of eligible buildings may choose not to include sub-metered or separately- metered energy consumption for broadcast antennas, cellular towers, electric vehicle charging, etc.

ENFORCEMENT FRAMEWORK AND RESOURCES REQUIRED

Depending on the number of buildings affected by the policy, one or more full-time staff support may be required to manage initial implementation and provide ongoing program support. Many cities in US use foundation support to staff their programs and provide resources for outreach and other program cost. This may be possible even in the Indian case. Local jurisdictions may have legitimate trust issues with third party involvement, so guidelines are incorporated on scope, funding source, inspector certification requirements, filing requirements, oversight, enforcement mechanism, quality assurance mechanism and conflict of interest

We suggest formation of Advisory and Technical working groups at the city level. The advisory group will have representatives from the city and key stakeholders. Together they will create vision for the city, set goals and targets and guide the policy design and implementation. They will be able to recommend suggestions about eligibility, exemptions, data concerns, budgeting, etc. to the city for bring about legislative change. The advisory groups will also be responsible for program monitoring and evaluation.

The technical groups will primarily comprise of staff with background in energy efficiency, data analysis, information technology and will have experts from academic and research background along with city's execution team. The technical working group will ensure development systems to ensure smooth compliance. They will oversee the efforts related to data coordination among agencies, data verification, analysis, and preparing reports for dissemination.

COMPLIANCE

In addition to stakeholders buy-in, the success of compliance will depend on efficient design of compliance process. It should not impose additional

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burden on building owners. Implementing agencies should provide necessary support through tutorials, webinars, in-person training, etc. to facilitate compliance.

The basic data required for disclosure may include information about building use type and intensity, floor space and energy consumption. The information on floor space and building use can come directly from the city records. Grid based energy consumption may be automatically fetched from the utility company server. This will eliminate the need of verification and ensure quality of data. Other information for detailed benchmarking and disclosure will be user certified and may be verified randomly or selectively by the city or third party. Wilful wrong entry of user data may be connected to stiff penalties to discourage such practices. The kind and amount of data required for disclosure should be sensitive to building types and resources available to their owners. It may be gradually expanded as program matures.

All users should use a standardized benchmarking tool to evaluate their performance. Bureau of Energy Efficiency has already started a building energy benchmarking program. Currently, it is available for hotels, hospitals and office buildings but can be easily extended to more building types. It provides a credible standardized tool to evaluate performance across building types and the country. In return, the benchmarking tool will benefit from the immense data collected from the disclosure program to improve its evaluation algorithm. The benchmarking report along with other information is to be submitted to the city via an online portal as the part of compliance process.

Good performing buildings should be rewarded and incentivised to maintain performance. They should be showcased as market and technical leaders. Short term incentives can be based on energy tariff, reduction in property tax, etc. to promote the policy. The poor performing building may be required to undergo auditing, retro commissioning, etc. assisted through other energy improvement programs. They may also be asked to be enrolled in specific DSM programs voluntarily or mandatorily.

In the initial phase, focus should be on outreach and awareness rather than penalties for non-compliance. As the program matures in terms of transparency, capacity building, and efficient compliance mechanisms, non-compliance can be dealt with penalties. The penalties can be in terms of fines, temporary increase in tariff rates or property tax to encourage compliance.

PUBLIC DISCLOSURE AND USE OF THE DATA

All the data collected as part of the disclosure policy will be stored in a central database at the city or state level. The decision regarding what data can be shared and with whom may be taken by the advisory group. Individually attributable data may be possibly made public after a period of 2-3 year. The technical committee may access the raw data to analyse ways to improve its program or design initiatives towards further reduction in energy consumption. The city can publish aggregated data in form of reports and visualization to establish baselines or track change over time, estimate reduction in emissions and set new goals. The data may be shared upon permission from the advisory group with researchers respecting privacy and agreed upon anonymity norms.

CONCLUSIONS AND WAY AHEAD

INGREDIENTS FOR SUCCESS

Some of the key ingredients to ensure success of the program from the enforcement agency side should include -

- **A clear outreach process:** A complete buy in from all stakeholders is critical to the success of the process. Reaching out to all stakeholders to communicate the private and social benefits of the program and seeking their cooperation is essential. Many cities with such programs deliver outreach through free in-person presentations and webinars that explain the benefits of the program to building owners and residents, and to walk them through the compliance process.
- **Help centres:** To conduct tutorials and publish checklists to assist owners who are going to disclose their buildings energy consumption for the first time. It should also maintain a list of certified professionals to help with benchmarking and disclosure compliance and also provide similar services free of cost to the needy segment. To expand coverage to multi-tenant, multi-use buildings, such centres should provide support to set-up sub-meters and smart meters to make tenants cooperate with the compliance process. To connect the building owners with other energy

efficiency programs and initiatives to those who comply with the law.

- **The right combination of incentives and penalties:** Penalty should be considered as the last option and city should reach out to building owners to assist them with the compliance process.
- **An incremental approach:** Start with buildings where collecting and reporting data is easier. Gradually expanding the eligibility to cover various segments of the market so that the compliance process and infrastructure required can be improved based on users and city's experience without causing discomfort to a large section of the society.
- **Inter-agency cooperation:** Key data required for disclosure compliance should be shared directly by the government body or utility on the online benchmarking platform with the consent of the building owner. This will largely avoid the need of data verification for many buildings, reduce compliance cost and efforts for the building owners and establish a good repository of credible data without any temporal gaps. Such cooperation will help to bring other services such as water and waste into the disclosure policy in the long run by establishing good precedence of data sharing.
- **Resolution of data confidentially and privacy norms:** Enforcement or coordination agencies must create enabling framework and standardized forms to allow for data sharing between city, utility, tenants and building owners.
- **A robust and user friendly web based digital infrastructure:** This would be essential for a smooth transaction of information, access to good benchmarking tool, and online report generation and compliance facility.
- **Continued effort to reduce the burden of compliance:** Keeping the cost of enforcement and compliance to the minimum so that it does not become burden to any of the stakeholders.

CHALLENGES

Some of the questions that needs to be addressed revolve around data, entity responsible for obtaining compliance, non-grid based energy consumption, etc.

Data related challenges in terms of definition, quality, privacy, management, verification, etc. are commonly faced by all implementation agencies. It is important to create strong protocols regarding these in consultation with all stakeholders.

The most difficult part of the energy data that is to obtain and verify is the non-grid based energy consumption e.g. diesel, coal or gas used in generators, boilers and kitchen. It is also the most difficult to verify and may constitute up to 40% of a commercial building's total energy consumption. This has to be addressed in some creative way.

Generally, it is the building owner who is liable to comply. But he/she has very little control over how the tenants or users will manage the building. It will be useful to provide standard template of agreement between the owner and tenant to allow sharing the data and requiring the use the energy responsibly. Some buildings have more than one meter while some meters serve more than one buildings. We feel that compliance at the building level is most appropriate then meter level as each building has a long term physical status, while meters location and the area they service may change over time. The help of utility may sought to aggregate the data of multiple meters that are located in the same building.

Time duration of energy data used for performance analysis is normally taken as one year. However, sometimes it may be useful to average consumption over two to three years. Long term averages are more stable but may not reflect recent energy conservation measures. This also needs further thinking.

INTEGRATION WITH OTHER POLICIES AND INITIATIVES

The biggest hurdle in the design, implementation and monitoring of government initiatives and policies is lack of credible data. The national building star labelling program by the Bureau of Energy Efficiency would benefit tremendously in terms of quality data for estimating performance scores. The disclosure policy can be made part of the smart city initiative of the government of India for allowing cities to track its emissions from buildings, evaluate efficacy of its energy codes and other programs in terms of their performance. Intention and design based codes like the Energy conservation building code (ECBC) schemes and green rating labels like GRIHA, LEED, IGBC, etc. can use credible baselines obtained through the disclosure policy.

Finally, once buildings are classified as designated users under the PAT (Perform, Achieve, and Trade) scheme under the National Action Plan on Climate

Change (NAPCC), credible baseline data will be required to estimate savings for compliance and obtaining carbon credits. The disclosure program will be immensely helpful by providing the most reliable and continuous data to support the wide implementation of the scheme.

The building energy disclosure policy will not only be a suitable instrument to support these initiatives but also help design other potential energy efficiency initiatives include auditing, retro commissioning, sub-metering, enrolment in a demand side management program etc. The disclosure policy will allow cities and states to choose among these and many other energy efficiency programs as a part of their new policies to further reduce emissions from within their jurisdiction. Part of the funding for the policy may then be requested from the beneficiary programs.

ACKNOWLEDGEMENTS

Part of this work was supported through Institute for Sustainable Communities (ISC) Grant to ps Collective in support of 'The Future is Now, India' program's objectives as well as ISC's cooperative agreement with the United States Department of State. We are thankful to the funding agencies and all the experts in US and India who shared their perspective on various issues related to building energy disclosure policy.

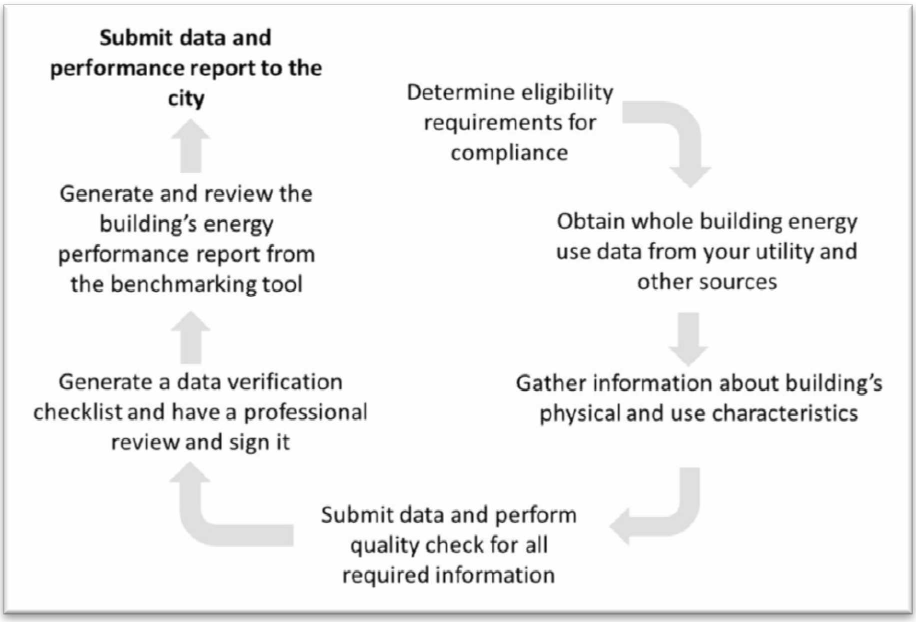

Figure 1: Typical disclosure compliance process for a building owner

Table 1: Typical data required for building energy disclosure

Data type	Data fields	Requirement	Source
Building characteristic	Year built, Address, Gross floor area	Mandatory	Property records, City
Building characteristic	Total heating and cooling area	Mandatory	Building owner
Building use information	Primary use, Occupancy, Operating hours	Mandatory	Building owner
Energy use	Energy used from Grid electricity, Diesel and Gas, Renewable and other sources	Mandatory	Utility, Building owner
Equipment and systems	Number of computers in office space, Mechanical system specifications	Good to have	Building owner
Special use	Data centre, Any other special use	Good to have	Building owner

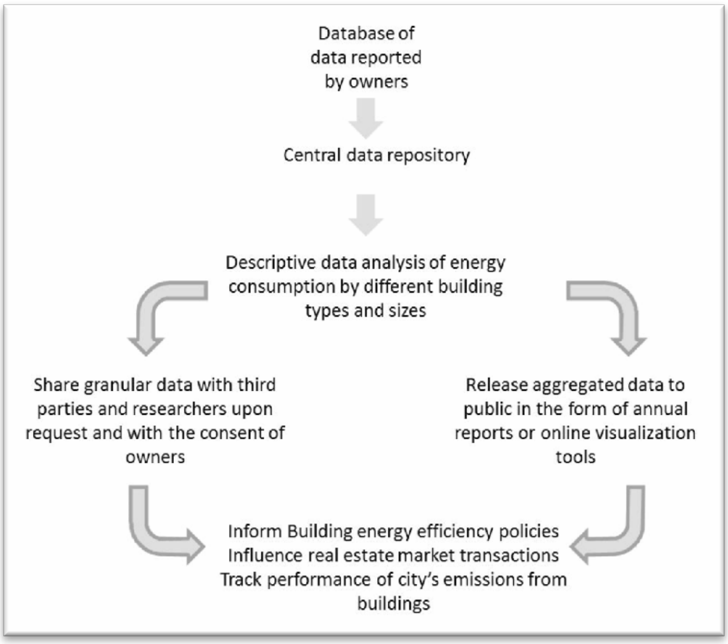

Figure 2: Some ways in which disclosure data is used by the city

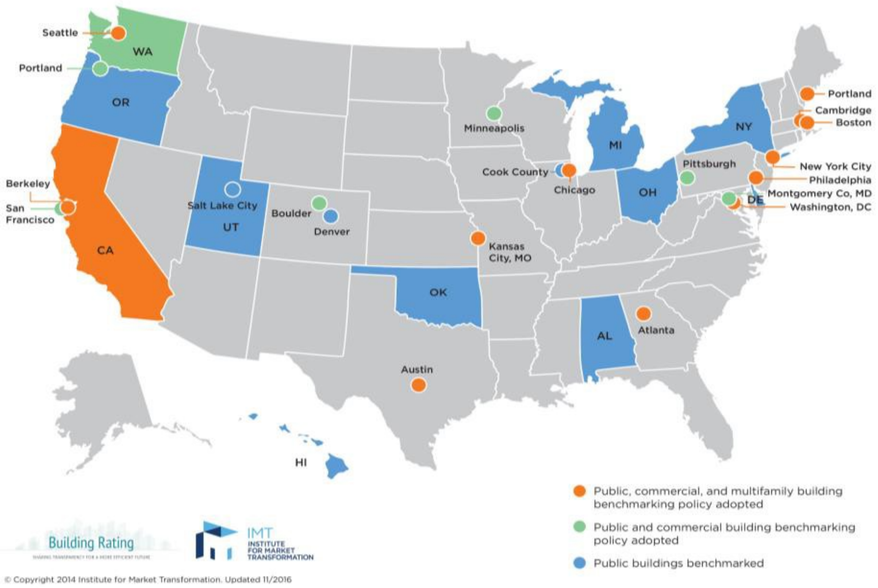

***Figure 3: Benchmarking and Transparency policies in the US as of 2016*[7]**

[7] Institute for Market Transformation downloaded from http://www.imt.org/resources/detail/map-u.s.-building- benchmarking-policies

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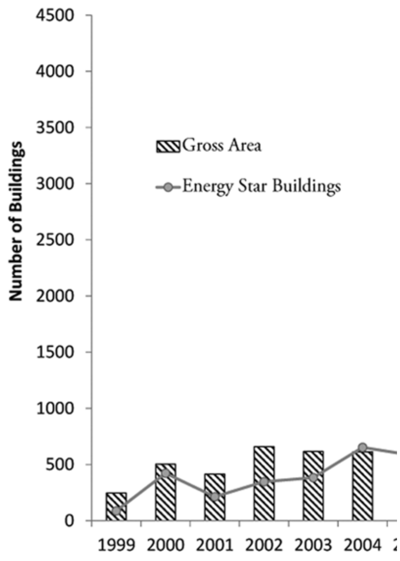

Figure 4: ENERGY STAR adoption in the US

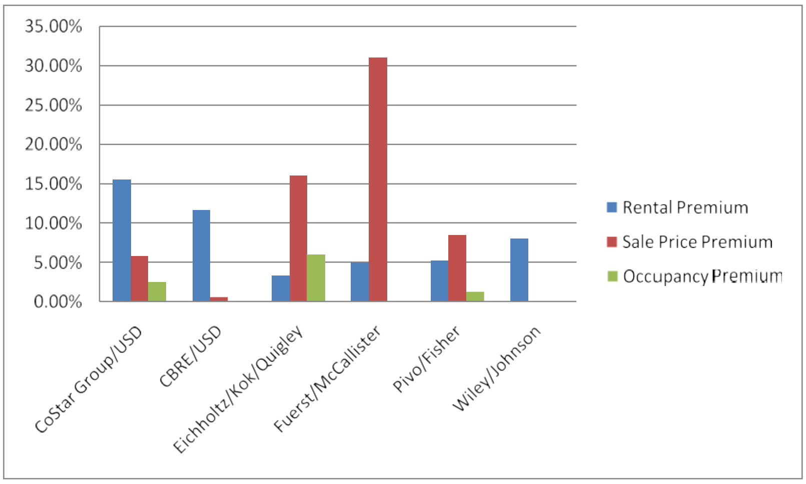

Figure 5: Impact on rent premiums, sale prices and reduce vacancy rates[9]

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[8] Kaza, N., Lester, T. W., & Rodriguez, D. A. (2013). The Spatio-temporal Clustering of Green Buildings in the United States. Urban Studies, 50(16), 3262-3282. DOI: 10.1177/0042098013484540

[9] Burr, Majelsik and Zigelbaum. (2013). The Future of Building Energy Rating and Disclosure Mandates: What Europe Can Learn From the United States, accessed from http://buildingrating.org/document/future-building energy-rating-and-disclosure-mandates-what-europe-can-learn-united-states (copyright permission requested)

RETHINKING ENERGY CONSERVATION BUILDING CODE (ECBC) IMPLEMENTATION STRATEGY IN STATES AND CITIES TO ALIGN WITH INDIA'S NATIONALLY DETERMINED CONTRIBUTIONS COMMITMENTS AND SMART CITY MISSION OBJECTIVES

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Keywords: Policy, Code Compliance, Nationally Determined Contributions (NDC), Smart City

ABSTRACT

The past decade has seen significant advancement in the availability of latest technology and building materials, development of credible research institutions, laboratory and R & D facilities, uptake of green building rating programs and enlargement of pool of energy-efficient building experts and execution of many capacity building programs to raise awareness about ECBC. However, all these positive ecosystem building activities have still not led to significant ECBC implementation in a time bound fashion. Since its launch in May 2007, only 10 Indian states have notified ECBC – a key first step to full ECBC compliance. With ECBC being mentioned in India's NDC at COP21 and the importance of building energy efficiency in sustainable smart city development, a renewed thrust is needed to make this a priority, considering that more than 50% commercial building stock is yet to be constructed in India.

The authors of the paper will highlight the challenges being faced by national and state government organisations on ECBC Implementation by synthesizing the findings from high-level regional consultations by focussing on the following four challenges and presenting possible solutions: a) Delineating the administrative and technical aspects of ECBC while understanding the functioning of govt. departments at national, state and local level; b) Enhancing coordination between key ministries and an urgent need to clarify their roles and responsibilities at different levels; c) Use of 3rd-party technical assessors to check for design-based ECBC compliance in the overall building design approval process; (d) Appropriate capacity building.

INTRODUCTION

Launched in 2007, the Energy Conservation Building Code (ECBC) is the first ever initiative by Government of India (GoI) to address energy efficiency in the commercial building sector. Developed by Bureau of Energy Efficiency (BEE), the code sets minimum energy standards for commercial buildings having a connected load of 100kW or contract demand of 120 KVA and above. The enactment of Energy Conservation Act (EC Act) in 2001, with primary objective of providing necessary legal framework for promoting energy conservation measures led to the formation of BEE and subsequent development of ECBC (BEE 2017). The constitution of BEE and launch of ECBC came along at a crucial period when India is combatting various development related issues and balancing it against rising energy consumption in the building sector.

The building sector in India is experiencing an unprecedented growth. It has 38% (~208mtoe) of the India's total primary annual energy consumption and 31% (296 TWh) of the total annual electricity consumption (IEA 2017) (NITI Aayog and Prayas 2017). Within commercial sector, the current built-up area is roughly 1.4 billion sqm and is expected to increase by approximately 60% in next 20 years (AEEE 2017). Residential sector electricity consumption under the business-as-usual (BAU) scenario is predicted to rise by more than eight times by 2050; however, using aggressive energy efficient strategies, the predicted rise would be between three to five times, curtailing the electricity demand significantly (Rawal and Shukla 2014).

The current development trend and the BAU energy consumption pattern poses twofold challenge: First, mushrooming inefficient stock with lock-in period ranging from 30-50 years demands more power and energy leading to higher power generation requirement that is highly capital and resource intensive. With majority of energy supply provided by non-renewable resources, how will India address energy poverty in the face of degrading energy security? Second, higher

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energy demand from non- renewable resources generates higher carbon footprint, posing adverse environmental impacts. This provides the context for the need of imbibing energy efficiency in the building stock and acknowledging it as a resource. In the beginning, to promote building energy efficiency, GoI prioritized commercial sectordue to the fragmented character of the residential sector. The focus was on developing and launching ECBC with the objective to make a difference in the commercial building sector that was projected to grow rapidly over the next 2-3 decades. This promoted significant advancement in domain specific activities and built a positive eco-system; however, since a decade of its launch only 10 states have notified ECBC a key first step to full ECBC compliance.

Immediate implementation of ECBC in commercial building sector is crucial for three reasons: First, the bulk of the development is yet to happen and timely implementation of ECBC will bring along energy efficient stock leading to noticeable rewards in the form of energy savings, reduced greenhouse gas emissions, thermally comfortable habitats for occupants etc. Second, the ECBC success stories will pave the way for residential energy efficiency initiatives to be launched – a much bigger potential waiting to be tapped. The residential segment, with its fragmented nature and daunting institutional challenges, has higher energy and electricity consumption, primarily due to its sheer size, than commercial sector and is facing an urgent need for a focused and sustained national level initiative. Third, the effective implementation aligns with India's Nationally Determined Contribution (NDC) commitments presented at United Nations Framework Convention on Climate Change (UNFCCC), mitigating climate change by implementing ECBC.

If unaddressed and unimplemented, the building sector will have major repercussions on environment and country's economy. While it is estimated that 1.2 gigatonnes of carbon dioxide (CO_2) emissions will be locked in by mid-century, there would also be major implications on India's national missions like Power for All, Housing for All and Smart Cities Mission (Shnapp and Laustsen 2013).

IMPLEMENTATION STATUS AND ROLES AND RESPONSIBILITIES

While ECBC was launched at national level by BEE, under the Ministry of Power (MoP) its implementation lies with state government (Urban Development Department (UDD) and Department of Energy (DoE)) and local government (Urban Local Bodies (ULBs)). A decade after the launch of ECBC, only 10 states have notified and 10 have amended ECBC (UNDP- GEF-BEE 2017). Also, the status of implementation within states having notified ECBC is questionable. Code adoption, implementation and enforcement involve multiple stakeholders and amongst them role of state and local government is the most pivotal and instrumental of all. The involvement of multiple government departments, with their overlapping and diffuse roles and responsibilities at various levels can aggravate issues related to smooth implementation. This is especially true for codes and standards related to building energy efficiency, as the technical capacity in terms of dedicated staff and knowledge on the subject within the sub-national government is limited. States like Andhra Pradesh, Telangana, Karnataka and Punjab are leading by example by making strong commitments and trying to create awareness amongst government officials and other stakeholders, and further amending their bye-laws, revising Public Works Department (PWD) Schedule of Rates (SoRs), building states' capacity and constituting ECBC cells. While the leading states are even developing online tools, to take advantage of technology platforms and capturing advanced knowledge for efficient implementation, there are states where the code implementation hasn't moved post notification (AEEE 2017) (Khosla 2016) (PEDA 2017). The implementation status of various states is further elaborated in the attached matrix below.

Table 1: Implementation status in various states (UNDP-GEF 2017)

State/UT	ECBC Amendment	ECBC Notification	Notification in state bye-laws	Notification at Municipalities	Enforcement	Schedule of Rates - PWD	ECBC Cell	Training & Capacity Development	Energy Simulation Software
Andhra Pradesh	√	√	√	√	√			√	
Arunachal Pradesh	√							√	
Assam	√								
Bihar	√						√		
Chandigarh UT									
Chhattisgarh	√						√	√	√
NCT of Delhi	√								
Goa									
Gujarat	√								
Haryana	√	√	√				√		√
Himachal Pradesh	√								
Jammu and Kashmir									
Jharkhand									
Karnataka	√	√				√	√	√	√
Kerala	√							√	
Madhya Pradesh	√						√		
Maharashtra	√						√	√	
Manipur									
Meghalaya									
Mizoram									
Nagaland									
Odisha	√	√					√		
Puducherry UT	√	√							
Punjab	√	√					√	√	√
Rajasthan	√	√							
Sikkim									
Tamil Nadu	√								

Telangana	√	√	√	√	√			√	
Tripura									
Uttar Pradesh	√						√		√
Uttarakhand	√	√							
West Bengal	√	√							

To achieve energy efficiency in existing commercial building stock and fast-track ECBC implementation, UNDP-GEF initiated ‘Energy Efficiency Improvements in Commercial Buildings (EECB)’ project in partnership with BEE. The project aimed at strengthening institutional capacities for enactment and enforcement of ECBC and enhancing technical capabilities and expertise of local building practitioners and service providers. During the journey, 10 states notified ECBC, five states established ECBC cells to assist and encourage implementation; and a large number of training programs were conducted to train different stakeholders for both government & private concerns. BEE’s Training of Trainer program was supported under EECB, to prepare a brigade of ECBC Master Trainers. The project also supported pilot projects to demonstrate ECBC compliance (UNDP-GEF-BEE 2017). The trainings specifically focused on the technical aspects of code, which was needed to create awareness in the technical fraternity.

Code compliance includes comprehensive understanding of the technical and administrative requirements of ECBC by respective stakeholders. The compliance with administrative requirements falls under the purview of central, state and local government departments; with EC Act 2001 defining their powers to implement code and help achieve the energy efficiency goals that India is committing to, in international forums.

Chapter Six of the EC Act 2001 defines powers of the state government to facilitate and enforce efficient use of energy and its conservation. Section 15 of the Act gives powers to states to enforce certain provisions for efficient use of energy and its conservation such as (1) amending ECBC to suit regional and local climatic conditions and may, by rules made by it specify and notify ECBC with respect to use of energy in the buildings, (2) creating awareness and disseminate information for efficient use of energy and its conservation and (3) organize training of personnel and specialists in the techniques for efficient use of energy and its conservation. Section 16 stipulates powers to establish fund for the purpose, Section 17 provides power of inspection and Section 18 declares power to direct (1) regulation of norms for process and energy consumption standards in any industry or building or building complex; (2) regulation of the energy consumption standards for equipment and appliances (GoI, EC Act 2001). Comprehending the roles and responsibilities at various government levels is the first step to implementation. At the national level, ECBC development and update responsibility lies with central government. Consequently, BEE with technical assistance from USAID, launched the first ECBC in 2007 and ECBC V2 in June 2017 (BEE, ECBC 2017). Ministry of Urban Development (MoUD) also contributes to code implementation by introducing energy efficiency at city and building level through model building bye-laws, smart cities mission, Central Public Works Department (CPWD) design guidelines, National Sustainable Habitat Mission (NSHM) etc. In a significant development, Chapter 10 of the model building bye-laws (TCPO, MoUD 2016), encourages incorporation of ECBC guidelines in state and cities bye-laws, although the authors of this paper strongly believe that the language can be more stringent and integration of the latest model building bye-laws with ECBC tighter.

At the state level, the code adoption i.e. notification and amendment needs to happen in parallel, once again with clear delineation of roles and responsibilities based on the expertise available within each department and by aligning with the existing rules and regulations. While code notification can be facilitated by DoE or UDD, the code amendment responsibility lies with the energy department; UDD is and must be responsible for amending Town and Country Planning (TCP) rules and regulation and building bye-laws to incorporate ECBC provisions once it is notified and amended at the state level. This can be facilitated by involving UDD during the code development and discussion stage to get early buy-in. The implementation at state level requires inter-ministerial coordination at the national level and inter-departmental coordination at the state and local level. Different states have proceeded differently, wherein some states have amended the code and then proceeded with notification, whereas others notified it first and then amended the code. In some cases, this approach has led to inordinate delay in the implementation. At state level, the role of the PWD is also very significant, as amendment of PWD design guidelines can ensure code compliance at all government buildings that are designed and constructed by the state PWD. Given the powers vested with state and the effort that BEE has put in, the authors believe that the code compliance and enforcement can be initiated by state rigorously.

Once code is notified at state level, the enforcement will lie under the local government purview. Local governments (primarily municipality) must start enforcing it in a mandatory fashion; alternatively, more forward-looking local government bodies can themselves encourage the process of implementation through revision of bye-laws and subsequent enforcement of the code. For example, the Chinese local governments, while adopting the national energy codes, often increase the code stringency. (Yu, Evans and Delgado 2014). The following schematic helps in explaining the roles and responsibilities of central, state and local government the relationships and their spheres of influence.

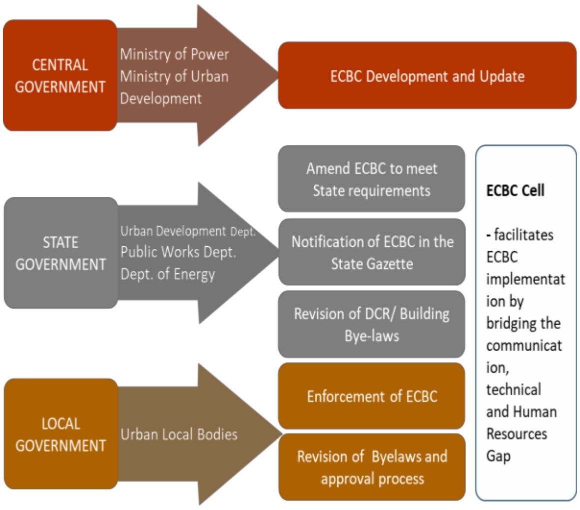

Figure 1: Government stakeholders' roles and responsibilities

ECBC IMPLEMENTATION PROCESS

ECBC overall implementation consists of three key steps broadly: Adoption, Implementation and Enforcement. The responsibility for enabling and implementing lies with the state and local government as discussed in the previous section. Along with government departments, technical experts are likely to play a key role in the overall implementation – first in terms of creating technical awareness and then in terms of design and execution of ECBC compliant buildings.

Code adoption i.e. notification and amendment falls under purview of the state government. To adopt code at state level, the State Designated Agency (SDA) has been constituted at every state level by BEE under the provisions of the EC Act. In general, SDAs along with UDD have the collective responsibility of code adoption. While code notification can be solely undertaken by SDA or UDD, amendment of code and its incorporating in other building design and construction guidelines (bye-laws, TCP rules and regulation, PWD Schedule of Rates (SoR)) require a variety of inputs from technical experts.

The code implementation, which includes demonstrating compliance in buildings, is technical experts' domain. This incorporates building design and systems compliance with ECBC's mandatory and prescriptive requirements or demonstrating compliance through whole building performance approach.

The code enforcement includes ECBC compliance check and falls under the purview of ULBs. A building construction and permitting process for majority of developers consists of two phases: In the first phase, the ULB approval is sought for proceeding with the construction by submitting building's design and construction drawings in accordance with the building bye-laws. In the second phase, ULBs furnish a No Objection Certificate (NOC) to the building owner or developer after ensuring that the intent of all relevant codes and bye-laws have been met during the actual construction of the project. Inclusion of ECBC in building bye-laws will mandate code compliance check during the building approval process leading to code enforcement. The enforcement process shall include devising inspections for code compliance at periodic intervals during construction.

IDENTIFICATION OF IMPLEMENTATION CHALLENGES: STATES' DEPARTMENTS PERSPECTIVE

Implementation challenges highlighted in the section are drawn from the five high-level regional workshops organized by NITI Aayog, BEE and Alliance for an Energy Efficient Economy (AEEE) with support from UNDP-GEF (AEEE 2017). These workshops with high-level participation of senior officials from state departments like SDA, UDD, PWD etc., initiated regional and inter-departmental dialogues to fast-track ECBC Implementation in states. Because of the focus of the workshops on cross-learning, and identification of best practices, these workshops witnessed tremendous participation from officials of all States and UTs across India. The common implementation challenges as narrated by state officials in these regional workshops are:

1. Ambiguity on government roles and responsibilities: One clear message that emerged from the intense deliberations during the workshops was the need for clarity on the roles and responsibilities of key government stakeholders including various central, state and city level

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divisions of the UDD and SDA. While it is a major challenge among most of the states, delineation of the responsibility is the biggest opportunity to fast track implementation.

2. Lack of government leadership: States like Andhra Pradesh, Telangana and Karnataka with successful ECBC implementation stories have one thing in common - the key role played by the government and the leadership demonstrated by them. ECBC notification through state's official gazette, a first step towards ECBC implementation could be easily achieved if the state's senior government officials demonstrate exemplary leadership towards ECBC implementation.
3. Lack of institutional framework: The SDAs are the strategic partners for promotion of energy efficiency in any state. However, their focus on energy efficiency is limited due to inadequate capacity and resources and shared responsibilities. It is vital to strengthen the SDAs with necessary resources, both in terms of budget and knowledgeable manpower, to enhance their performance as per the roles envisaged under the EC Act, 2001. For large scale implementation of ECBC in states, relevant state officials need to be made aware and mobilized to explore different models such as Third-Party Assessors (TPAs), scale-up in-house capacity building, ensure continuity of personnel, among others. For larger states, it would be ideal to establish permanent ECBC cells with representation from the SDA and the UDD.
4. Lack of structured capacity building programs: Successful ECBC implementation requirements include a combination of technical and administrative know-how; however, majority of training programs are focused on providing technical details covered in ECBC. States like Telangana restructured capacity building programs for effective code implementation by covering both the aspects.

During the deliberations in the workshop, the state officials also suggested ways to fast-track implementation by:

1. Lowering connected load and contract demand limit of buildings for ECBC compliance: States like Manipur, Arunachal Pradesh argued that lowering the connected load limit from 100kW to 50 kW will lead to higher penetration of energy conservation measures in commercial building belonging to states with fewer number of large commercial buildings. As per current requirement, the numbers of buildings under code purview are very few and can't justify the efforts being put in by different departments of state.
2. Developing Online Compliance Check Tools: Online tools for drawings and document submission, compliance checks and subsequent approvals for effective, transparent and time bound ECBC compliance, generated a lot of interest among states' representatives. Citing Greater Hyderabad Municipal Corporation (GHMC) online tool development effort, participants expressed the need for creation of similar online portal (GHMC 2017) (NRDC 2016).
3. Learning from the international experiences: Building Energy Passport or Energy Management Information System could supplement ECBC in the near future for realization of energy efficiency in actual energy performance of buildings. Since ECBC is primarily a design code, it does not emphasize much on the actual energy performance of building, once operational. In an age of increasing accountability, it is important for policy makers to start thinking about ensuring actual energy performance on an on-going basis rather than just on design intent or initially submitted numbers.

ADDRESSING KEY CHALLENGES

The identified challenges questions the gaps in the existing implementation process, underscores the missing links and subsequently suggests a path forward in response to the questions and explores opportunities in order to fast track the process. The paper suggests high level implementation process which is likely to succeed based on the feedback gathered during the workshop and subsequent analysis and synthesis. The recommendations are:

1. Delineating the administrative and technical aspects of ECBC while understanding the functioning of govt. departments at national, state and local level for apposite delegation of implementation responsibilities to the right stakeholders: The code requirements can be delineated into administrative and technical requirements. Architects, engineers, energy auditors and green building consultants etc. are responsible for ensuring technical compliance with the code. The growing need to design and construct green and energy efficient buildings, resulted in upsurge of capacity building programs along with significant efforts to create a large pool of ECBC

trained professionals and has eased the scarcity of technical experts to demonstrate compliance.

According to ECBC, "Administrative requirements relating to permit requirements, enforcement, interpretations, claim of exemption, approved calculation methods and right of appeal are specified by the authority having jurisdiction" (BEE 2007). This clearly puts the onus on state and local government for adoption and enforcement. While state and local government have the lead responsibility when it comes to implementation, it requires backstopping and support mechanism from the central government, much more so in the initial phase when experience and expertise is in short supply.

A broad level classification of roles and responsibilities for ECBC overall implementation is illustrated in Figure 2. It shows that the notification falls under purview of government. Subsequent to notification and amendment, the stakeholders can be arranged under two heads: first, building design and construction stakeholders which shall look after technical aspects and second, regulatory bodies i.e. Government stakeholders, which shall look after administrative aspects.

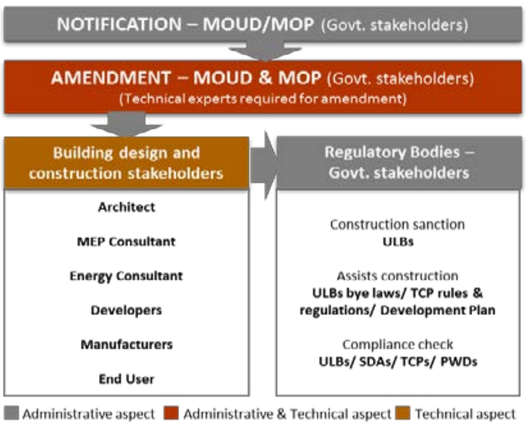

Figure 2: Technical and administrative aspects

Understanding the functioning of government departments at various levels having significant role in ECBC implementation will lead to appropriate delegation of implementation roles and responsibilities. A high level structure and relationship between different government departments at national, state and local level is illustrated below:

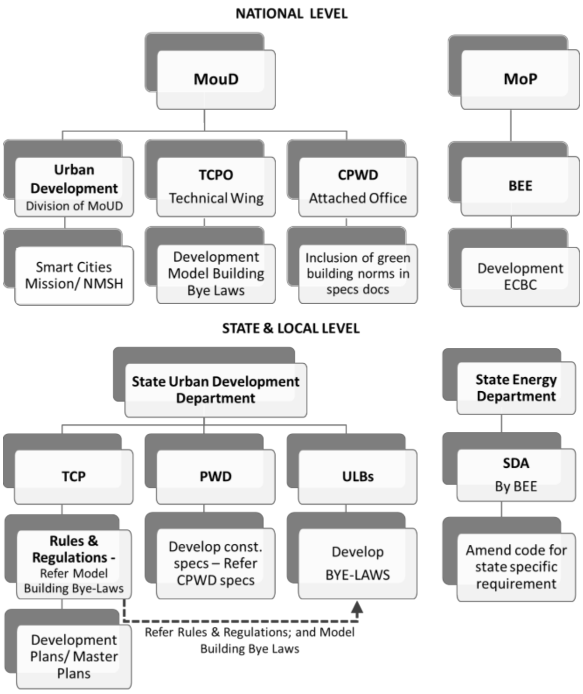

Figure 3: Flow of functions at Centre, State and Local level

2. The roles and responsibilities of state departments like UDD, TCP, PWD differ from state to state, where some states may follow a typical hierarchy represented above that was derived from the interviews conducted and feedback received from different state govt. officials. For instance, the PWD department follows the code compliance, if mandated by state; however, they are not dependent on state to amend their design and construction specs and can set examples by implementing ECBC in the buildings that are designed and constructed by them. Similarly, ULBs under constitution-74th amendment have powers to amend the bye-laws to incorporate energy code and can also enhance its stringency level, irrespective of any direction from state's urban development department (MoUD). Enhancing coordination between key ministries and an urgent need to clarify their roles and responsibilities at different levels: The involvement of multiple ministries in the implementation process requires strong and focused coordination at several levels which can be achieved through demonstrated leadership firstly. For example, formation of a high-powered committee chaired by a senior bureaucrat such as state's Chief Secretary/ Principal Secretary of Power/ Urban Development department with members from all relevant departments will enhance coordination through improved and acceptable delegation of implementation tasks.

Under this leadership model, the whole process can be fast tracked through monthly reporting/ meeting. States like Andhra Pradesh and Karnataka progressed under the leadership of senior bureaucrats who had the vision and demonstrated these kinds of leadership. The coordination and implementation process under the leadership of Andhra Pradesh Chief Secretary is delineated in the figure 4, clearly indicating the pivotal role of Chief Secretary. During the 5 regional workshops state officials suggested forming two committees: (1) Apex Committee Chaired by Chief Secretary and (2) Steering Committee Chaired by Principal Secretary of DoE or UDD. These two committees can provide necessary direction and thrash out issues for effective roll out and implementation of ECBC.

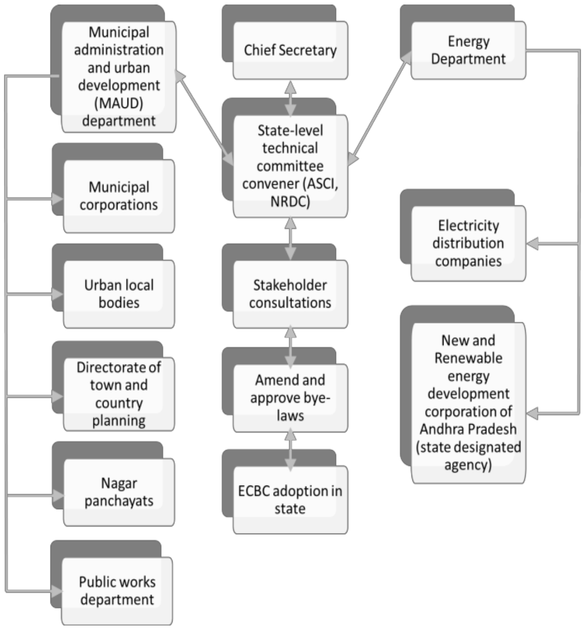

Figure 4: Andhra Pradesh ECBC implementation – government department coordination (Khosla 2016)

Comprehensive delineation of roles and responsibilities of pertinent government departments to build institutional structures leading to effective code implementation on a medium term is the second important point. Each department (centre/ state and local) must be given specific tasks and joint responsibilities must be avoided. This will improve coordination and instil sense of ownership within each department. Under the proposed approach, challenges shall be highlighted and addressed. The responsibilities of adoption and enforcement tasks to mainstream ECBC are captured in the following matrix.

Table 2: Proposed roles & responsibilities structure (UNDP-GEF-BEE 2017)

Tasks related to mainstream ECBC	Responsibilities Central Government	State Government	Local Government
ECBC ADOPTION			
Set-up ECBC committee to implement code		SDA	
Review the ECBC and customization of code to suit regional and climatic conditions		SDA	
Define criteria of applicable building types		SDA	
Make legal notification in the state gazette for mandatory implementation of code		SDA/ UDD	
Develop enabling mechanisms and processes for mainstreaming ECBC	BEE	SDA and UDD	ULBs
Revision of Schedule of Rates (SoR)	CPW D	PW D	
Revision of State General Development Control Rules/ ULB's Building Bye-Laws		SDA and UDD	ULBs
Develop ECBC implementation Rules e.g. Third Party Assessor (TPA) Model	BEE	SDA and UDD	ULBs
Use public online tools/ endorse third party simulation software to show compliance	BEE	SDA	ULBs
Develop technical capacity of building sector stakeholders	BEE	SDA	ULBs

Tasks related to mainstream ECBC	Responsibilities Central Government	State Government	Local Government
ECBC ENFORCEMENT			
Institutionalize mechanisms for enforcement and compliance checking in ULBs & Electrical Inspectorate		SDA	ULBs
Set-up of robust Monitoring and Verification (M&V) system	BEE	SDA	ULBs

3. Use of 3rd-party technical assessors to check for design-based ECBC compliance in the overall building design approval process: A major challenge in implementation for states having notified ECBC is to check ECBC enforcement by the local government. The task requires compliance check of the technical details of the code on the ground by the local government officials, which sometimes lack the technical capacity to understand and evaluate the building systems. While capacity building programs are running in full swing in many states to ramp-up local government capacity, their benefits may not be felt in the medium-term. To fast track enforcement, TPA model has been suggested by C.E.P.T. University, Ahmedabad, which stresses on creating a cadre of professionals outside the public sector (CEPT University). Under the model, a TPA is assigned to the project, which reviews the project during design stage and construction phase, on behalf of local government and ensures Energy Conservation Measures (ECMs) are appropriately incorporated in the building. The model also suggests appointment of technical committee by BEE to further appoint quality assurance (QA) bodies to oversee the operation of the TPA model. The operating model for third part assessment for ECBC compliance checks is presented in the figure below, indicating the roles and responsibilities at national, state and local level.

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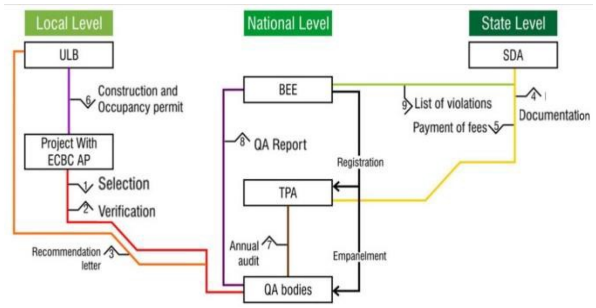

Figure 5: TPA model (CEPT University)

4. Appropriate capacity building: Capacity building is a long-term solution to fast track implementation and in order to reap higher EE benefits in the buildings sector, undertaking structured trainings targeting the right audience is a must. Different training modules are needed for different stakeholders such as senior bureaucrats, government officials representing UDD, SDA, PWD, policy makers, practicing architects and engineers. Other suggestion to scale-up capacity building and generating awareness about ECBC is by including ECBC in the curriculum of various architectural and engineering courses and organise dedicated events such as regional workshops. While these are broad level approaches, to fast track implementation, each state is required to address their challenges at state and local level.

CONCLUSION

India will experience massive growth in the commercial and residential building construction over the next two decades. Recognising energy efficiency as a resource and enhancing energy efficiency of the upcoming building stock is imperative for India's development. While the Government of India has done an admirable job in setting ambitious renewable energy targets, only focusing on generation without plugging energy wastage and embracing energy efficiency will prove very costly for India. The situation is akin to putting water in a leaky pot and will not serve very well unless demand side efficiency is emphasized and given importance before supply side focus on renewables will start to bear fruit in a carbon constrained environment.

Following interventions are suggested:

2. Roll out roles and responsibilities for all relevant government stakeholders at the earliest and publish annual ECBC implementation status report for every state at the state, municipal corporation and ULB level;
3. Make ECBC enforcement mandatory in all Indian states and UTs and direct the development authorities to not issue design approvals until building design show compliance with ECBC;
4. Ask all the government ministries and departments to immediately comply with ECBC for all government building design and construction with a connected load of 100 kW or more;
5. Mandate disclosure of energy use (Energy Performance Index) for all public and private commercial buildings with a connected load of 100 kW or more and immediately install meters to start monitoring energy consumed by air-conditioning and fans, lighting, plug power and elevators to instil a culture of data-driven energy management.

The broad level recommendations are based on the challenges highlighted during the high-level five regional workshops with participation from more than 300 central, state and local level government officials across India. The methodical understanding of the existing efforts, identification of challenges along with rational near and long term solutions for every state is required while drafting strategies to fast track ECBC implementation at state and local level. While some of the recommendations are part of various states implementation strategy, the adoption is slow paced due to several reasons. The technical experts' role is crucial to devise different and state specific approaches and resource allocation for code Adoption, Implementation, and Enforcement. The tiered approach and resource allocation for smart cities by CEPT University and PNNL respectively are few of the examples (Rawal, Vaidya, et al. 2012) (Tan, Yu and Evans 2016).

Mandatory enforcement of ECBC in India is the need of the hour and it will positively impact its Nationally Determined Contribution and Sustainable Development Goals commitment. At the same time, mandatory enforcement will have a positive impact on India's Smart City Mission because its building stock will avoid a lock-in inefficiency of 30-50 years putting a negative burden on India's energy security situation.

ACKNOWLEDGEMENT

AEEE team would like to express their sincerest gratitude and thanks to the UNDP-GEF program for their support, to NITI Aayog and the Bureau of Energy Efficiency for their guidance and support throughout this project.

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LIGHTING ENERGY SAVING POTENTIAL IN INDIA BY 2030 WITH DIFFERENT MARKET PENETRATION ROAD MAPS FOR ENERGY EFFICIENT LIGHTING FIXTURES
AN APPROACH TO OPTIMIZE GHG ABATEMENT TARGETS

Govinda Somani, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

Keywords: Energy efficiency, lighting energy, GHG abatement, life cycle cost, payback

ABSTRACT

US DOE estimated lighting energy use around 15 percent of the total global electricity demand [2]. Exponential rise in electricity price and climate change concerns have shifted market focus towards energy efficient lighting sources like LED [2]. Reference [2] also estimate an increase in share of LED fixtures by 5 times to USD 25 billion by 2020 compared to 2013 level and a marginal decrease of 20 percent in the market share of T8 & T5 to USD 20 billion by 2020. Fixtures like CFL will constitute only 5 percent of total market and T12 will almost phase out.

India is one of the fastest growing economies. Commercial building space in India has been estimated at 830 million square meters in 2011 with a projected growth to 3435 million square meters by 2030 (Compound Annual Growth Rate (CAGR) of 8.39 percent) [3] [6]. In year 2011, the average LPD of public and private commercial building is estimated to 9.07 and 12.3 watt per square meter respectively [3]. Reference [3] also estimated the increase in commercial building lumen-hour demand in India by 72 percent in next decade. Increasing population and economic activity will be the main triggers for this growth.

Lighting energy is a significant component of building energy use. Different lighting technologies are available in the market with their respective energy saving potential and financial implication. Such a complex financial inter-relation of energy efficient (EE) fixtures calls for a detailed understanding of techno-economic performance of such fixtures to understand the affordability of these products based on energy saving potential, practical application, financial implication, life cycle cost, rate of return, and payback. Furthermore, a phase out plan was drafted to allow smooth market penetration of EE fixtures in Indian commercial market segment.

Keywords—Energy efficiency, lighting energy, GHG abatement, life cycle cost, payback

INTRODUCTION

Lighting comprises of 15 to 20 percent of the total building energy use. Commercial buildings use lighting energy even during the day time because of low daylighting availability or specific functional requirements. As per the study conducted by BEE and ECOIII in 2010, in the commercial buildings category, a total of 398 million lighting fixtures have been estimated with 250 million stocks of CFLs, 138 million stocks of fluorescent Tube lights, 0.44 million stocks for LEDs, and 6 million stocks of incandescent lamps. In terms of approximate load distribution of national demand for commercial buildings, tube lights (T8, T12) account for 52% of the lighting load followed by CFL (38%) and incandescent lamps (4%). T5 accounts for only 6% and LEDs account for 0.04%. (Dr. Garg, 2011). Many energy efficient lighting products are available in the market. On one side, EE fixtures could add to the overall construction cost of building but on other hand it could help to reduce operational cost (electricity bills). The selection of a lighting fixture should be based on techno-economics analysis, which requires a comprehensive study on the technical specification, energy saving potential, practical application, financial implication, life cycle cost, rate of return, and payback period. This techno-economic analysis ensures that the selected measures are not only energy efficient but are also cost effective for the building industry.

This study aims to understand the techno-economic performance of various EE lighting products [5]. Based on the techno-economic analysis, a market penetration plan for EE fixtures has been drafted to highlight the energy saving potential of EE lighting fixtures in next 2 decades. The study intents to understand the current LED market penetration plan of EESL and focuses advance economics tools for an optimized market penetration plan and better GHG emission reduction by 2030. The broad objective of the study are as follows:

1. Collate details on different EE lighting products as per Indian market along with the technical specification and overall lighting design cost.
2. Undertake a techno-economic analysis.
3. Propose a phase out plan of inefficient lighting fixtures and allow market penetration of EE fixtures vis-à-vis the market penetration plan of LED undertaken by EESL.

METHODOLOGY

The methodology adopted is divided into – Baseline Analysis, Techno-economic analysis & market transformation road map.

A. Baseline Analysis

Prerequisites and baseline analysis

a. a. Candidate lamps list: As a part of ECBC 2017 update process, a lighting working group has been constituted by Bureau of Energy Efficiency (BEE). Under the said working group, a survey with key lighting organizations like Indian Society of Lighting Engineers (ISLE) and Electric Lamp and Components Manufacturers Association of India (ELCOMA) as well as manufacturers were conducted to understand the product variety, local cost, and efficiency of various EE lighting fixtures. The survey result is considered for the candidate lamp list.

b. Setting a baseline: A baseline needs to be defined a per the current market standard for a typical lighting design in Indian building industry.

B. Techno-Economic Analysis

Stringency analysis procedure

The steps in the process consist of the following:

1. Consider a working plane (m^2) of a space where candidate fixture is installed.
2. Tabulate the wattage of each lamp with the efficacies, life expectancy, cost and average light loss factor

For lighting power density

3. Define the spaces as listed in ECBC 2017.
4. Each work plane has a defined lux level as per the NBC.
5. Calculation: LPD for each space category was calculated using the below formula-
   a. Number of fixture (N) required

$$N = (Lux \; X \; A) / (Lm \; X \; MF \; X \; UF) \qquad (1)$$

Where,

- Lux level (Lux) is as per National Building Code (NBC)
- Lumen output (Lm) is the market standard from survey
- Area (A) is the area for the targeted lux in square meters
- MF is the Maintenance factor - as per NBC and industry standard.
- UF is the utilization factor - as per NBC and industry standard.

9. Based on the number of fixture, the LPD is calculated.

$$LPD = (N \; X \; W) / A \qquad (2)$$

Where, W is the watt of the fixtures used

10. Estimate the first cost (relative cost only) for overall lighting design using candidate product
11. Perform the LCC analysis and record the EE potential

Economic analysis

The LCC model is used to identify the cost-effective lighting products or systems. LCC considers all the cost associated with the product in its life cycle. It includes cost like initial investment, maintenance cost, salvage cost etc. LCC depends significantly on external factors like climatic zones, building type, usage pattern etc. [7].

$$LCC = Initial\ Cost + PV \; x \; kWh \qquad (4)$$

Where,

- Initial cost: The construction cost including material, labour, and construction.
- PV: The present value (PV) of all the electricity charges paid in the life span.
- kWh: the energy performance index (kWh/m^2)
- assume an average energy price for the nation

C. Market transformation road map

Propose a phase out plan with most optimized GHG abatement potential and compare it with the market transformation plan of EESL.

Summary of methodology section

The proposed methodology forms the framework of the development of this research study. The baseline analysis task sets the benchmark of the current market standard. The techno-economic analysis task evaluates each technology available in Indian market on the basis of its energy saving potential and cost effectiveness. The phase out plan task devises an optimized GHG abatement potential and compare it with the market transformation plan of EESL.

BASELINE ANALYSIS

A. Baseline Analysis

To estimate the baseline LPDs, a survey was conducted in different cities of India. The survey questioned the typical lighting design fixtures used for some of the listed spaces and corresponding LPDs. The survey highlighted the adoption of LPD values stated in Energy Conservation Building Code (ECBC) 2007. As per the study of BEE and ECOIII, national demand (kW) and number of fixture estimated for each lamp type has been used to understand the annual lighting energy use for commercial buildings in 2011 w.r.t. each technology (**Table 1**). This detailed breakup will help us to devise the phase out plan and estimate the saving potential. As per the estimate

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commercial floor space in 2011, the annual average lighting energy use was pinned to 35.2 kWh per square meter per year.

Table 1 lighting demand estimated for year 2011 subcategorized within different lamp type as per the estimated market share in India

	Lamp type	Units in India (millions)	National Demand (kW)	Annual lighting demand (GWh)
1	CFL	250	3,800,000	11,096
2	T5	21	600,000	1,752
3	T8	47	1,800,000	5,256
4	T12	69	3,400,000	9,928
5	LED	0.44	4,000	11.68
6	Bulb	6	400,000	1,168

B. Energy conservation measures (ECM)

Different types of lighting fixtures, like CFL, FTL (T12, T8, T5), light-emitting diode (LED), are available in the market. It was important to understand the sub-categorization of each lamp type and estimate the average energy performance of each available type as per the Indian market standard.

Table 2 showing a list of lamp wattage selected in each category together with its cost. (source - internal survey)

	LAMP TYPE	W	LUM EN	LUM/ WATT	COST (INR (USD))	COST INR/W
1	CFL	36	2,625	65	130 (2.00)	3.61
2	T5	28	2,110	75	150 (2.30)	5.34
3	T8	36	2,050	57	55 (0.85)	1.53
4	T12	40	2,225	50	45 (0.70)	1.14
5	LED	15	1,650	110	490 (30.0)	32.5

The sub category of lamps was based on wattage. Efficacy within a lamp category varies with wattage category. The cost of the fixture depends on market demand of subcategory type rather than the size of watt or efficacy. For example, a 36 W CFL costs just USD 2 per lamps in India compared to 13 W fixture costing USD 2.10. Only lamp subcategories with optimized cost to efficacy ratio and most commonly sold in market were selected for the study (TABLE 1).

Summary of baseline analysis section

ECBC 2007 is a decade old document. Given the rapid transformation in lighting industry in last 1 decade, it is acceptable that the market has reached up to a maturity level and has adopted the lighting standard of ECBC 2007 as minimum performance level. It is observed that the efficiency listed in ECBC 2007 could be met by CFLs or T8. The same is also reflected in Table 1, which states that CFL constitute of 67% of the lighting units installed in 2011.

TECHNO-ECONOMIC ANALYSIS

A detailed calculation was undertaken to estimate number of fixture (of selected wattage) required to light a space as per its lux level defined in NBC. It was found that the number of fixtures estimated through the simulation or the formula (Section 2) are nearly same. The number of fixture(s) further helps to estimate the LPD for a space, the total cost (USD /m^2) to lit per unit space, and the annual energy used (kWh/m^2-yr).

Incandescent lamps are obsolete now. Based on the analysis, it was found out that T12, with an efficacy of 50 lm/ watt, is least efficient & cheapest lamps and T8 out performs T12 in efficiency by mere 14%. Moreover, technology like CFL, T5, and LED outperform T12 by 30%, 50%, and 120% respectively (TABLE 3). To understand the LPD performance with respect to cost, a regression graph was plotted. It was observed that products like LED, CFL, and T5 are expensive compared to T12 but with efficient efficacy, the candidate product will be able to light a space effectively with relatively less LPD. It was observed that in a space like office, a reduction of nearly 40% and 60% in LPD/ annual energy consumption is possible by replacing a T12 fixture with a T5 and LED respectively.

Table 3 Percentage reduction in energy use (internal analysis)

	LAMP TYPE	STANDARD CATEGORY	LUM/ WATT	%ESCAL-ATION
1	T12	36 W	50	Reference
2	T8	35 W	57	14%
3	CFL	40 W	65	30%
4	T5	36 W	75	50%
5	LED	15 W	110	120%

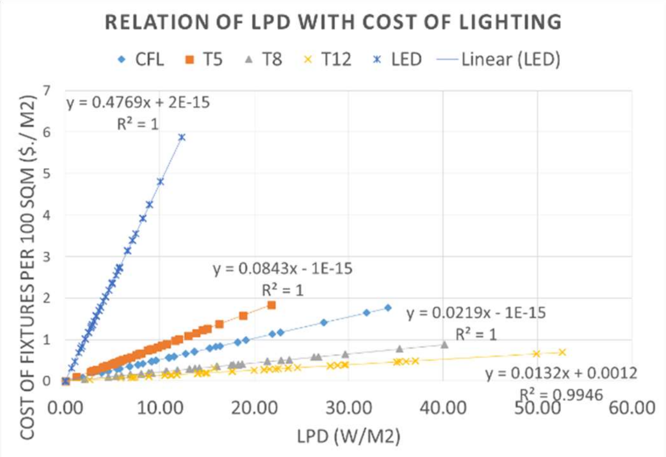

Figure 1 Relation of LPD with cost of lighting

To understand the trend of cost of lighting with LPD, a regression graph was plotted with all the candidate products. It was observed that to achieve a given LPD, LED is most expensive option followed by T5 and CFL respectively, but the increased cost of energy efficient fixture could be compensated with increased efficacy of the fixture. To understand the relation between additional cost and increased efficacy, economic analysis was conducted.

Economic analysis

Correlations were plotted to analyse techno-economic factors when a T12 is upgraded to EE fixtures (**Figure 2- Figure 5**):

1. Additional cost of switching to another fixture: This correlation plots the difference in the cost of lighting design. It includes the cost of fixtures and the difference in utilization/ maintenance factor.
2. Money saved annually: This correlation plots the reduction in energy used in monetary terms.
3. Net present value (NPV) of all savings done in a life period: This co-relation plots NPV, based on discounted rate
4. Simple payback period: Based on the additional cost and annual energy saved, this correlation plots the simple payback period for an EE fixture.

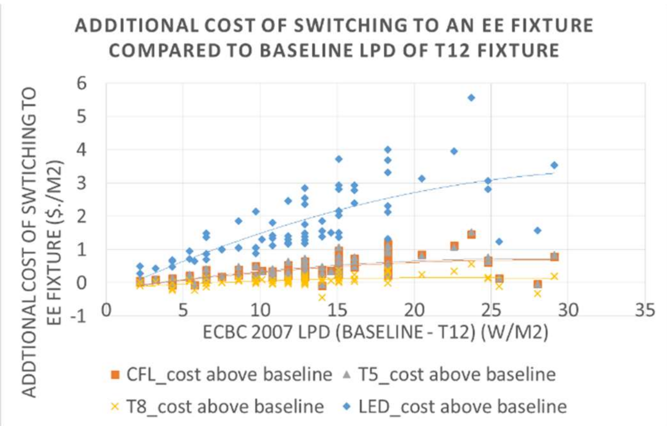

Figure 2 Additional cost of switching to EE fixture compared to baseline LPD of T12 fixture

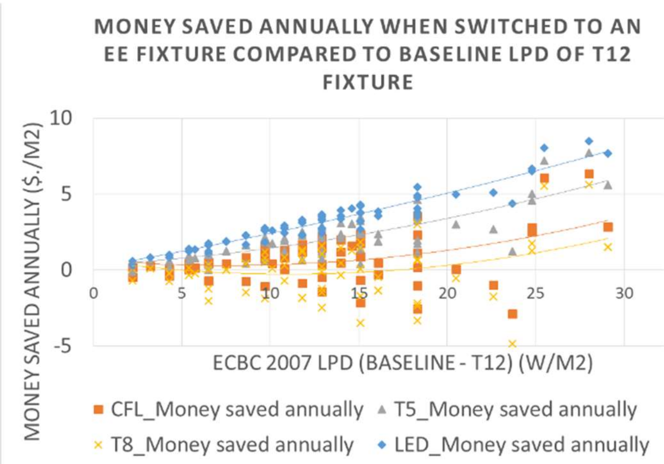

Figure 3 Annual savings (USD) when switched to EE fixture compared to baseline LPD of T12 fixture

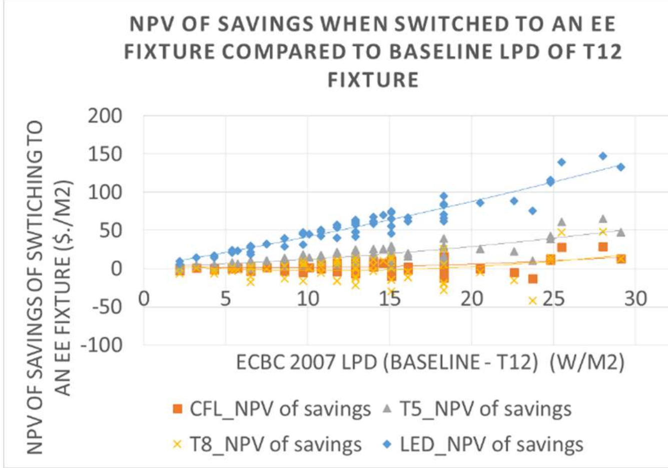

Figure 4 NPV of savings when switched to an EE fixture compared to baseline LPD of T12 fixture

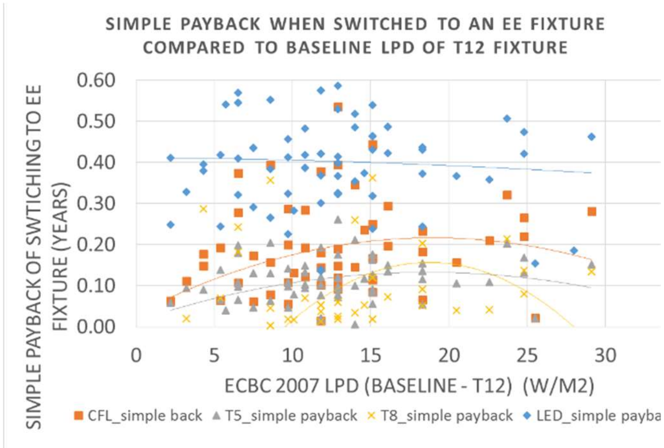

Figure 5 Simple payback when switched to an EE fixture compared to baseline LPD of T12 fixture

<u>Summary of techno-economic analysis section</u>

1. The additional cost of switching to an EE fixture in both the cases is marginal for T5 fixture and CFL. LED is comparatively expensive. Cost of light installation based on lighting design for a T5 and CFL are almost same. Though the cost of T5 are 25% higher than CFL, the utilization factor of T5 is 22% less than CFL making the installation cost similar. LEDs are 3 times more expensive than T5 and uses only half the energy compared to T5.
2. Money saved annually due to reduced energy consumption is nearly 3 to 4 times.
3. The NPV of energy saved during the life time (5 years) of a fixture is 5 - 8 times the total fixture cost based on per unit fixture requirement making the up gradation lucrative.
4. Simple payback of all EE is less than a year. The average simple payback of LEDs when replaced with T12, T8, CFL is of 0.46, 0.65, and 0.85 years. The simple payback of LEDs when replaced with T5 is of 1.6 years. The average

simple payback of T5s when replaced with T12, T8, CFL is of 0.21, 0.36, and 0.60 years.

5. Based on the analysis, the percentage reduction in energy use if an inefficient/ less efficient fixture is replaced with an EE fixture is listed in **Table 4**.

Table 4 showing the % reduction in energy use in each fixture in case of replacement of an inefficient fixture with an EE fixture

	Bulb*	T12	T8	CFL	T5	LED
If replaced with CFL						
% reduction	67	35	16	0	-	-
If replaced with T5						
% reduction	72	54	41	30	0	-
If replaced with LEDs						
% reduction	91	75	68	62	42	0

*bulb represents the typical incandescent bulb

MARKET TRANSFORMATION ROAD MAP

Market Penetration approach

In 2011, the percentage proportion in electrical load of LEDs in India was 0.04%. The cost of LEDs were three times for expensive in 2011 than in 2017. Thus, it is assumed that LEDs were introduced in India by 2011 or so. On contrary, in 1994, T5 lamps with cool tip become the leading fluorescent lamps operated on electronic ballasts with up to 117 lm/W with good colour rendering [22]. T5 is a more mature technology compared to LEDs. Moreover, as per the findings of this paper, in 2017, LEDs are 3 times more expensive than T5 and uses only half the energy compared to T5. In spite of a mature technology and lot cheaper than LEDs, market share of T5 in 2011 was only 6%.

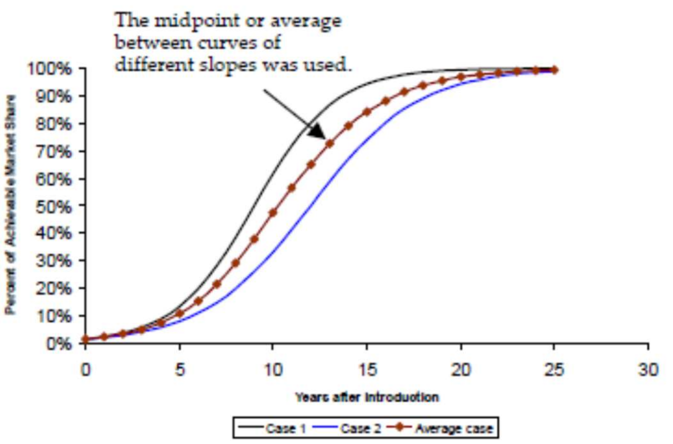

Figure 6 showing percentage of achievable market share of a technology v/s years after its introduction [16]

To understand the percentage of achievable market share w.r.t. number of years, after introduction of a technology, the S-Curve of market penetration has been considered. S-curve provides the rate of adoption of technologies, which is a function of the technologies characteristics and market conditions. The curve begins with a slow start, followed by steep growth, and then a plateau which is characteristic of many technological capabilities and product life cycles. As per the S-curve, the possible market share of T5 after 1.5 decades of its introduction should have been around 80% compared to the actual 6% market share of T5 in 2011.

Currently, government of India is focused in increasing the adoption of LED technology in the country. Many programs have been implemented to increase the market penetration of the LEDs in the Indian market but given the technology was introduced in the market in 2011, the possible market share by 2018 is around 20% and it will take another 1.2 decades to have 95% market share for LEDs (**Figure 6**).

In order to understand the cumulative market penetration curves w.r.t. payback of a technology, Kastovich (for replacement market) and Navigant curves were considered [17]. These to be the most appropriate curves to calculate the market penetration potential, because they reflect investments in electric products, with a focus on the replacement market, which is analogous to the retrofit market. The curves provide the cumulative market penetration 10-20 years after product introduction, as a function of payback. The Kastovich curve is more aggressive than the Navigant curve, a midpoint between the two was thus considered in the analysis.

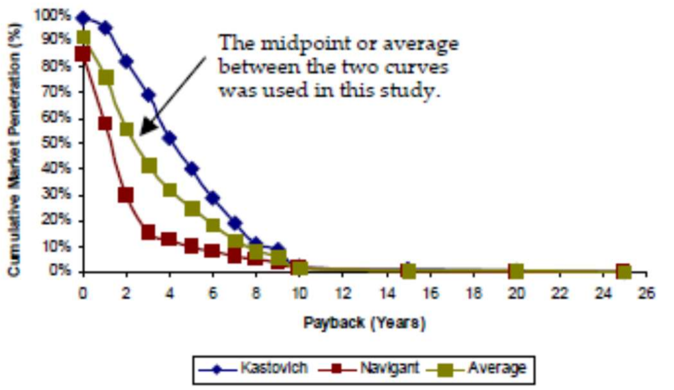

Figure 7 showing cumulative market penetration potential as a function of number of years for pay back of a technology [17]

As concluded, the average simple payback of T5s, when replaced with T12, T8, CFL, is of 0.21, 0.36, and 0.60 years. The payback time of T5, when replaced with T12 or T8, is half compared to the replacement with LEDs. As seen from graph, the cumulative market penetration potential of T5 (technology which has been introduced in the market 2 decades before) is nearly 90%. The payback of LED is also very cost effective, but it will take at least another 1.5 decades for the LEDs to have similar market penetration potential. The same has been also substantiated by EESL in their presentation [18]. By 2016, EESL expects LEDs to have 20% of market share and the same shall rise to 85% of market share by 2031, after 1.5 decades from now.

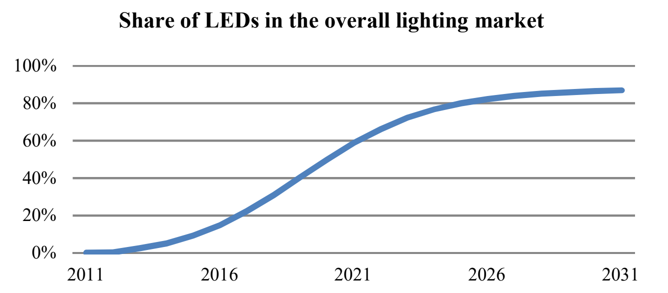

Figure 8 showing market share projection of LEDs in commercial buildings by 2031, estimated and presented by EESL [18]

Market transformation scenarios

Two different scenarios are considered – 1) LED market transformation plan adopted by EESL, and 2) T5 inclusive LED market transformation plan proposed in this paper.

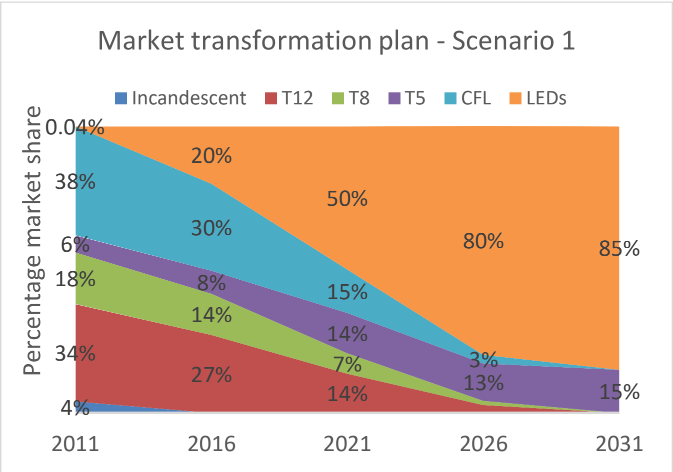

Figure 9 showing Scenario 1 of LED market transformation of EESL

<u>Scenario 1- LED market transformation (EESL approach)</u>

Based on figure 8 and EESL market projection for LEDs, a market transformation plan has been plotted where,

a. In 2016, LEDs replaces the incandescent bulb completely and reduces the market share of T12, T8, and CFL by 20% resulting in a market share of 20% for LEDs & 8% for T5.
b. In 2021, after 10 years of introduction of LEDs, the achievable market share for LEDs is 50%. Thus, in 2021, LEDs further reduces the market share of T12, T8, and CFL by 50% from the 2016 level, resulting in a market share of 50% for LEDs and 14% for T5.
c. In 2026, LEDs further reduces the market share of T12, T8, and CFL by 80% from the 2021 level, resulting in a market share of 80% for LEDs and 13% for T5.
d. In year 2031, LEDs captures its potential market resulting in a market share of 85% for LEDs and 15% for T5.

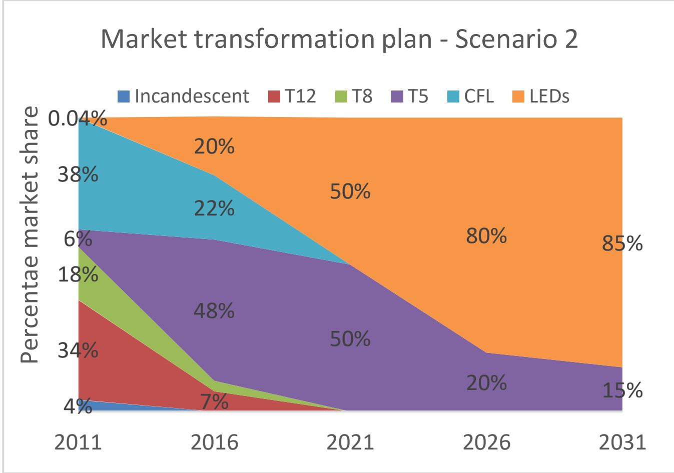

Figure 10 showing Scenario 2 of T5 inclusive LED market transformation

<u>Scenario 2 of T5 inclusive LED market transformation:</u>

In scenario 2, market share of the LEDs is kept same as proposed by EESL, but T5 adoption & market penetration is also integrated. In scenario 2, LEDs to penetrate into the market of CFLs and T5 penetrates into the market of T12 and T8.

a. In 2016, after over 15 years of introduction of T5s into the market, T5s to capture 80% of the market of T12 and T8. LEDs to capture 20% of overall lighting market reducing CFLs market share to 22% from the 2011 level. Resulting market share is of 20% for LEDs and 48% for T5.
b. In 2021, the achievable market share for LEDs is 50%. Thus, in 2021, LEDs further reduces the market share of T12, T8, and CFL by 50% from the 2016 level, resulting in a market share of 50% for LEDs and 50% for T5s.
c. By 2026, the LEDs, comparatively mature technology, to be a preferred buy in the market over T5 resulting in a market share of 80% for LEDs and 20% of T5.
d. The projected market share of LEDs and T5s by 2031 is 85% and 15%.

GHG abatement potential of different Market transformation plans

TABLE 5 SHOWING THE REVISED LPD WITH AN UP GRADATION TO AN EE FIXTURE FROM A BASELINE COMPOSITION OF 2011

Assessment year of below table	2011
Calculation is to estimate the savings if inefficient lamps is replaced with listed fixture	

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If replaced with CFL	
% reduction	20%
Revised average LPD (W/m^2)	10.5
If replaced with T5	
% reduction	45%
Revised average LPD (W/m^2)	7.3
If replaced with LEDs	
% reduction	70%
Revised average LPD (W/m^2)	3.9

Based on the estimated commercial building floor space in year 2011, the average LPD in 2011 is estimated to 13.15 W/m^2 making the annual lighting use of 30,652 GWh (average use of 9 hours a day and 312 days a year). The commercial building sector is projected to grow with a CAGR of 8.39% annually till 2030. With an LPD of 13.15 W/m^2, our business as usual (BAU) commercial building energy use will rise by 500% by 2030. With a use of an efficient fixture in place of an inefficient fixture, the reduction in energy use and revised national average LPD for commercial building is listed in **Table 5**.

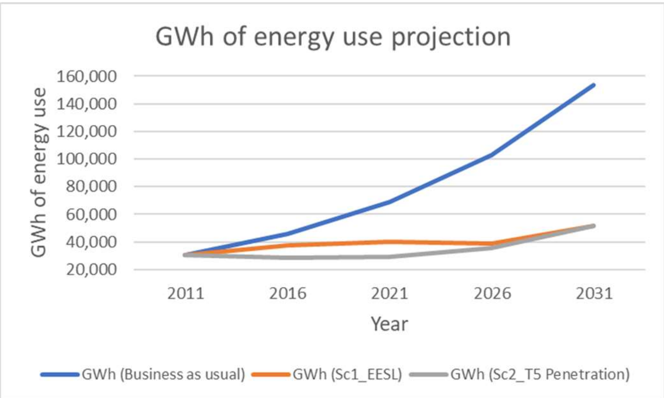

Figure 11 showing energy use projection of BAU, SC1, and SC2

The technology like T5 have reached to maturity in terms of their efficacy optimization but LED is a growing market with the technology still undergoing drastic up gradation in terms of their efficacy. The projected efficacy of LEDs is expected to be around 200 lm/W compared to 100 lm/W estimated currently by 2030 but as the technology efficacy would grow, our lux level requirement for a space shall also grow with time which would nullify the benefits from efficacy upgradation.

Table 6 showing steps to estimate percentage energy saving of Scenario 2 over Scenario 1

Projection category	2011	2016	2021	2026	2031
Commercial space (million m2)	830	1,242	1,858	2,779	4,158
Energy tWh (BAU)	30.7	45.9	68.6	102.6	153.5
Scenario 1 (SC1)					
Average LPD (W/m2)	13.2	10.8	7.7	5.0	4.4
Lighting installed capacity (GW)	10.9	13.4	14.2	13.9	18.3
tWh of energy use	30.7	37.5	40.0	39.0	51.3
% saving over BAU	0%	18%	42%	62%	67%
Scenario 2 (SC2)					
Average LPD	13.2	8.1	5.6	4.6	4.4
Lighting installed capacity (GW)	10.9	10.1	10.4	12.7	18.3
tWh of energy use	30.7	28.4	29.1	35.6	51.3
% saving over BAU	0%	38%	58%	65%	67%
% saving of SC2 over SC1	0%	24%	27%	9%	0%

If we estimate the energy saving and GHG abatement potential for the two scenarios discussed in this paper, it is evident, that the market transformation plan of EESL (scenario 1) has a remarkable saving potential and is expected to reduce the energy use of commercial buildings to one-third by 2031 compared to Business as usual (BAU) case (Fig 11). But if we compare the energy saving potential of scenario 1 and scenario 2, it is interesting to note that the T5 inclusive LED market transformation plan (Scenario 2) would have saved 25% more energy in 2016 compared to LED market transformation plan of EESL. Compared to the energy use projection for 2021 and 2026 with scenario 1, scenario 2 would have further reduce the energy use by 27% and 10% respectively (Table 6, Figure 12).

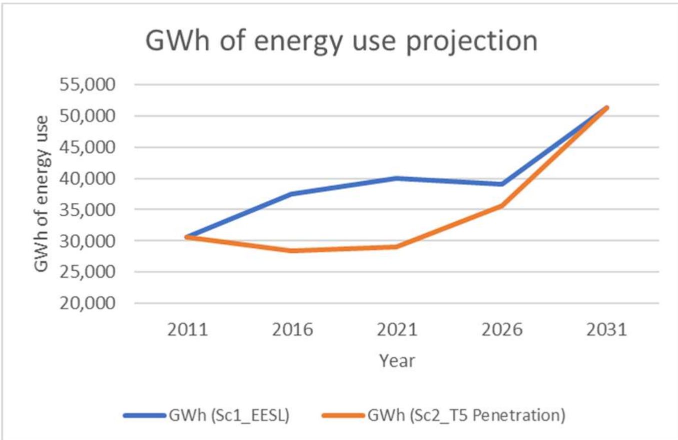

Figure 12 showing energy use projection of SC1, and SC2

GHG emission reduction potential:

In 2010, Central Electricity Authority (CEA) estimated the baseline CO_2 emission for the Indian Power Sector. CEA concluded that for every MWh of energy generated in India about 0.85 tCO_2 was emitted in 2009-10 [21]. The Planning

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Commissions envisions a percentage reduction in energy intensive by a factor of around 24.16% (24.44 % for 8% GDP growth and 23.88% for 9% GDP growth) with determined efforts by 2030 [20]. The total GHG abatement potential of Scenario 1 and Scenario 2 is 526.5 million tCO2 and 615 million tCO2. The T5 inclusive LED market transformation plan (Scenario 2) has 17% more potential to save carbon emission by 2031 and would have helped to save 89 million tCO2 by 2031 in just commercial lighting use.

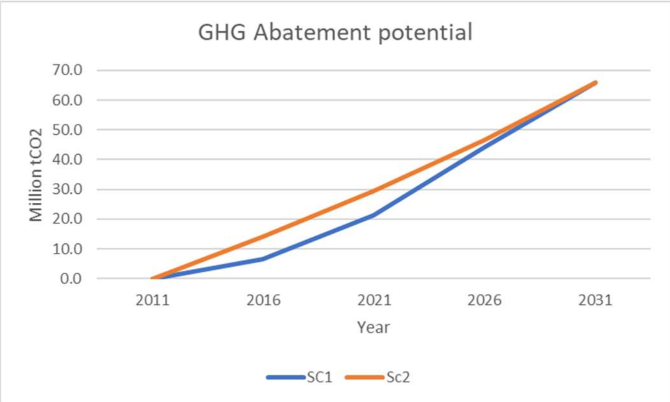

Figure 13 showing GHG abatement potential of SC1 and SC2 (million tCO2)

If we extrapolate the same study to residential building, which has 3 times more demand of lighting energy use than commercial buildings in India and has higher share of incandescent bulbs, T12, and T8 compared to commercial buildings, the impact of T5 inclusive LED market transformation strategy would be 3 times more and would have saved approx. 270 million tCO2 by 2031.

Table 7showing estimation of cumulative GHG abatement potential by SC1 and SC2 [19]

Year	emission factor	tWh of energy use saved		GHG million tCO2 saved in each year	
		SC1	SC2	SC1	SC2
2011	0.85	0.0	0.0	0.0	0.0
2016	0.80	8.3	17.5	6.7	14.0
2021	0.75	28.6	39.5	21.4	29.5
2026	0.70	63.6	67.0	44.3	46.6
2031	0.64	102.2	102.2	65.9	65.9
Cumulative total million tCO2 saved for all years (2011 to 2031)				526.48	615.56
GHG abatement potential of SC2 over SC1 in commercial building sector (million tCO2)					89.08
GHG abatement potential of SC2 over SC1 in residential building sector (million tCO2)					267.25
TOTAL GHG abatement potential of SC2 over SC1 (million tCO2)					356.33

<u>Summary of techno-economic analysis section</u>

Based on the discussions of this section, we conclude:

a. The market penetration plan depends on the S-curve and the years of introduction of a technology in market. Thus, the market penetration potential of T5s are higher than LEDs as per 2016. Given the payback of both the EE technologies is less than 1 year, the achievable market share is around 85% after 15-20 years of introduction of the technology in the market. LEDs will achieve the market share by 2031 but T5 could achieve it by 2016 itself.

b. The first scenario of market transformation is as per the proposal of EESL to promote LEDs in the market and the second scenario is proposed based on T5 inclusive LED market transformation plan.

c. It is concluded that Scenario 2 would have saved 25% and 27% more energy in 2016 and 2021 compared to LED market transformation plan of EESL.

d. If we extrapolate the same study to residential building as well, the T5 inclusive LED market transformation plan would have saved approx. 270 million tCO2 by 2031, would be 3 times more than the plan of EESL.

<u>CONCLUSION:</u>

LEDs have proven to be extremely effective due to their long lifespan and increased efficiency but LEDs are still considered to be an evolving technology. Based on the S-curve of market penetration, since the introduction of LEDs in the market is just few years old, it would still take around 1.2 decades for LEDs to capture the lighting market of India. On the other hand, T5 fluorescent bulbs have performed significantly better in multiple studies that are critical to commercial and residential usage. If we are looking at retrofitting our building from old T12 or T8 lighting fixtures to a more efficient technology, T5 is also a cost effective and robust solution.

Many international countries, who are also in process of maximizing the market share of LEDs, have well understood the requirement of T5 inclusive approach. In countries like Australia, China, and Europe, T5 has a market share of 40%, 40%, and 30% respectively [19]. On contrary, India reported a 6% market share for T5 in 2011. So, what exactly had stopped us from having a similar approach and adopted a better strategy for cumulative reduction in greenhouse gas emissions by 2030?

With the analysis reported in this paper, it is evident that a detailed techno-economic analysis and a comprehensive understanding of existing market potential, available technology and its relative payback period is very much important. The same analysis, clubbed with the market transformation economics and penetration model could help in devising a more robust plan and optimize the market transformation strategy and climate change initiatives. India has set a very aggressive INDC targets, and if in 2011, with the help of comprehensive study and with the adoption of T5 inclusive LED market transformation plan, Indian could be in a better position to meets its target in more cost-effective and guaranteed approach.

ACKNOWLEDGEMENT

I would like to take this opportunity to thanks Ms. Anamika Prasad, Mr. Karl May, Mr. Saurabh Diddi, Mr. S. Vikash Ranjan, and Mr. Tanmay Tathagat for their continuous support and inputs. Your vision and guidance have helped me a long way to undertake the research and present this paper.

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LEGAL AND POLICY SUPPORT TO THE IMPLEMENTATION OF ECBC IN INDIA – THE «ACE: E^2» EU FUNDED PROJECT

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Keywords: Energy Efficiency Buildings ECBC

ABSTRACT

India is the world's 4th total energy consumer, growing at ca. 4.2% annually, and the 4th CO_2 emitter and is still highly dependent on fossil energy sources, at 73% of total energy consumption (IEA, 2016). Also, India is one of the fastest growing economies of the world. In 2016-17, India's Gross Domestic Product (GDP) growth was 7.11%, making it the one of the fastest growing nation of the world (Ministry of Statistics and Programme Implementation, 2017). The sustained positive growth of India's GDP has led to a proportionate rise in the demand for energy supply, where the most important factors are increasing incomes and urbanisation. Envisaging the rapid urbanisation in the coming years, the Government of India (GoI) has introduced the Energy Conservation Building Code (ECBC) which sets minimum energy standards for new commercial buildings. This code, currently at a voluntary stage, is aimed to become mandatory, for all States and Territories of India.

In the European Union–India Energy Panel meeting, held in March 2014, which was reconfirmed in mid-2016, it was agreed, by both sides, that legislation related to the building sector will be prioritized. Therefore, within the above framework of bilateral collaboration, the EU has launched a series of EU-funded Technical Assistance projects to support India in the achievement of its energy and climate targets. Among these projects, the ACE: E^2 project aims at supporting the Indian Bureau of Energy Efficiency (BEE) to implement ECBC in four selected States.

This paper presents the objectives, the methodology and the so-far achieved results of the project. Attention is also paid to issues related to ECBC adoption at national level while the work intends to create a knowledge transfer practices from the EU to India in order to support the boosting of the local energy efficiency industry to explore its huge potential.

INTRODUCTION

International Energy Agency (IEA, 2016) in its Key World Energy Statistics, published in 2016, has gathered data on the world energy consumption, where it is indicated that, during the last four decades (1974-2014), the world primary energy has grown by 55.47% while global CO_2 emissions have increased by 52.26%. The main trends, among many, of the world indicators presented show that: 1) the population growth rate is below the GDP growth 2) primary energy consumption is growing at a higher rate than population 3) CO_2 emissions have grown at a lower rate than primary energy 4) buildings constitute one of the larger worldwide economic sectors, but, also, one of the larger energy users (Commission of the United Nations for Climate Change, IPCC, 2014), and, therefore, a major driver of global warming.

In its last update, US Energy Information Administration (EIA, 2017) published, for 2016, estimations where 40% of the total US energy consumption consumed by the residential and commercial sectors, (about 11.43 million GWh). These sectors account for nearly all of the energy consumption in U.S. buildings.

In Europe, the total building stock is close to 24 billion m^2 and almost 75 % of them are residential buildings, while the rest is tertiary buildings. The energy consumption of the tertiary sector has faced a constant increase during the last 30 years. The increase rate is 1.1% for the years 2010-2020, dropping from 1.5% in the period 1974-2004. But, there are notable differences between the member states (M-S), as in UK the building consumption has increased at a rate of 0.5%, while in Spain by 4.2%, mainly due to climatic conditions and the spread of building services in the country (i.e. extensive use of HVAC systems). Taking into account that 74% of the European population lives in urban zones, urban climatic conditions and local urban climate change affect a significant part of the European population and have a serious impact on the global energy and environmental quality of the built environment.

In EU, the building sector has been identified as one of the key sectors to achieve its «20/20/20»targets. A crucial policy instrument to achieve these goals is the full implementation, by M-S, of the Energy Performance of Buildings Directive and its recast. These Directives are posing important measures in order to improve the performance of the aging European building stock and, simultaneously, to create a new fleet of "healthy" and energy efficient buildings.

In India more than 70% of its primary energy needs are met through imports, mainly in the form of crude oil and natural gas (e.g. Kumar, 2016).

Electricity is being utilised across all sectors in India, namely industry, buildings (commercial and residential), traction and railways, agriculture and others (Figure 1).

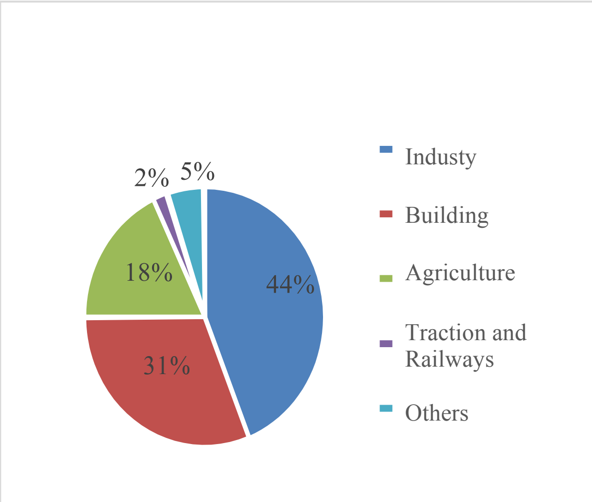
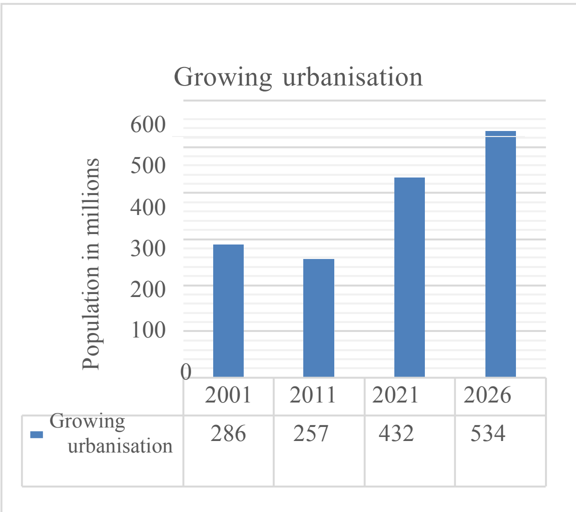


Figure 1: Sector wise electricity consumption in India (2016)

Approximately one-third of electricity generated in India is consumed by the building sector (residential as well as non-residential). According to the 2011 census, 30% of the Indian population (i.e. ca. 36.3 crore) live in cities. It is estimated that by 2050, this figure will reach 50% (CREDAI, CBRE, 2015), due to rapid urbanisation.



Graph 1: Growing urbanisation in India (by 2026)

This spiralling growth (Graph 1) in urbanisation can be attributed to significant opportunities in the construction sector in the cities. The classification of the construction sector is shown in Figure 2.

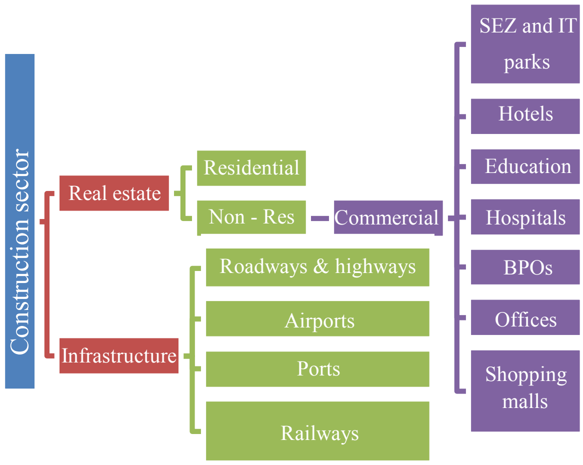


Figure 2: Classification of construction sector

It has been observed by Mohideen (2015) that the non-residential (commercial buildings) real estate segment has moderately higher levels of construction activity across major cities when compared to the residential segment.

In India, with substantial urbanisation in the past two decades, the demand for new commercial workplaces has risen. As per the Ministry of Urban Development (MoUD), with 30% of India's population living in urban areas, a significant portion of people work and use existing commercial spaces in these urban areas. It is also estimated that new commercial floor space will rise at an annual rate of 5–6% for the next one-and-a-half decades (BEE data).

Given the growth anticipated in the building industry, the EU and the Government of India have introduced several regulations, policies and programmes to promote energy efficiency, in order to avert an energy crisis in the near future, which are presented below.

EU & India Initiatives to Improve Energy Efficiency in Building sector

The European Energy Union framework strategy (Energy Union, 2015) ensures that Europe has secure, affordable and climate-friendly energy. For Europe, wiser energy use, while fighting climate change is both a spur for new jobs and growth and an investment

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in Europe's future. Based on these principles, remarkable work has been done to tackle the high-energy consumption in European building stock, by introducing, fifteen years ago, the principles for the energy performance of buildings. These are formulated and presented by the Energy Performance of Buildings Directive (EPBD), which is dated from December 2002. The EPBD had set a common framework, from which the individual M-S developed or adapted their individual national regulations. In 2008 and 2009, this EPBD underwent a recast procedure and the new Directive was adopted on May 2010, as EPBD recast (2010/31/EU, 2010).

Among other clarifications and new provisions, this Directive introduces a benchmarking mechanism for national energy performance requirements for the purpose of determining cost-optimal levels to be used by M-S, for comparing and setting these requirements. The EPBD (recast) has begun a change process in the construction sector, by influencing planners, engineers and investors to take more into account the need for wide-spread and better energy efficiency measures, in new and, currently, existing buildings.

The EPBD (recast) has also drawn attention to the fact that, as a major source of direct and indirect CO_2 emissions, the building sector must contribute to the 2030 and 2050 GHG reduction goals set by EU (EC, 2011).

It should be added that the European Commission is working, now, closer with M-S to ensure interpretation and transposition of the Directive into national law, meaning full implementation of the EPBD is completed swiftly. M-S are issuing energy performance certificates, even though some standards are not stringent enough and the relationship between the certificate and the energy use is not sufficiently clear; also, most M-S have targets for all new buildings to be "*nearly zero energy*" by 2020, however, there is no still a common EU definition of "*nearly zero building*".

Regarding India, the Government enacted the Energy Conservation Act (EC Act), in 2001 (EC Act, 2001). The purpose of this Act was to improve the energy conservation scenario in India. This Act encourages central and state government to implement Energy Efficiency (EE) measures across the nation.

In case of commercial buildings, the Government of India has taken several initiatives to improve the energy efficiency for both, existing and new building.

• **Existing building (commercial)**

In a country like India, where the building stock is growing rapidly, retrofitting of existing structures and replacement of old energy-consuming equipment is often one of the more effective means to achieve energy efficiency. The equipment inside an existing building can generally be replaced within 10 to 20 years. However, a building's shell or envelope is often unchanged for decades, except for basic maintenance. Renovating a building's envelope is often necessary to reduce heating and cooling loads. Technical approaches to buildings renovations need to be guided by specific climate conditions and sound economic justifications. Therefore, the BEE took several initiatives to promote a favourable environment for the large-scale implementation of energy-efficient measures. These initiatives are:

1. **Energy Services Companies (ESCO):** ESCOs are engaged in performance-based contracts with clients to implement measures which reduce energy consumption and costs in a technically and financially viable manner. ESCOs provide a business model through which the energy-savings potential in existing buildings can be captured and the risks faced by building owners can be addressed as well.
2. **Star rating scheme for commercial buildings:** BEE has developed a Star Rating Programme for buildings which is based on the actual performance of a building in terms of its specific energy usage in $kWh/m^2/year$. This programme rates buildings on a 1–5 star scale, with 5-star labelled buildings being the most efficient. The scheme is propagated on a voluntary basis and the label provided under it is applicable for a period of five years from the date of issue.
3. **Designated Consumers:** The EC Act has empowered the central government to notify energy-intensive sectors as Designated Consumers (DCs). The act lists 15 energy-intensive sectors, including commercial buildings. However, currently, only nine industrial sectors have been notified as DCs under the Perform, Achieve and Trade (PAT) mechanism. As a part of its medium-term strategy, BEE has identified hotels as DCs. This will further extend the scope of efficiency initiatives to other existing commercial building types.

• **New building (commercial)**

The EC Act empowers the central government to prescribe **Energy Conservation Building Code (ECBC)** in the country. BEE developed the ECBC that was formally launched by Ministry of Power (MoP) in May 2007 for its implementation in commercial buildings on a voluntary basis. A revised version of ECBC is expected to be launched in 2017. As of the 2017 effective date, the code is applicable to all new constructions of commercial buildings with a Connected Load equal to or more than 100kW or a Contract Demand more than or equal to 120 kVA. However, this code is not applicable to those commercial buildings which:

1. Do not use either electricity or fossil fuel.
2. Use energy primarily for manufacturing processes.
3. Is in conflict with safety, health, or environmental codes.

ECBC is a code that sets the minimum energy efficiency standards for design and construction. It encourages energy-efficient design of buildings so that the building function, comfort, health or productivity of the occupants are not constrained while taking into account economic considerations. ECBC defines the norms of energy performance and considers the climatic regions of the country where the building is located.

The code takes into account the five climates zones (hot dry, warm humid, temperate, composite and cold) present in India.

The provision of this code applies to following building components:

1. Building envelopes,
2. Mechanical systems and equipment, including HVAC
3. Service hot water heating
4. Interior and exterior lighting
5. Electrical power and motors

Under the EC Act, 2001, while the central government has powers to develop a national ECBC, the state governments have the flexibility to modify the code to suit local climate or regional needs and implement it.

Brief detail about the status of implementation of ECBC in India, as on January 2017, is presented in Table 1.

Table 1: Status of implementation of ECBC in India

SR. NO	STATUS OF ECBC (JANUARY 2017)	NAME OF THE STATE
1	States that have ***notified the code***	1. Odisha 2. Rajasthan 3. West Bengal 4. Karnataka 5. Andhra Pradesh 6. Telangana 7. Haryana 8. Punjab 9. Uttarakhand 10. Puducherry (UT)
2	States that have ***amended the code***, as per their climatic and local conditions	1. Uttar Pradesh 2. Kerala 3. Gujarat 4. Tamil Nadu 5. Maharashtra 6. Bihar 7. Tamil Nadu 8. Madhya Pradesh 9. New Delhi (UT) 10. Chhattisgarh 11. Assam
3	States that have not done any work in the implementation of ECBC	All remaining states and Union Territories (UT)

The amendment of the code was done based on the climatic zone of the state, as defined under ECBC User Guide (BEE, 2009).

Opportunities & Challenges implementing ECBC

Currently, ECBC is implemented on a voluntary basis and Government of India aims at making it mandatory. However, during the initial implementation stage of this code, government faced many challenges. The challenges faced to make ECBC mandatory in states are mainly related to following areas:

a) Policy & institutional structure

b) Technical & managerial capacity

c) Material & technology availability

d) Financial challenges

The challenges/barriers and easing measures required at state level are as outlined in the Table 2 (EIA, 2015).

CHALLENGES	EASING MEASURES REQUIRED
POLICY AND INSTITUTIONAL STRUCTURE	
Absence of mandatory standards: • ECBC is currently voluntary, so there are no minimum energy performance codes for most buildings and building components in any of the building bylaws	• Authorities and personnel of building departments at national, state and municipal level capable of implementing and enforcing the ECBC
Absence of policy guidelines for building bylaws: • Most municipalities do not have a uniform and practicable building energy code especially for passive and solar designs and no clear implementation guidelines are in place for state and municipal bodies for developing and/or implementing building energy efficiency programs and policies.	• Analysis of current regulatory mechanisms and capacities of institutions that support Energy Efficiency (EE) in commercial buildings and identify the gaps. • Formulation of a sustainability plan for BEE, which include the assigning of its long term mandate to implement the ECBC, staffing, implementation procedures, budget and resource requirements needed for the implementation of a mandatory ECBC, as well as its administration and enforcement structure.
No structure for ECBC implementation: • Even if mandatory, there is no effective institutional structures at national, state and local level for ECBC administration and enforcement including code checking and inspections; so far been implemented with limited participation from state and municipal authorities; lack of capacities of these institutions; • The EC Act empowers the state governments to amend the energy conservation building codes to suit the regional and local climatic conditions. • This provision may in longer run lead to large deviations from the	• Authorities and personnel of building departments at national, state and municipal level capable of implementing and enforcing the ECBC • Strengthened mechanisms and structures for ECBC implementation and gathered energy performance

CHALLENGES	EASING MEASURES REQUIRED
ECBC that has been developed by the BEE. • This may lead to confusion among builders, developers and designers.	
Lack of government champions due to knowledge gap: • There is lack of knowledge of benefits related to energy efficiency in buildings among the politicians and policy makers at national as well as state/municipal levels. • Building energy efficiency practices have still not been adopted by most government agencies for their own buildings or for the construction done by these agencies. • "Success stories" are not widely disseminated	• Strengthened system of information dissemination to stakeholders by conducting of workshops focusing EE options in commercial buildings and requirements under ECBC for key stakeholders from national government, state agencies municipalities, utilities, regulators as well as enforcement agencies
TECHNICAL AND MANAGERIAL CAPACITY	
Strong first cost bias: • The building market is diverse and characterized by fragmentation into various players. • The complexity of interaction among these participants is one of the greatest barriers to energy-efficient buildings. For example, building owners tend to underinvest in energy efficiency during building design and construction. • The developers don't gain from the initial investments in building energy efficiency.	• Awareness of property managers, developers and owners who are interested in, EE buildings
Lack of awareness of energy savings opportunities: • There are no energy use baselines for most building types. • Building designers and owners are unaware of energy efficiency opportunities and techniques. • Information on energy saving potential in buildings is also not available.	• Completed specific training programmes for key stakeholders and certified practitioners

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CHALLENGES	EASING MEASURES REQUIRED
• Building audit methodologies need to be improved.	
Lack of technical expertise: • There are very few technical experts and consultants providing building energy efficiency related services. • This forces many teams to hire international consultants at a high cost and also impacting the pace of design and construction.	• Training curricula and modules incorporated at training institutes. • Tools in place for energy-efficient building design (guidelines, handbooks, software)
MATERIALS AND TECHNOLOGY AVAILABILITY	
Non-availability of energy efficient equipment/ materials in the local marketplace: • Most energy efficient equipment and materials are imported, often with high cost mark-ups and duties imposed.	• Set of specifications for EE building materials
Lack of equipment testing / certification: • Programmes for standards, and testing equipment for energy-saving features of building materials and equipment are not in place.	• Technically capable and equipped building materials testing laboratories
FINANCIAL CHALLENGES	
Lack of financial incentives for energy efficient equipment/materials: • Energy Efficiency of buildings is not given due consideration in funding and incentives from the government. • Revision of regulatory framework is required regarding duty relaxation, incentives and tax benefits. • Also financing energy efficiency is not too lucrative for financial institutions due to uncertainty about returns. • There is a need for innovative financing schemes to promote EE in buildings. Lack of awareness: • The lack of awareness of the short amortization cycle and/ or the lack of incentives for investors and contractors to build ECBC compliant buildings and/ or lack of awareness that low energy bills can be a powerful marketing argument for future rental contracts.	• Fiscal and regulatory incentives for investors
High cost of borrowing money: • This can be a strong impediment to incremental funding in efficiency that would be offset by future savings of energy costs.	• Financing schemes designed with banks for investors to comply with ECBC

It is necessary that these areas get strengthened in each state in order for implementation of ECBC to be efficient and effective in achieving the set target of the Government of India. It has been 10 years since the ECBC was introduced but still a very limited number of states/UTs have completed notification. A key challenge above is the limited human resources capacity, in terms of personnel experienced in relevant legislation development and implementation and available to the BEE and to the key agencies in the individual States. Against this background, it is our understanding that a key role of the present assignment is to tackle the challenge presented by that resource gap, by assisting with the process of developing an enduring technical and managerial capacity within the States. Given that ECBC is one of the important initiatives of the GoI and only 9 states and a UT have adopted it, it was important to understand why its implementation is not happening in India and what areas are to be focused on.

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Based on the secondary and primary research it was deduced that there were the following barriers:

1. Awareness about the code among the stakeholders
2. No integrated approach has been adopted.
3. Close working of urban development authorities, urban local bodies, discoms and state designated agencies (SDAs), as the procedures are slow and bureaucratic.
4. Limited availability of technical professionals
5. Limited policies at state level to enforce the adoption of ECBC in the building industry.
   - No integration of the code in the building bylaws and building permit approval process.
6. Limited infrastructure for public to learn and use
   - Absence of communication framework
   - No centralised repository system
   - No demonstration projects to show ECBC benefits
7. Availability of financial mechanism
   - No incentive mechanism
   - No penalty mechanism

The above-mentioned barriers are very well met by the M-S of EU during the implementation of EPBD. Therefore, with this intent this project under the EU-India partnership was launched.

The **objective** of this project is to *"Assist the implementation of energy efficient legislation in 4 selected States, namely, Maharashtra (MA), Madhya Pradesh (MP), Odisha (OD), Bihar (BH) based on EU experiences, assisting them in setting up procedures for energy efficiency and to implement the nationally developed Energy Conservation Building Code (ECBC) scheme."*

ACE: E^2 project contributes to the above identified barriers by addressing the capacity building issue, the lack of demonstration, etc.

The role of EU-Funded ACE: E^2 project for implementing ECBC in 4 States of India

ACE: E^2 project is financed by European Union, as part of a well-established framework for strategic energy cooperation between the EU and India, titled **"Clean Energy Cooperation with India" (CECI);** which aims at enhancing India's capacity to deploy low carbon energy production and improve energy efficiency, thereby contributing to the mitigation of global climate change.

The CECI project facilitates the transfer of knowledge and technological know-how, from the EU experience to the Indian context, supports the involvement of the European businesses in the energy sector (RES, EE, etc.) and by fostering their cooperation with Indian actors in the area of EE in buildings.

The CECI project will be implemented through three separate Framework Contracts, as follows:

- **Lot 1:** Technical assistance and advisory services for setting up the first offshore wind-farm pilot in India;
- **Lot 2:** Technical assistance and advisory services for the implementation of solar parks (PV); and
- **Lot 3:** *Legal and policy support to the development and implementation of energy efficiency legislation for the building sector in India in collaboration with the Bureau of Energy Efficiency.*

Activities to be done for implementing ECBC in 4 states

The overview of activities to be conducted, for each state, for implementing ECBC, by ACE: E^2 team is given below:

1. Preparation of the roadmap for implementation of ECBC.
2. Situation analysis of the state
3. Identification of concerned officials from relevant stakeholders, i.e. SDA, Works Dept., etc., for ECBC implementation
4. Mechanism to ensure the compliance and enforcement of the code
5. Integration of amended ECBC state policies
6. Notification of the code
7. Demonstration of ECBC on several new commercial buildings
8. Building materials and testing centres educational institutes
9. Creating pool of ECBC master trainers
10. Capacity of implementing organization
11. Defining capacity building, training and awareness program

The results envisaged under this project is as below:

Result 1: Energy efficiency legislation for the building sector in India is updated and applied, using the experience of EU regulation and standards in this area. In particular, ECBC implemented in 4 selected States.

Result 2: Design studies to retrofit/construct at least eight (8) existing/new buildings, according to very high energy efficiency requirements, two in each state.

Result 3: Capacity developed at the state level to continue the implementation of the ECBC.

Result 4: National level coordination activities carried out.

Result 5: Improved access of EU companies in the Indian market, resulting in better exposure of India to European energy efficiency technologies and practices.

Result 6: the relevant Joint Working Groups in the framework of the EU-India Energy Panel are adequately supported with technical inputs and logistical support.

In order to achieve the required results, following approach was adopted.

Step 1 - Situation Analysis: To establish the present situation and identify gaps, barriers and challenges for implementation of ECBC in each state.

Step 2 - Development of Operational Mechanism: Compliance and enforcement mechanism for implementation of ECBC

Step 3 - Stakeholder Consultation: To discuss and take inputs from relevant stakeholders

Step 4 - Preparation & Submission of Notification Document: Preparation of a notification document and facilitating the process of ECBC notification.

Step 5 – Capacity Building and awareness workshop: Create pool of ECBC Master Trainers and organise an awareness workshop for all the stakeholders in all the four states.

Step 6 – Demonstration projects: Identification of buildings (new commercial buildings) to be constructed in the selected four states and provide technical assistance in designing, compliance and enforcement of **ECBC** compliant building.

The proposed approach is being adopted for all the four selected states. The detailed methodology is discussed in the subsequent section.

METHODOLOGY

In order to implement ECBC in the four selected states, the ACE: E^2 project team supported the SDAs of Maharashtra, Madhya Pradesh and Bihar, and the Urban Development Authority (UDA) of Odisha to set up local competent ECBC cells, comprising of an Engineer and an Architect.

ECBC cells, considered as an important element in the implementation of the project, conduct background research related to the implementation of ECBC for each state. Post the research, a detailed situation analysis for each state was prepared.

The situation analysis helped the project team to understand, in detail, the scenario of the respective state to adopt ECBC. This study further helped the project team to propose an applicable compliance and enforcement mechanism for each state. In order to propose the applicable compliance and enforcement mechanism, the project team also reviewed the international scenario. In the international scenario, the project team reviewed the following top ten (according to the 2014 ranking) energy consumers of the world: China, USA, India, Russia, Japan, Brazil, Germany, S. Korea, Canada and France.

Post development of enforcement and compliance mechanism a stakeholder consultation meeting has been organised in all the four states. In this stakeholder consultation meeting, all the primary, secondary and tertiary stakeholders have been invited and the entire enforcement and compliance mechanism was discussed. This integrated approach had helped the project team to develop a robust enforcement and compliance mechanism for all the four states.

Based on the stakeholder discussion, a detailed ECBC implementation document was prepared and was submitted to the state designated agency for their review. The following steps are to create the pool of experts and to demonstrate eight (8) ECBC compliant buildings, two in each state. The demonstration action is considered as of great importance for the success of ECBC in the States. A pool of local experts will be trained by experienced trainers on the peculiarities of the code in each of the four States, in order to be able to handle all future difficulties and to support the local engineers/architects in implementing thoroughly and correctly the ECBC.

RESULTS

The adopted methodology helped the project team in defining a robust mechanism to implement ECBC in each state.

The results for each state (MH, MP, OD, BH) are presented below.

- **Background research:** Work done in the past to implement ECBC in the state
  - **Maharashtra**: A roadmap to implement ECBC was prepared by Shakti Sustainable Energy Foundation. Also, climate classification for the state of Maharashtra was prepared, and redefined by Rachana Sansad School of Architecture.
  - **Madhya Pradesh**: The Urban Management Committee (UMC), Ahmedabad had proposed a roadmap to implement ECBC in the state of Madhya Pradesh.
  - **Odisha:** The state had notified ECBC in 2011.
  - **Bihar:** Energy Efficiency Services Limited (EESL) had developed a roadmap to implement ECBC in the state.
- **Situation Analysis as part of the project:** A detailed situation analysis of all the four states was conducted and following information were identified as seen in Table 3:

Table 3: Situation of all the four states

PARAMETER	MH	MP	OD	BH
Number of electrical connections (commercial buildings) with connected load more than 100 kW (2016)	10,652	1,115	522	365
Growth in number of electrical connections in the past five years (2011 – 2016) – CAGR	19%	11%	9%	31%
Expected Energy Consumption by 2030 (GWh)	16,058	387	424	NA
Number of climatic zones	4	2	3	2
Number of Technical/accredited professionals available to support the implementation of ECBC in the state (indicative numbers)	489	9	10	2

- **Operational Mechanism:** After analysing the situation of each state, for all the four states, Prescriptive and Whole Building performance method have been proposed to comply with the code. For enforcement, Third Party Assessor (TPA) model has been proposed.
- **Stakeholder Consultation:** Stakeholder consultation has been organised in all the four states and inputs from all the stakeholders, on the operational mechanism were collected and an ECBC implementation report was prepared.
- Status of Implementation of ECBC in all the four states:

Table 3: Status of adoption and implementation of ECBC in all the four states

PARAMETER	MH	MP	OD	BH
Notification of ECBC – Tentative timeline	August 17	Oct 17	Notified	Dec17

- Vendor meetings are organized at state level to address material availability issues in states.
- Training programs for key stakeholders such as Development authorities, ULBs, discoms and other departments are planned
- Programs to create pool of master trainers in Odisha, Madhya Pradesh and Bihar are planned.
- Technical assistance to 8 demonstration buildings to be provided.

CONCLUSION

The building sector is responsible for more than 40% of the total energy consumption, worldwide, producing a considerable impact on global energy consumption and on the environmental quality of the built environment.

In the same path, India, one of the world's larger energy consumer and CO_2 emitters, has enacted the Energy Conservation Act, in 2011 and, based on that, the Energy Conservation Building Code for commercial buildings, but on a voluntary basis for the States. During the past decade, many States notified and implemented the ECBC, others are in the process of notification and some are lagging.

The EU-funded ACE: E^2 Project, started in April 2016 with a duration of 42 months, is aiming to provide legal and policy support to the development and implementation of energy efficiency legislation for the commercial building sector of four selected states of India, namely, MH, MP, OD and BH, in collaboration with the Bureau of Energy Efficiency of India.

During the first year of project implementation, the team mobilized all active forces per state working on energy efficiency, such as ED and SDAs, etc.

and to prepare all necessary arrangements for two states (MH and MP) to be ready soon to notify the ECBC, to start the required training and demonstration activities in OD and to work on fundamental issues for notification in BI. We found that the collaborative work of EU experts, the local coordination team and the local experts in States can provide solid results in promoting Energy Efficiency in commercial buildings in India.

STRATEGY TO SUPPORT NATIONAL LEVEL IMPLEMENTATION

In addition to these tasks, after gauging the acuteness of the challenges mentioned in the above sections, we have identified a need to create a "Common Forum at national level", where all the state representatives (SDAs and UDDs) come together to share their experiences (success stories/challenges) and work together to move forward for implementation of ECBC.

Therefore, a **Common Implementation Forum for Energy Conservation Building Code** is being proposed at National Level under this project. This forum will support all the states across India to come together, learn from each other and successfully adopt, and implement ECBC in their states. A national level workshop is proposed to develop a common consensus on Energy Conservation on commercial buildings.

ABBREVIATIONS

CECI Clean Energy Cooperation with India

CEPT Centre for Environmental Planning and Technology

DC Designated Consumers

EC European Commission

ECBC Energy Conservation Building Code

EE Energy Efficiency

EU European Union

GEC Green Energy Corridors

MoP Ministry of Power

M-S EU Member States of European Union

MNRE Ministry of New and Renewable Energies

NIWE National Institute of Wind Energy

PAT Perform, Achieve and Trade

RECI Renewable Energy Corporation of India

SDA State Designated Agencies

UDD Urban Development Department

ULB Urban Local Bodies

UMC Urban Management Committee

UT Union Territories

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EVALUATING NATIONAL ENERGY EFFICIENCY POLICY ADOPTION AND OUTCOMES

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Keywords: International, scoring, best practices

ABSTRACT

National energy efficiency rankings are an effective tool to motivate policymakers to implement energy efficiency programs and policies. ACEEE's International Energy Efficiency Scorecard (Kallakuri et al, 2016) aims to encourage some of this healthy competition by ranking 23 of the world's largest energy-consuming countries on their energy efficiency actions and outcomes. Arriving at a suitable methodology to evaluate country-level energy performance can be challenging given vast demographic, economic, and geographic differences between countries but ACEEE's approach aims to provide countries with a collection of best practices to draw from in addition to providing a high-level view of energy use in each country.

This paper discusses the methodology used to rate countries in the ACEEE International Energy Efficiency Scorecard on energy efficiency efforts and outcomes in the buildings, industrial, and transportation sectors as well as on a number of national metrics. To demonstrate the rankings in action, we will use India as an example and compare its performance against the other 22 countries overall and in each of the 4 evaluated categories. Finally, we highlight some areas of improvement for the country.

INTRODUCTION

Energy efficiency is particularly important given that the global demand for energy has risen rapidly. The world's total primary energy consumption more than doubled between 1973 and 2013. In 2013 the world consumed 13,541 million tonnes of oil equivalent (Mtoe) of which coal, oil, and natural gas supplied 81% (IEA, 2015). Global energy demand is projected to grow another 30% by 2040 (IEA, 2016). Yet energy efficiency remains massively underutilized globally despite its proven multiple benefits and its potential to become the single largest resource for meeting growing energy demand worldwide (IEA 2014a)

In an effort to understand how efficiency factors into national energy policy, the 2016 International Energy Efficiency Scorecard examines the energy efficiency policies and performance of 23 of the world's top energy-consuming countries.[1] Together these countries represent 75% of all the energy consumed on the planet and accounted for over 80% of the world's gross domestic product (GDP) in 2013 (World Bank, 2016a, 2016b).

The Scorecard serves two primary purposes. First, it presents readers with a basic comparison of energy use and efficiency policy efforts in the top energy-consuming countries. Second, it identifies a number of best practices and policies that countries can implement to take advantage of untapped efficiency potential.

METHODOLOGY

We used 35 metrics to evaluate each country's national commitment to energy efficiency as well as its efficiency policies and performance in the buildings, industry, and transportation sectors. The 23 countries included in the report are among 25 of the largest energy-consuming economies in the world. Table 1 below ranks the energy use of the 23 countries evaluated.

Table 1: Country Rankings by Total Primary Energy Consumption

COUNTRY	TOTAL PRIMARY ENERGY CONSUMPTION (KTOE)
China	3,009,472

[1] We looked at the top-25 energy-consuming countries, but could not obtain enough data on two of them (Iran and Ukraine) to include in the Scorecard.

US	2,188,363
India	775,445
Russia	730,890
Japan	454,655
Germany	317,658
Brazil	293,683
South Korea	263,828
France	253,323
Canada	253,198
Indonesia	213,641
Saudi Arabia	192,181
Mexico	191,274
UK	190,952
Italy	155,372
South Africa	141,271
Thailand	134,065
Australia	129,141
Spain	116,727
Turkey	116,485
Taiwan	108,631
Poland	97,589
Netherlands	77,391

Source: IEA, 2016b

Whenever possible we collected data and indicators on energy consumption and energy efficiency policy from centralized, internationally recognized sources such as the IEA, the World Bank, the World Energy Council, the Organization for Economic Co-operation and Development (OECD), and the International Council on Clean Transportation (ICCT). We supplemented this information with country-level research by ACEEE staff. We sought the counsel of in-country and subject-matter experts by circulating data requests to confirm that we had accessed the most accurate information.

Metrics are either policy or performance oriented. Policy metrics are qualitative and evaluate whether or not a country has a specific policy in place (e.g. fuel economy standards). Performance metrics are quantitative and measure energy use or energy intensity either across the economy as a whole or within a particular sector. Performance metrics in this report do not measure the performance/enforcement of specific policies.

The maximum possible score for a country was 100. We awarded up to 25 points in each of the 4 categories: national efforts, buildings, industry, and transportation. Point allocation is split 60/40 between policy and performance. This weighting reflects the fact that the performance metrics in part measure factors other than energy efficiency such as the local climate's impact on the degree to which buildings are heated or cooled. We awarded the highest score available for a given metric to at least one country, which means that if any country were to emulate the top practices and results in each metric, it could obtain a score of 100. (However no country scored full points on all the metrics, indicating that all of them have room for improvement.)

Finally, to a small extent our analysis includes policy efforts that emerge from subnational governments where such policies affect the country as a whole (e.g. state-level building codes in the United States or Canada's EnerGuide building labelling program, which has a wide reach in the country). These efforts can sometimes be as effective as or even more effective than national policies. However their relative importance varies among nations, and the widespread collection and analysis of state, local, or regional information was beyond the scope of what we intended the International Scorecard to achieve.

While this is the methodology we settled on for the 2016 edition of the Scorecard, we acknowledge that our methodology could have used a variety of different metrics or different relative values for the metrics, which would have resulted in changes in the rankings. Similar efforts to evaluate energy efficiency policies and progress at the national level exist however the methodological approaches remain very varied. The World Bank Regulatory Indicators (RISE) for Sustainable Energy report is one such effort. The RISE analysis is a policy-only scorecard that uses a set of indicators to help evaluate national policy and regulatory frameworks for sustainable energy (World Bank 2016c). Energy efficiency is one of 3 energy pillars that are evaluated. The other two are energy access and renewable energy. Unlike the ACEEE International Energy Efficiency Scorecard, RISE does not evaluate the efficiency in the Transportation sector.

The other big efficiency ranking effort that has appeared in recent years is Europe's ODYSSEY-MURE Scoreboard. This scoreboard scores energy efficiency performance and policies separately for all European countries across multiple energy sectors (households, transport, industry and services). It relies on detailed annual energy efficiency reports each country submits to the European Union (EU) – data that is often not available for non-EU countries. Neither of the two efforts above combine policy and performance metrics to come up with a single rating system, which the International Energy Efficiency Scorecard does.

It is challenging to find a methodology that adequately captures energy efficiency efforts and allows for comparison across a range of countries. Physical factors such as geographic size, climate, elevation, and availability of natural resources determine to a great extent the energy a country uses. Climate heavily influences the energy used for heating and cooling buildings, while land area and topography affect energy used for transportation. Economic structure is another factor that governs energy use and demographic composition and population density also affect overall energy consumption, as do other social factors such as income levels and energy inequity. These conditions are difficult to control for, and we were not always able to account for them in our scoring methodology. In general we made only modest adjustments to raw data to enable basic comparisons across countries. Specifically, we adjusted building energy consumption for national average heating and cooling degree days and adjusted industrial energy consumption to reflect the same subsector balance between countries.

Our methodology was also crafted around consistent and accessible data. Not all countries track data specific to energy efficiency, such as the energy consumption per square foot of residential-building area or the energy intensity of freight transportation. In some cases our choice of metrics to cover key aspects of energy efficiency and energy use in each sector was limited by a lack of data consistency.

Table 2 shows the 35 metrics and their associated point allocation. Scoring criteria performance metrics are based on natural cut points in the available data. Criteria for policy metrics are much more subjective but based on expert opinion about best practices and are reviewed by country experts to ensure that scoring does not penalize countries for any reason.

Table 2: ACEEE International Energy Efficiency Scorecard Metrics and Points

METRIC	METRIC TYPE	POINTS
National Efforts		
Change in energy intensity between 2000 and 2013	Performance	6
Spending on energy efficiency	Policy	5
Energy savings goals	Policy	3
Efficiency of thermal power plants	Performance	3
Tax credits and loan programs	Policy	2
Spending on energy efficiency research and development	Policy	2
Size of the energy service companies (ESCOs) market	Performance	2
Water efficiency policy	Policy	1
Data availability	Policy	1
Buildings		
Appliance and equipment standards	Policy	5
Residential building codes	Policy	4
Commercial building codes	Policy	4
Building retrofit policies	Policy	4
Building labelling	Policy	2
Appliance and equipment labelling	Policy	2
Energy intensity in residential buildings	Performance	2
Energy intensity in commercial buildings	Performance	2
Industry		
Energy intensity of the industrial sector	Performance	6
Voluntary energy performance agreements with manufacturers	Policy	3
Policy to encourage energy management	Policy	2
Minimum efficiency standards for electric motors	Policy	2
Mandate for plant energy managers	Policy	2
Mandatory energy audits	Policy	2
Investment in manufacturing research and development (R&D)	Policy	2
Share of combined heat and power (CHP) in total installed capacity	Performance	2

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Policy to encourage CHP	Policy	2
Agriculture energy intensity	Performance	2
Transportation		
Fuel economy standards for light-duty vehicles	Policy	4
Fuel economy of light-duty vehicles	Performance	3
Fuel economy standards for heavy-duty tractor trucks	Policy	3
Vehicle miles travelled per capita	Performance	3
Freight transport per unit of economic activity	Performance	3
Energy intensity of freight transport	Performance	3
Use of public transit	Performance	3
Investment in rail transit versus roads	Policy	3
Total Points	Policy	100

RESULTS

Germany earned the top spot this year with a score of 73.5 points. Closely following were Japan and Italy, tied for second place with a score of 68.5. The lowest-scoring country was Saudi Arabia with a score of 15.5 points. Brazil and South Africa rounded out the bottom three, although with significantly higher scores of 32.5 and 33 points, respectively. India earned a place in the middle of the pack, in 14th place. For a number of the lower-scoring countries, particularly Saudi Arabia, scores were not necessarily representative of national efforts on energy efficiency because of problems we encountered in our efforts to find reasonable data. As Figure 1 shows, all countries have significant room for improvement, as even the top-scorer missed 26.5 points.

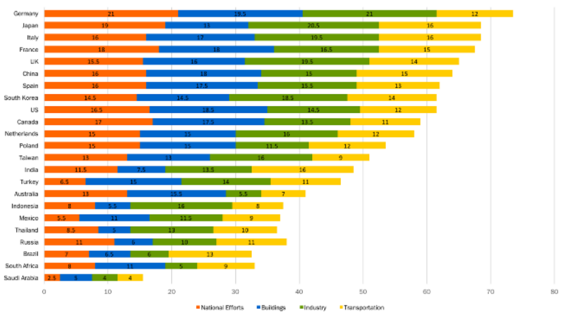

Figure 1: ACEEE International Energy Efficiency Scorecard Overall Scores and Rankings

While overall scores are informative, a look at the breakdown in how countries score on individual policy versus performance metrics is also revealing. We see different leaders emerging when we rank countries according to the policy-related metrics. Table 3 highlights these differences.

Table 3: Policy vs Performance Metric Rankings

COUNTRY	POLICY METRIC RANK	PERFORMANCE METRIC RANK
Australia	16	21
Brazil	21	18
Canada	6	18
China	4	9
France	2	7
Germany	1	3
India	14	11
Indonesia	22	4
Italy	2	5
Japan	6	1
Mexico	20	15
Netherlands	11	13
Poland	12	9
Russia	18	15
Saudi Arabia	23	23
South Africa	17	22
South Korea	8	8
Spain	10	5
Taiwan	13	12
Thailand	18	20
Turkey	15	13
UK	8	2
US	5	15

Many EU countries scored the highest on policy metrics, along with China, the United States, and Canada. These countries are taking the most action on energy efficiency through policies and programs. The EU countries led for their buildings and industry efficiency policies, while the United States is a leader in the buildings sector. Most of the countries that scored well on the policy metrics have some sort of unifying national energy-reduction goal in place.

The performance metric rank shows a more mixed group of leaders. While the EU nations again did well, so did a number of less developed Asian countries such as Indonesia, largely because their economies are not nearly as energy intensive as some of their more

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developed counterparts. The EU nations that topped this list were more likely to do well on performance metrics because of their targeted energy efficiency policies. However, as discussed earlier, rating countries on their energy performance is very difficult given the number of factors that impact energy use and the vast differences in demography, climate, and economic conditions between nations. The combination of policy and performance metrics gives us a more complete picture of the progress a given country is making on energy efficiency.

CASE STUDY: INDIA

India ranked in 14th place overall in the 2016 rankings with a total score of 48.5 points. Table 4 shows how India scored on each of the 35 metrics used to evaluate countries on their energy efficiency policy and Figure 2 shows progress in each of the 4 sectors: national efforts, buildings, industry, and transportation.

Figure 2: ACEEE International Energy Efficiency Scorecard Overall Scores and Rankings

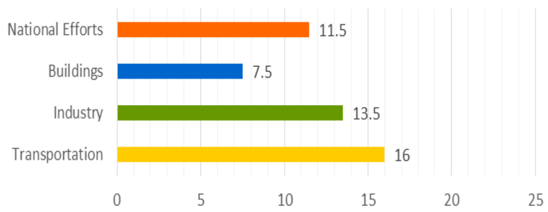

Table 4: Scores for India by Metric

METRIC	MAX. POINTS	INDIA SCORE
National efforts total	**25**	**11.5**
Change in energy intensity	6	5
Spending on energy efficiency	5	0
Energy savings goals	3	2
Efficiency of thermal power plants	3	0
Tax credits and loan programs	2	2
Spending on energy efficiency R&D	2	0
Size of the ESCO market	2	1
Water efficiency policy	1	1
Data availability	1	0.5
Buildings total	**25**	**7.5**
Appliance and equipment standards	5	0
Residential building codes	4	1
Commercial building codes	4	2.5
Building retrofit policies	4	0
Building labeling	2	1
Appliance and equipment labeling	2	1
Energy intensity in residential buildings	2	1
Energy intensity in commercial buildings	2	1
Industry total	**25**	**13.5**
Energy intensity of industry	6	0
Voluntary agreements with manufacturers	3	3
Mandate for energy managers	2	2
Mandatory energy audits	2	2
CHP installed capacity	2	0.5
CHP policy	2	2
Standards for motors	2	0
Energy management policy	2	2
Investment in manufacturing R&D	2	0
Energy intensity of agriculture	2	2
Transportation total	**25**	**16**
Fuel economy standards for light-duty vehicles	4	3
Fuel economy of light-duty vehicles	3	3
Fuel economy standards for heavy-duty trucks	3	0
Vehicle miles travelled per capita	3	3
Freight transport per unit of economic activity	3	0
Energy intensity of freight transport	3	2
Use of public transit	3	3
Investment in rail transit versus roads	3	2
Total	**100**	**48.5**

If we look at each of the evaluated sectors individually, India scores the greatest number of points in the Transportation section, tying with Italy and Japan for first place with 16 points. Countries generally did not score as well in transportation as in other sectors. The average score for this section was approximately 12 points out of the 25 points available. Passenger miles travelled per capita by passenger vehicles in India is the lowest of all 23 countries analysed. More than 65% of passenger trips made in India utilize public transit, with only a moderate level of government investment in rail versus roads. However, it is important to note that India's successes in the transportation sector are significantly influenced

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by the status of its economy than with its efforts to reduce energy consumption in both passenger and freight transportation.

In the National Efforts section, India ranks 15th with a score of 11.5 points. Spending on energy efficiency programs per capita as well as on energy efficiency research and development is very low. Additionally, the operational efficiency of thermal power plants in India is the lowest of any country analysed, largely due to an aging power plant fleet. Germany takes first place in this category with a total score of 21 and is closely followed by Japan and France with 19 and 18 points respectively. The EU countries stood out for having aggressive national energy savings targets as well as loans and tax incentives to encourage private investment in energy efficiency. Germany earned the maximum possible points for its high spending per capita on energy efficiency (higher than any country evaluated in the 2016 report), highlighting the government's dedication to reducing overall consumption. Japan's performance in this section results from high scores on the thermoelectric-efficiency metric as well as strong performances in R&D investment and tax incentives.

India's weakest performance comes in the Buildings sector with a total score of 7.5 points out of 25. With only 7 appliance standards in place, voluntary building codes, and no building retrofit policies, there is much room for improvement in this energy sector with regards to both performance and policy. Germany once again took first place in the buildings section with a total score of 19.5 points out of 25. Following closely behind were the United States, China, and France. Germany excelled in the building codes and retrofit categories, earning the top score for both metrics. The German government has also implemented mandatory building- and appliance-labelling programs. The United States earned the most points for its appliance standards. China's high ranking in the buildings section reflects the comprehensive policies the country has implemented to address its buildings-related energy use, including comprehensive appliance standards and labelling as well as its building codes for both residential dwellings and commercial facilities.

Finally, in the Industry section, India scored just over half points and ranked in 14th place. This category was dominated by EU countries with Germany receiving the top score with 21 points (out of 25 points), followed by Japan with 20.5 points. The United Kingdom and Italy tied for third with 19.5 points each. The top-scoring countries generally had lower energy intensities, a high percentage of industrial electricity generated by CHP or comprehensive policies in place to encourage CHP deployment, and voluntary government programs aimed at improving energy efficiency in partnership with businesses. The European countries did a consistently good job across all metrics, and they stand out for their voluntary agreements and mandatory energy audits for facilities.

POLICY RECOMMENDATIONS

To more effectively compete on the global energy efficiency stage, India could target the implementation of a few key policies that have a large energy efficiency potential.

Building energy codes and retrofit policies - The country could further bolster its voluntary energy codes for both residential and commercial buildings by adding requirements for existing residential and commercial buildings. Globally the existing building stock tends to be old and inefficient, providing a tremendous opportunity for energy savings. Countries can more fully capture building energy savings by adopting policies to require improved efficiency during a building redesign or retrofit.

India could also focus on making building codes mandatory for new buildings, as much new construction is likely as India's economy grows.

Appliance and equipment standards and labelling – Mandatory appliance standards and labelling go a long way to helping consumers make educated decisions about purchases. National appliance and equipment efficiency standards assure a minimum level of energy efficiency for household and commercial appliances, providing savings for consumers and businesses. Labels increase the salience of energy efficiency at the point of purchase and encourage buyers to factor in energy savings into their decision matrices. With only 7 appliance groups covered by a minimum energy performance standard, and only 4 that require labels this is a largely untapped area of efficiency potential for India.

Heavy-duty fuel economy standards – Freight vehicles in India account for approximately 60% of on-road diesel use. This represents a significant untapped energy efficiency opportunity in the transportation sector (IEA 2015b). While the country has recently adopted fuel economy standards for passenger vehicles, no standards exist for heavy-duty vehicles. Recently adopted programs in the United

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States, Canada, Japan, and China can serve as examples to India. The US has finalized phase 2 of its heavy-duty program which will combine with phase 1 to reduce heavy-duty fuel consumption by almost 40% by 2027.

India's recent recommitments to the Paris agreement and their subsequent INDC submission will hopefully lead to the implementation of a range of energy efficiency policies as a means to reach ambitious greenhouse gas reduction and energy use targets. The International Scorecard can be used as a resource to help identify additional areas for improvement in India and possible best practices.

CONCLUSION

The 2016 International Energy Efficiency Scorecard compares energy use and energy efficiency policies among 23 top energy consumers in the world to give readers a bird's eye view of the energy efficiency policies and progress in each country. The rankings are dominated by European Union countries such as Germany, Italy, France, and the United Kingdom, and by East Asian nations such as Japan and China.

Lower scoring countries have the opportunity to build energy efficiency into their continued economic growth by implementing policies in their industrial, buildings, and transportation sectors and can use the Scorecard as a guide. Nations can learn from one another by emulating best policies, practices, and performance. More-developed countries have a responsibility to lead by example and implement ambitious policies that will further reduce energy consumption.

Additionally, one of the primary barriers to understanding energy use and efficiency policy progress is a lack of access to accurate data. The Scorecard hopes to encourage countries through its rankings to make this data publicly available to improve their overall rankings and create a more robust ranking product.

While energy efficiency can be a challenging concept to evaluate, the ACEEE International Energy Efficiency Scorecard has used an approach that combines both policy and performance metrics to provide a general picture of energy use and energy efficiency policy at the national level and to provide countries with an interest in addressing energy consumption with a set of best practices.

RESPONSE TO COMMENTS

Methodology and Point Allocation for Metrics

As mentioned in the body of this paper, the scoring methodology for the ACEEE International Scorecard attempts to provide an overview of energy efficiency policy and energy use in 23 of the largest energy-using countries in the world. Therefore, we prioritize policy metrics that have significant efficiency potential and are achievable in our evaluated economies in addition to performance metrics that track the subsequent changes in energy use.

For each metric, we create an individualized scoring system that is based on best practices, expert opinion, or in the case of quantitative metrics, natural cut points in the data. At least one country earns the maximum number of available points in each metric. Points are awarded to other countries relative to the top-scoring nation. In general, we award a larger number of points to policies that have the most energy efficiency potential. For example, the energy efficiency potential embedded in appliance and equipment standards is significant and therefore, this metric is awarded 5 points out of 25 in the buildings section of the analysis. We ensure that countries are not unfairly penalized in our analysis by vetting our methodology with in-country experts

Additional details on the specific methodologies used to award points for each metric can be found in the 2016 International Energy Efficiency Scorecard report.

India's Transportation Score

The paper highlights that India's successes in the transportation sector are largely a reflection of the level of economic development rather than active efforts to reduce consumption in both passenger and freight transportation.

As we have discussed, energy use is affected by many more factors than efficiency. However, given that the goal of the ACEEE International Energy Efficiency Scorecard is to provide a high-level view of energy use and efficiency policies, we do not adjust country data for any of these factors unless absolutely necessary. Additionally, the Scorecard does not attempt to evaluate enforcement of policies and it is unclear to what extent transportation policies (e.g. fuel economy standards) in India are being monitored.

Data Availability

Encouraging countries to start collecting energy efficiency data and making it more widely and freely available is an underlying goal of the ACEEE International Energy Efficiency Scorecard. In addition to publishing the Scorecard report every two years, ACEEE releases a companion self-scoring tool that allows interested countries to submit data to us and rank themselves against our evaluated countries. This self-scoring tool was the main reason we were able to include Taiwan and South Africa in our 2016 rankings and also points us in the direction of new and useful data sources for future iterations of the International Scorecard. The Conclusion section has been adjusted to reflect this point.

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EMERGING ENERGY EFFICIENCY INNOVATION TRENDS IN INDIA: THE BIG PICTURE

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Keywords: Energy Efficiency, Innovations, Ecosystem, Policies, Climate Change

ABSTRACT

The paper looks at UNIDO programmes in India for cleantech innovations and explores some of the best examples of innovative start-up concepts. India is now witnessing a steady emergence of energy efficiency (EE) innovators who are bringing innovations to the table, with overlapping linkages to wider resource efficiency. Many of these innovators are first- generation entrepreneurs, often backed with advanced technical training and some work experience. This paper presents a perspective on, what drives these innovators to venture out to be entrepreneurs? What are the enabling and stimulating factors that spur EE innovations? What does it take Indian industry to create conducive environment and take it forward and catalyse innovations in energy efficiency? The paper captures learning from UNIDO's Global Cleantech Innovation Programme and stakeholder experiences which provides insight into challenges to commercialize the innovations and address the above questions.

INTRODUCTION

Efficient and clean technologies can lower costs and reduce environmental impact, and are already driving the deployment of renewable energy and energy efficient technologies across the globe. Technology innovations are playing a critical role in enabling access to modern energy services while also improving the efficiency of the existing energy systems. The UNIDO (United Nations Industrial Development Organization) efforts are geared to drive sustainable industrial development in developing countries and economies in transition. Hence UNIDO recognizes the importance of cleantech innovation in these emerging markets, driven by demand, at the lowest possible cost, that could accelerate access to affordable, clean energy for low-income and middle-income populations. To this end UNIDO puts great emphasis on cleantech innovations in achieving United Nation's Sustainable Development Goals (SDGs) - SDG 7 emphasizes sustainable energy for all, SDG 9 is to build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation, SDG 11 is for sustainable cities and communities, and SDG 13 for addressing climate change (VEF 2017). Achieving such bustling innovation-economies would require functioning ecosystems spearheaded by Start-ups and entrepreneurs, and supported by research institutions, companies, investors, and Governments, thereby driving the SDGs and Paris Agreement goals.

Some of these objectives are being realized through UNIDO's Global Cleantech Innovation Programme (GCIP), designed for SMEs to leverage the power of entrepreneurship to address the most challenging energy and environmental problems. GCIP identifies and nurtures cleantech innovators and entrepreneurs besides enabling local innovation ecosystems. The crux of GCIP is the 'Accelerator' programme that aims to fast-track start-ups. Over an 8-month period, the cohort of start-ups chosen through a competitive process gets the opportunity to work with a group of national and international mentors to help them move up with their business. The biggest value prospective for these start-ups is the mentor network. A network of senior executives from cleantech industries, seasoned entrepreneurs and angel and venture capital investors play a critical role in vetting their business plans. At the end, besides a gaining a solid insight of their target markets, GCIP enables these start-ups to pitch to investors, and other partners who can further their business.

For this paper, learnings from the GCIP programme in India are considered. The paper explores some of the best examples of innovative start-up concepts and the cleantech ecosystem in the country. India is nowwitnessing a steady emergence of EE innovators who are bringing game-changing innovations to the table, with overlapping linkages to wider resource efficiency, especially under the climate change regime. The paper thus will look at some of the experiences in the country to understand the energy efficiency innovations in the overarching cleantech realm, enabling policies, institutions, and markets,

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besides reflecting up on the experiences of countries who have traversed these roads and have cemented cleantech market transformations.

CLEANTECH INNOVATIONS IN SMES

About 80% of the industrial enterprises in India are Small and Medium Enterprises (SMEs) with less than INR 10 Crores of assets. Numerous studies have shown that resource efficient and cleaner production can drive their competitiveness and reduce their environmental impacts. To this end UNIDO recognizes that SMEs can play dual roles in cleantech market transformation, as they can don the roles of both cleantech entrepreneurs and end-users. Hence the GCIP programme was designed to work with SMEs in driving clean technology innovations and services. In India, the GCIP programme was launched in May 2013, in collaboration with the Ministry of Micro Small and Medium Enterprises. Over the last three years, GCIP India programme shortlisted and mentored 69 cleantech entrepreneurs/start-ups working in four technology categories namely Energy Efficiency, Renewable Energy, Waste Beneficiation, and Water Efficiency. These innovators were trained and mentored by a wide network of technology and business mentors, spread across the country - on the sustainability and viability of their technology and business models. Thus, innovators gain better insights into the commercialization of their products. GCIP also provides national and global platforms for these innovators to reach out to wider stakeholder communities.

UNIDO's experiences working extensively with SMEs show that entrepreneurship thrives in countries where there is minimal red tape, strong rule of law, ready access to venture capital, government funding and a vibrant support network for entrepreneurs (GCIP, 2016). Experiences from developed countries indicate that with appropriate government policies and dedicated support structures, SMEs can thrive as critical catalysts to leapfrogging economies to low- carbon economic transitions. The GCIP programme hence collaborates with national policy makers for strengthening the supportive policy framework for SMEs and entrepreneurs and as well catalyses investment by bringing wider stakeholder interactions and tangible partnerships.

Empirical research shows that small-scale technologies and services and newer production processes are found to have the greatest potential to create about 50% of emission reduction (Anbumozhi et al, 2016). Consequently, IPCC puts onus on the role of low-carbon technologies and services in reducing and stabilizing greenhouse gas (GHG) emissions cost efficiently. SMEs thus have a critical role to fulfil in clean technology development and deployment across industry verticals and value chains.

CLEANTECH LESSONS FROM THE FORERUNNERS

Favourable environs are critical for a cleantech entrepreneur to drive the technology evolution from lab to demonstrated prototypes to commercially ready products. Migendt (2017) scours through various studies and shows the systemic interdependencies of conducive policies and access to finance that influence the innovation-ecosystem. Innovation policies could stimulate institutional investors (like private banks, insurance companies, investment, and pension funds, that scout for long term investment and stable returns) by mandating investments in these sectors. When there is an absence of such policy agenda investments are sought from other sources like Venture Capitalists (VCs) that bring early stage growth equity capital with a huge risk/return profile, while Private Equity (PE) offers late stage expansion equity with lower risk/return profile, and others.

Globally the cleantech world has been mired with traditional challenges in deploying technology innovations. Cleantech start-ups are generally characterized by slow scalability, asset heaviness and slower payback period, hence policy interventions have played a key role in creating a market-pull. In his examples from Germany and US, Migendt (2017) shares the experiences of forerunners in the Cleantech market transformation. Germany's political will and social commitment to sustainability has been the overarching driving force to their fast-paced success in the cleantech space. Hence stable regulations played an important role in creating market pull- mechanisms (like feed-in tariff and cash rebates) that have been critical to solar and wind energy market transformation. Such long-term and reliable measures fostered the demand-side for cleantech markets, hence driving innovations. The US showed that private investors like VCs can play critical roles in helping emerging markets and viable business models and thus play a key role in cleantech market transformation (*ibid*). An MIT study showed that over 2006-08, private equity worth over USD 25 billion was invested in cleantech, primarily by the VCs in Silicon Valley, USA. This period coincided the era of peak oil prices and increased global dialogues on climate change action among nations governments that led to various green policy initiatives and fast paced technology innovations worldwide (Gaddy et al, 2016). These VC investments went to companies working on new solar panels, batteries, biofuels, others. Figure-1 shows global PE and VC investments in cleantech over the decade

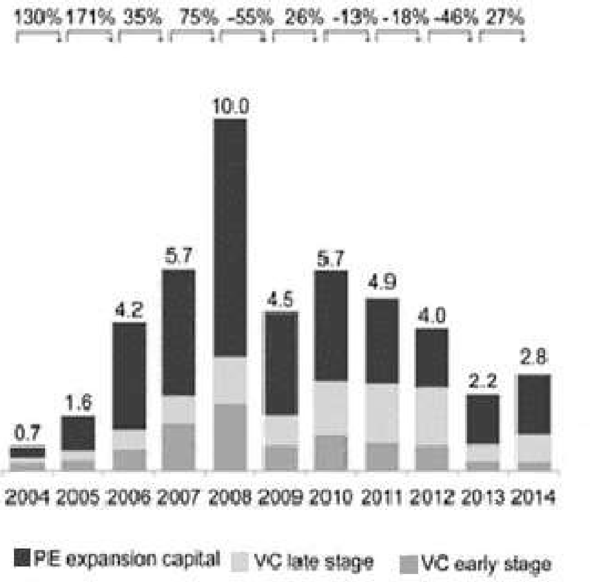

Figure 1: Global VC Cleantech investment trends (Migendt, 2017)

Cleantech development needs time and money to tap into target markets. Start-ups risk the 'Technology Valley of Death' that hovers in the early stages of technology development especially when the entrepreneur struggles to find capital to develop a commercially viable prototype. The next big chasm appears in the commercialization phase, when the start-up is ready to scale up, but fails, leading to 'Commercialization Valley of Death' (Jenkins & Mansur, 2011). Setting-up production facilities for scaling up became exorbitant in many cases and the period was also met with the glut of cheaper alternatives in the commodity markets. According to Bloomberg, much of the private equity in the peak of cleantech investments in the US were spent on materials and manufacturing processes; i.e., about 80% was spent on deployment of cleantech infrastructure and value chain enablers (*cited* in Bhattacharyya & Maheswhari, 2014). This left many start-ups with very less working capital for any other activities to invest, like R&D, expanding sales forces etc.

Once in market, these innovations compete with established technology, and tend to lose out in procurement processes scripted by 'cost terms' and not in terms of 'efficacy'. Thus, the paybacks period turned out to be longer for the cleantech sector to the disappointment of the VCs. Gaddy et al (2016) assess the loss to the US cleantech sector; the sector saw USD 5 billion invested alone in 2008 but dropped to USD 2 billion by 2013. Thus only 24 cleantech companies were founded in 2013, compared to 75 companies in 2007. The period saw more than 50% of the investment not yield returns. Figure-1 shows a jump in cleantech investments over 2006-08 – this period is sometimes thought to mirror newfound global climate consciousness and opportunities for cleaner technologies. However, the cleantech sector investments also reflected the global meltdown of the financial sector, taking a nosedive in 2009. Early-stage VC investment market took the biggest hit and this changed the investment landscape in cleantech. Today early-stage start-ups struggle the most to obtain funding such that in 2016, 87% of total cleantech VC funds went to late-stage investment, i.e., more companies that were near or at profitability (Saha & Muro, 2017). This shows that only a few new cleantech technologies are getting past the early stage such that even potentially disruptive new technologies might never be brought to markets.

Despite such setbacks, the cleantech sector managed a comeback in the global agenda for keeping the average temperature rise below 2°C. The Paris Agreement that came into force in 2016 puts greater emphasis on early stages of technology cycle and brokers for climate technology finance for research and development, besides tech transfer (UNFCCC, 2016). Despite the challenges, over the last decade the cleantech sector has slowly grown and diversified from cleaner energy technologies to those that increase performance, productivity, and resource efficiency. This broadens the scope and opportunities of risk-taking cleantech start-ups with the agenda to commercialize their clean-technology innovations.

ENERGY EFFICIENCY ENTREPRENEURSHIP AND INNOVATION IN INDIA: GCIP INDIA LEARNINGS

The Global Cleantech Innovation Index 2017 ranks India at the 29th position in its 40-country list of nations (GCII, 2017). The report, which looks at countries' potential to produce entrepreneurial cleantech start-ups and commercialise cleantech innovations over the next 10 years, points out to a big lull in overall innovations in India, despite strong cleantech innovation drivers. Yet the report finds that Indian entrepreneurs bear a positive outlook at the opportunities for cleantech innovation, primarily linked to the robust renewable energy investment in the country. India saw FDI worth USD 14 billion (INR 90,841 crore) invested in the RE sector over 2013-16, while government incentives up to USD 1 billion were made available (capital cost support for setting up projects, generation-based incentives etc) to the sector (Clean-Technica, 2016). Analysts point out that India's pledge to exponentially increase its renewable energy capacity to 175 Giga Watt (GW) power by 2022 has boosted investor confidence and made way for cheaper financing.

The cleantech space provides similar promise of reducing fossil fuel consumption and reducing greenhouse gas emissions. Given the myriad ways in which energy is utilised, energy efficiency finds applications across the sectors and technologies. Energy generation, distribution, and use, today, smugly fit together with energy efficiency and digital disciplines. Energy efficient appliances and services are integral in strengthening clean energy discourses where technologies can monitor and moderate energy use. Application of efficiency needs to happen in other spaces where energy conversion and energy wastage takes place. Some firms have forayed into this space without much success. If UNIDO's GCIP India experiences are yardstick to cleantech innovation trends in India, it can be safely said that greater awareness about Climate Change and the Bureau of Energy Efficiency's (BEE) effort to drive energy efficiency in the large industries must have to some extent trickled down to SMEs and have encouraged more entrepreneurs to venture out. About 40% of technology start-ups and entrepreneurs mentored in the GCIP India programme were across cooling appliances, energy use efficiency and efficiency in process applications. In the following discussions, we highlight the emergence of cleantech entrepreneurs and capture their challenge in replicating and scaling up the market, besides sharing insights of the ecosystem.

High-efficient Ceiling Fans: A Mumbai based start- up founded by a core team of IIT-IIM graduates in 2012, all in their 20s, have applied unique algorithm to the electronic control systems and developed ceiling fans that are highly energy efficient and consumes 65% less electricity compared to ordinary fans available in the market. Their inspiration lies in the energy saving opportunity in the ceiling-fan market of INR 4,000 crores (USD 615 million) where annually four million fans are sold in India. These fans are priced at almost double the cost of an average fan. The start-up points out that the initial cost of their fan is easily recovered within a year and this is possible within a few months in case of use in industries. This is achieved by addressing two important aspects, especially in small-scale industries like Ceramic clusters which use large number of standard ceiling- fans (of 75-80 watts). Fans run for 24 hours around the year for drying processes (and are shut down only for maintenance). Further these fans are also replaced every 12-15 months because of overheating of motors.

By offering 28-watt energy efficient fans (in comparison to a standard 75-watt fan) with 3-year guarantee period, the start-up assured the Ceramic manufacturer reduced energy costs (by more than half) and extended longevity of the product. These attractive paybacks enabled the start-up in getting 500 installations with its first Ceramic customer and now finds more interests from other ceramic industry manufacturers. Thus, aggregation of demand in industrial sectors which traditionally use fans for drying and cooling will be pivotal in the success of the start-up. Hence the team is aspirational that their innovation has the potential to emulate the success of LED lighting market in the last 5 years, in commercial, and residential sectors as well. Given the large energy saving potential their product offers, the start-up has been able to relatively scale up its production with a fast-paced demand, while maintaining the quality (with failure rates less than 1%) and is now working towards developing a strong and scalable sales network. The team feels that creating a strong brand value is critical as 80% of the ceiling fan sales happen with retail customers.

Yet, the start-up faces challenges being a new entrant and because of their lack of experience in Ceiling Fan manufacturing sector. Despite their sound knowledge and access to technology, owing to the absence of an innovation ecosystem in the country, the cost and time for building a prototype was high. This also affects their continued R&D to bring in more efficiencies and the team's objectives to diversify into other areas of technology. Further, there is always the constant challenge in ensuring product quality with the supply- chain vendors, given the poor precedence for standards in the ceiling-fan

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industry. The current efficiency benchmark by the star-labelling scheme in India pegs 5-star fans (highest energy efficiency category) at 50 watts. Hence, the start-up finds itself pitting against established manufacturers and supply chain that caters to the larger market. However, by aggregating demand, the start-up has been able to demonstrate superior energy savings and offer competitive product prices – which is a model that the team is pursuing aggressively. The team has recently supplied 5000 units to an SME industry and the start- up is also participating in a large demand-side management programme with a leading utility for a ceiling-fan replacement programme. With these developments, the team hopes to scale up manufacturing and thereby access VC funds with less hurdles.

Energy Efficient Moulding in Foundries: India is the third largest casting manufacturer in the world, producing an estimated 10.2 million metric tons of castings as per international standards. It caters to a wide set of industries across automobile parts, agricultural implements, machine tools, diesel engine components, pump-sets, and valves, to name a few. Casting is a very energy-intensive process such that energy use in the foundry sector is much higher than that of the organised large-scale sector. An established manufacturer ventured out to address its own need to replace Obsolete Compressed Air Operated Jolt Squeeze Moulding Machines that had only 30% power transmission efficiency. The resultant innovation was hydraulically operated High-Pressure Moulding Machines. The new machine delivers 4 to 5 times higher squeezing force than the traditional machines, and yet consumes 30% to 50% lower energy, and provides better finish to mould thereby reducing the rejections (and material loss besides time and energy). This machinery, apart from energy saving, would give access to MSME foundries to inaccessible technology upgradation, and improves their process, saves in the weight and rejections – which have a huge impact on their competitiveness. In marketing, this innovation to rest of foundries, the biggest hurdle was not of finance, but acceptance of the innovation among SMEs. The company points out that the sector is very conservative and reluctant to invest in an improved technology. Also, such technology upgradation among smaller foundries might be a challenge. Hence influencing the larger ones is an immediate priority as they might have the bandwidth to accommodate both efficiency offered, while improved working condition in the shop-floor shall play an important role in increasing the overall productivity of foundry systems and processes. However, as innovations are not common in the foundry sector, the key challenge remains in educating other larger foundries. Hence the team stresses that certifying energy efficiency of the product could play an important role in educating and creating awareness among the owners and operators. The credibility of such a certificate can be strengthened with the cooperation and acceptance of Tier-1 companies who are the biggest buyers will be important in influencing the value chain. Hence the team now puts much effort into educating the stakeholders in foundries about the economic benefits of a high-pressure moulding machine, which consumes less energy compared to the other technology. However, without a formal ecosystem for testing, validation and certification, an efficient product finds it is perennially difficult to penetrate the market and share the benefits with the user.

Radiant Cooling for Buildings: In the efforts to achieve energy efficient cooling in buildings, an entrepreneur based in Hyderabad recognized there was very little improvements to the use of air ducts for ‘cooling distribution’ and took up the challenge of changing the cooling distribution by using pipes embedded in the floor, or panels in the ceiling instead of air ducts, thereby reducing inefficiencies in cooling distribution and consequently cooling generation too. The innovation in the design of radiant panels and pipes provide 30-50% reduction in electricity consumption by the chiller units, thus eliminating the need for fan motors in air handling units (AHUs). By circulating chilled water through pipes embedded in the ceiling or floor, of commercial or residential spaces, radiant cooling eliminates the need for fan motors. In addition, conventional (air-based) cooling requires chilled water supply at a temperature of 7°C, whereas radiant cooling requires water chilled only to 16-18°C. This leads to additional electricity and commercial savings as the compressor in the chiller consumes less electricity by operating at higher temperature. With four patents filed in radiant cooling technologies, the entrepreneur estimates the potential market for radiant cooling technology at INR 20,000 crore/year (USD 2,500 million) across IT services firms, hospitals, educational institutions, industrial shop floors, aircraft hangars, etc., in India. A McKinsey study estimates that improving energy efficiency in buildings (new construction and retrofits in existing ones) in India can create savings of 2,988 MW, estimated at USD 42 billion per annum (*cited in* IISD, 2014). Thus, targeting commercial and industrial building facilities that need year-round air conditioning, the radiant cooling systems can play a critical role in addressing the fast-paced cooling requirements in the country. The entrepreneur shares that radiant cooling has the greatest potential to complement the efforts of Green Buildings rating systems that spurred the demand for energy efficient space cooling technologies. Despite the well-known split incentives from rapidly adopting energy efficient technologies in buildings, he points out that unless organizations such as the Indian Green Building Council (IGBC), and other stakeholders prioritize and orient the market for EE innovations, the building sector will continue to be plagued energy efficiency challenges.

These examples demonstrate that innovation in energy efficiency follow a different approach, especially in the SME sector. One of the leading energy efficiency experts and advisor to various industries in India, points out that for innovations to succeed in the SME sector it must be market driven – i.e., when end-user demand defines the innovation. The target market and the economics in adaptation of the technology, will playout in the consumers value proposition in adopting a technology – such that the market demand and the technology are wedded well where the pricing is right. Given the price sensitivities of Indian SMEs, historically various efforts to bring energy efficiency intervention into SMEs have not yielded the desired results. On the other hand, often 'exotic' technologies fail to capture and address the actual realities that SMEs face, despite being driven and funded by various bilateral and governments programmes. Emergence of young entrepreneurs bringing cleantech innovations in addressing the gaps, as noted in the section below, provides hope of a turn-around.

EMERGING INNOVATIONS BUSINESS MODELS

To understand the innovation ecosystem that is slowly and steadily evolving in India, we are considering here two examples of cleantech start-ups that were mentored under the UNIDO's GCIP programme. A start-up based in Mumbai provides Waste HeatRecovery (WHR) products and another based in Delhi National Capital Region offers Cold Storage for dairy and other perishable products.

Innovations responding to a clear market demand: The WHR start-up targets recovery of wasted heat in the industrial and commercial process and space cooling and heating market in India. The manufacturing sector, which constitutes mostly of SMEs that struggle with low productivity relative is estimated waste around 20%-50% of its energy input. Almost half of the energy used in a refrigeration cycle is expelled as waste heat and this is as high as 95% for air compressors close to 95%. The WHR start-up uses a patented design that the team fabricated to capture the current installed base of commercial and industrial chillers in India pegged at a market opportunity of USD 5 billion. This otherwise wasted energy can be recovered by heat transfer technologies and can be used for low-grade heat or pre-heating, saving valuable spend on fossil fuels such as coal, diesel, fuel oil and natural gas. The start-up's flexibility to provide improved design to the product are protectable and cannot be easily replicated. With its technology piloted in various industries the start-up has initiated early level dialogue with corporates such as Godrej, Thermax, and Kirloskar and are in discussion on working with them as Original Equipment Manufacturers (OEM) partners. Currently the start-up is engaging in direct customer sales while is panning out to shift sales towards ESCOs and OEM channels for greenfield installations.

The other start-up, mentored by the GCIP India, provides thermal energy storage for cooling & refrigeration power backup. In India, 40% of perishable produce (worth ~USD 10 billion) is wasted as Cold Storage solutions are not available for 90% of agricultural products due to inconsistent grid availability. To meet this Cold Storage demand would require 2TWh/year of electricity in India. The start- up's 'energy storage technology' stores electricity in cold medium such as water/ice, which provides more efficient and lower cost power backup for cooling than alternatives such as diesel generators and large electrochemical battery banks. Thermal storage does not need high start-up electric current (as the compressor is not turned on) and can have high storage capacity to meet the desired backup duration. This can be retrofitted to an existing refrigeration system for providing cooling during outages/non-solar hours. This patent pending technology is integrated with modular Cold Storage for farm produce and bulk milk coolers to provide round the clock cooling[1]. In these places, the grid power is available only up to just 7 hours,

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hence the Cold Storage is also integrated with solar for off-grid applications.

Nurturing evolving business models: Both the above cleantech start-ups are being incubated under Sangam Ventures, an early stage cleantech VC fund. Such incubation programmes play a critical role in providing technology and business mentoring for start-ups in which they invest in exchange of an agreed upon equity. In these cases, equity providers like Sangam provide incubation support, where they work closely with start-ups with an objective of helping the company 'exit the fund' successfully (such that investors recover their returns on investments)[2]. Sangam points out that while the market opportunity for both the products are high, their business models vary given the nature of their target markets. The WHR start-up's business model hinges on targeting those customers who need energy savings – whose energy use is either subject to scrutiny because of the cost or a regulatory need (for example under the PAT[3] scheme). The Cold Storage solution is addressing an energy service gap which arises from unreliable electricity supplied and the costs of energy service alternatives. In the case of the former one, policy signals from PAT and other energy saving policy and regulatory initiatives will continue to play a crucial role. Hence the WHR team finds an ideal partnership with ESCOs and can also behave like an off-the-shelf product. Since much of their targets are SMEs, ideally an ESCO model could help the solution penetrate its target market. ESCOs have already laid inroads into the energy saving markets in India where they offer comprehensive solutions and services to their customers to improve energy efficiency. For instance, recently, the Department of Expenditure under Ministry of Finance has decided to take up services of (EESL), to retrofit energy efficient appliances in all their premises across the country. This means more than 10,000 large government/private buildings will be retrofitted where EESL intends to bring in investments of around INR 1,000 crore by 2020[4]. Ideally such aggregation of demand via ESCOs should reach out to innovators who offer WHR solutions, energy efficient ceiling fans, efficient cooling, among others.

The Cold Storage solution addresses a niche sector, with a specific intent of replacing inefficient battery mechanism or polluting diesel generators or providing technology intervention. Further the Cold Storage market is heavily based on a services model, hence brand, distribution and service network is needed for wide-spread proliferation. Both these companies have robust technologies that OEMs could be interested. Sangam highlights that the investments in the Cold Storage solution is driven by its potential to integrate isolated villages into the agriculture supply chain. Understanding and addressing the famer's accessibility (system designed for off-grid and on-grid solutions, custom-fit), affordability (energy storage solution providing significant savings over diesel and other battery technologies) and above all, the reliability (the uses of cold storages to 100% without a need for expensive power back up solutions and product longevity) will be critical to the penetration of the product and better price discovery.

[1] Cold Storage (5-20 MT of farm produce stored in 4-16C temperature range) and bulk milk coolers (500-2000L of milk as per ISO cooling standards)

[2] The exit strategy is the VC's way of cashing out on its investment in a portfolio company. A fund will usually invest in a portfolio of ten to twenty start-ups over the first five years and harvest the returns in the remaining five years. Those returns materialize when a portfolio company is acquired by another firm or when it issues shares on a public market through an initial public offering

[3] Perform Achieve and Trade (PAT) is a mission by the Govt. of India for improving energy efficiency in specific industries via trading of energy saving certificates

[4] EESL's energy efficiency projects to bring in Rs 1,000 crore investment, India Infoline http://www.indiainfoline.com/article/news-top-story/energy-efficiency-projects-eesl%E2%80%99s-energy-efficiency-projects-to-bring-in-rs-1-000-crore- investment-117081200040_1.html accessed on 13 Aug 2017.

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THE WAY FORWARD

GCIP experiences have shown that when an investor examines a start-up business hinged on an innovation, ideally the start-up's performance, its ability to manage risk and its offerings' differentiated value proposition for competing in the dynamic business environment (locally or globally) - are scrutinised. Thus, VCs like Sangam invest in cleantech start-ups not necessarily only for the technology on the offer, but often in the ability of the company to come-up with more products that have large market potential, in the immediate future. In the case of the WHR start-up that offers heat recovery solution from chiller installation, Sangam has identified the team's technically ability to develop broader innovative solutions catering to energy conservation opportunities in comfort cooling, refrigeration, and cold-store solutions demands in the building and commercial installation market. Energy conservation in buildings is already a high priority to Bureau of Energy Efficiency and the electricity utilities in the country. Air-conditioning consumes almost one-third of the total electricity used in a building and is the second-most electricity guzzling equipment after lighting, in the country. Thus, positive policy signals play an overarching role in attracting investors and other equity providers and other stakeholders to participate and drive the innovation ecosystem.

GCIP experiences have shown that access to patented technologies within labs and R&D centres will be a game-changer for enterprising start-ups to explore and bring forth innovative energy efficiency solutions from laboratories to markets. A functioning innovation ecosystem would involve start-ups networked organically to R&D labs and academic centres, OEMs, Industry associations, financing agencies and others. The WHR start-up, discussed above, licensed the patented technology in a similar manner developed at one of the IITs. However, a 2015 report[5] by NITI Aayog raises concerns on the efficacy of accelerator and incubators programmes that are supposed to catalyse such networks. Even though many incubators are being housed in universities, science and technology parks, and R&D facilities, only a few of them have built on the linkages with the research climate in the universities. The report shared that prototypes of patented technologies available in these labs were not necessarily piloted or demonstrated. Further, the report shared that many incubators were not sufficiently connected to established corporates. Thus, both, incubators and their start-ups tend to lack exposure to 'real world' problems, and fail to generate productive solutions for current needs.

Access to finance is still a challenge for many innovators. India offers favourable cleantech-specific government initiatives for start-ups, like Start-up India and Make in India, driven by various EE and RE policies and ambitious GHG reduction agenda. Yet GCIP innovators share that much of the private equity was offered to mature companies that have demonstrated profitability. Start-up India, for instance has earmarked to provide INR 10,000 crore as VC funds to start-ups. Similarly, there is a host of initiatives (under the Department of Science & Technology, Technology Development Board, Department of Industrial Policy, and Promotion, NITI Aayog, just a few to name) some of them specially for cleantech start-ups. However, experiences shared by GCIP innovators show that compared to start-ups in other sectors (information technology, service delivery, demand aggregation) cleantech start-ups take longer time to achieve commercial success due to a lack of immediate demand from retail market and favourable mechanisms that help replication and scale up. Such time-lag puts VCs on a backfoot.

However, India's successful LED market transformation shines through as a hope for many EE innovators. As a super ESCO, EESL has demonstrated it success in aggregating demand through mass procurements bringing various players to compete in tender processes, thereby discovering robust pricing for LEDs, agriculture pumps and other energy efficiency appliances. As echoed by GCIP innovators above, an opportunity for energy efficient innovations in procurement processes are much aspired for; ESSL can thus hold the mast to India's cleantech market transformation, giving a breather to the innovators and building confidence in the investor communities.

The role of government in cleantech innovations and market transformation also needs careful treading. If experiences from forerunners are any reference for India, Migendt (2017) shares that the US has a large base of private equity providers with large funds at their disposal that can be steered to cleantech. Germany, on the other hand, has fewer PE investors leading to inadequate investment rounds for companies that are urging to grow. The role of extensive public investments has the danger of stepping on the toes of private

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sector entities and crowding them out. But, the public sector is necessary to provide subsidies for R&D, provide capital support for crash-dry SMEs and step-in when private entities steer away from some sectors. VC/PE investors may not be always interested in Cleantech businesses that are asset-heavy with larger lock-in period of funds. Such issues were witnessed by some of the GCIP innovators as well. Migendt uses the case of Tesla Motors in the US which saw a combination of long- term financial policy measures aiding innovations, early and growth stage private equity investments and accessible IPO markets enabled the start-up to scale- up and commercialize.

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