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Study on Evaluating Net-Zero Energy Potential for a Proposed Apartment Building

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Highlights

- The purpose of the study is to assess net-zero energy potential for a proposed apartment building.
- The study is conducted for a proposed G+12 apartment building located in Sonipat, NCR.
- After applying three different identified internal profiles (low-mid-high consumption) the BAU case EUI is in the range of 92 to 88.
- ECM's - IMAC MM 90% temp. setpoints, shading, NV, efficient envelope, efficient PTAC system were identified as energy conservative measures (ECM's).
- After all ECM's were applied one upon another the EUI is in the range of 37 to 31 (66% reduction from BAU case). Which gives a payback period of 8 months.

Abstract

The floor area of residential buildings in India is evaluated twofold (16.0 billion m2 to 31.6 billion m2) and the residential energy consumption is assessed to trifold (246 TWh/y to 748 TWh/y) between 2017 and 2030, as per NITI Aayog (2015). This development of residential floor space, combined with an increment in electricity production, leads to critical energy demand within the up-and-coming decades.

The purpose of the study is to assess net-zero energy potential for a proposed apartment building, suggest effective energy conservative measures, and see the financial achievability of the same by reporting the payback period and internal rate of return (IRR).

Keywords

Net-zero energy, Residential buildings, Internal rate of return, simulation, energy savings, incremental cost, Eco-Niwas Samhita.

Introduction

Background

India — the second-most populous (1.37 billion in 2019) nation of the world [1] - is anticipated to have the biggest population in the world by the year 2030 [2]. Concurring to the 2011 census information, India's number of households was 246 million with a population of 1.2 billion [3]. Under the 2011 average household measure (4.9) suspicion, there will be 307 million households in 2030.

Significance

The study would contribute in terms of providing the proposed option which can achieve net-zero energy residential building and its feasibility & added extra investment. The relationship between reduction in energy performance index (EPI) reduction, energy conservative measures (ECM's) & added extra investment will also help to understand/draw some conclusions for any building developers/contractors/architects.

Research objectives

- To find the IRR of net-zero energy residential buildings and to compare/analyze it with the savings with existing residential energy codes.
- To analyze the relationship between energy conservative measures, & added extra investment cost for net-zero energy residential buildings.

Scope of the study

The study will cover the economic feasibility of each energy conservative measure and the potential of photovoltaics at present state of art technology to combinedly achieve potential net-zero residential building. The plug load data to calculate equipment power density is gathered by conducting a survey and the study is done for a specific G+12 apartment.

Limitations and challenges of the study

- As the study is done for a specific building the results of this study might not represent/capture the entire residential building scenario.
- The study will propose energy conservative measures (ECM's) based on the climate and sensitivity analysis and reports IRR or the same. Hence the study doesn't capture all the possible ranges of ECM's.

Literature review

Development process for net-zero energy buildings

Net Zero Energy graph

A base case will be developed based on the architecture & service drawings, construction specifications, and usage schedules. After that the pathway to a Net ZEB is given by the balance of two actions:

- Reduce energy demand (x-axis) employing energy conservative measures (ECM's)
- Generate electricity as well as thermal energy carriers using energy supply options to get enough credits (y-axis) to achieve the balance.

In most circumstances, major energy conservative measures are needed as on-site energy generation options are limited, e.g. by suitable surface areas for solar systems, especially in high-rise buildings [4].

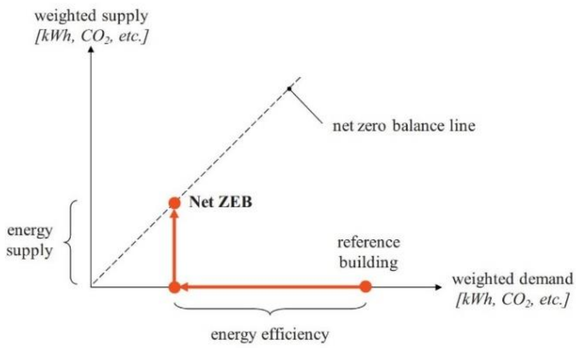


Figure 1 - Graph representing the Net Zero Energy concept

Building energy simulation input data

BES models require the input of building conditions, much of which is specific to a building or analysis objective, such as geometry, internal loads, system configuration, and control. Other input data is obtained from external sources, which define properties of building materials, system performance coefficients, and the local weather conditions [5]

Input data of the residential building's appliance usage is a critical element for the BES model as for the same the methods to collect appliance usage data have been gathered/studied.

Methods to collect appliance usages patterns

Among these strategies, it was expressed that in situ estimation can give high-quality comes about with point-by-point data on energy consumption and the usage pattern. In situ measurement was the strategy utilized in a few studies such as the end-use metering program (Sweden, 2005–2008), the family power overview (the UK, 2010–2011), and STANDBY control (France, 1997–1999), the REMODECE (12 European nations, 2006–2008). [6]

So, the proposed equipment/plug load survey is conducted via hand-given survey forms. The parameters collected were occupancy Density (W/m^2-person), lighting power density (W/m^2),& equipment power density (W/m^2). The electricity consumption of each type of appliance was theoretically calculated by formula.

Equation 1 - Electricity consumption

Electricity consumption (kWh) = power rating * working hours * number of items

Internal Rate of return (IRR)

Internal Rate of Return (IRR) is a financial metric that helps estimate the profitability of a potential investment. It is the discount rate that makes the net present value of the cash flows equal to zero. In other words, NPV equals zero. It is widely used in discounted cash flow analysis. It is ideal for analyzing capital budgeting projects. [7].

Equation 2 - Net present value

NPV = (Cash flows /(1+r)^n) – Initial investment

Where
r = IRR
n = time period.
The initial investment is the first investment made into the project.
Cash flows = All the cash flows during the period of investment.

IRR can't be used as a standalone measure for one project. One can use IRR to compare two projects/design options. A project with a higher IRR will be more desirable.

Methodology

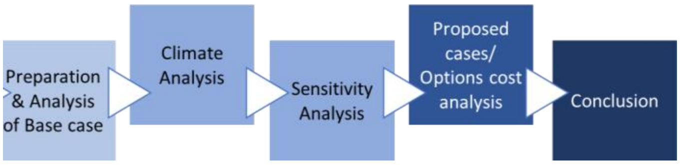


Figure 2 - Methodology

Part 01: Preparation & Analysis of Base case
The base case is developed by using proposed building architectural drawings, Equipment Plug load survey results (for internal conditions), building as usual (BAU) construction assemblies, and packaged terminal air conditioner (PTAC) as an HVAC system.
Base case results analysis: Rooftop PV potential analysis (to arrive at target EPI), Residential Daylight anatomy (RDA), Comfort hours (Heating/Cooling), Primary energy breakdown, energy consumption by different end uses, and ENS compliance check for BAU case.

Part 02: Climate Analysis
Environmental parameters chart (to understand the high humidity and high-temperature zones), Climate Categorization into nine modes (to arrive at potential thermodynamic strategy).

Part 03: Sensitivity analysis
The following sensitivity analysis is conducted to analyze/forward on design stages.

- Standardized regression coefficient (SRC) for the cooling load (kWh), SRC for the Heating load (kWh), SRC for total site energy (kWh), Comfort hours percentage vs Window open %.
- Once the design stages are generated, comfort hours percentage vs different design stages analysis is conducted by simulating without any HVAC system to analyze/compare comfort hours as per IMAC 90% acceptance band.

Part 04: Design stages/Proposed case cost analysis
For each option/case incremental cost is calculated upon BAU case, payback period, and internal rate of return (IRR) is calculated to analyze the feasibility of the option. Parametric analysis for the ENS compliance case analysis is done to demonstrate the savings & IRR of ENS compliance cases.

Part 05: Conclusion
Proposed design option – their savings, payback period, and IRR with further discussion.

Results & Analysis

Preparation & results from the Base case

Project Data

The location for the faculty housing is in Sonipat, Delhi. The As-Is case is modelled as the base case. The building has a total of Ground +12 floors.

The Equipment/Plug load survey is conducted to derive the electrical plug load (EPD) and Lighting plug load (LPD) values. A functional faculty housing (apartment) adjacent to the proposed apartment building is chosen for the survey as the occupants can be of the same economic class.

Table 1 - Building Typology

Building Type	Residential
Location	Sonipat, Delhi
Built-up Area	8,244 m^2
Number of Floors	Ground + 12
Floor Height	3.15
Window Wall Ratio (WWR)	18%
Orientation	E-W long axis
Floorplate	687 m^2

Table 2 - Climate Typology

Climate Type	Composite climate
Summer Months	March to June
Winter Months	November to February
Monsoon Months	July to October

Software/Tools used

Table 3 - Software's/Tools used

Energy simulation	EDLS Tas (version 9.5.1), DesignBuilder v6.1.6 (EnergyPlus v8.9)
Lighting simulation	LightStanza
Result's analysis	DesignBuilder results in the viewer, Microsoft Excel

Input values for the base case

Table 4 - Envelope values used for making the base case

Parameter	Value	Units
BAU Wall U-value	2.10	W/ m^2.k
BAU Roof U-value	3.70	W/ m^2.k
BAU Glazing U-value	5.70	W/ m^2.k
SHGC	0.70	Ratio
VLT	0.75	Ratio
Model Infiltration	0.70	ac/h

Weather file

For the entire analysis, the weather file used is,
"IND_DL_New.Delhi-Safdarjung.AP.421820_TMYx.2004-2018".
The weather file is downloaded for the source https://climate.onebuilding.org/WMO_Region_2_Asia/IND_India/index.html

Input values for the base case

The survey results/responses are used to make the schedules and input parameters /data like EPD, LPD, and occupancy density.

Three different profiles (low-mid-high consumption) were identified and are used to get the range of EPI's for BAU case and at each ECM's analysis. The Electrical power density (EPD value is changed in these profiles from 4W/m^2 to 7 W/m^2 (after adjusting no. of hours of usage).but the Lighting power density is kept as constant with 0.7 W/m^2 (derived from the LED usage response).

For all the service spaces like corridors/staircase and lift spaces, a scheduled EPD of 19 W/m^2 has been used. For the primary use areas (Living area/Hall, bedroom) PTAC system has been used as an HVAC system.

Best case results

Table 5 - Standard design results

Parameter	Value
Energy Performance Index (kWh/m^2.year) range	88 to 92
Unmet Hours (Cooling)	15
Unmet Hours (Heating)	0

Table 6 - Performance summary

Parameter	Value
Max. Heating Load (kW)	15.98
Max. Cooling Load (kW)	36.28

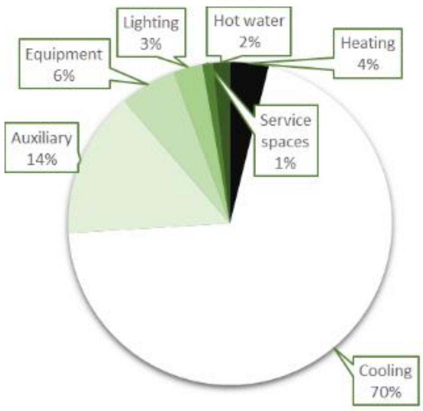
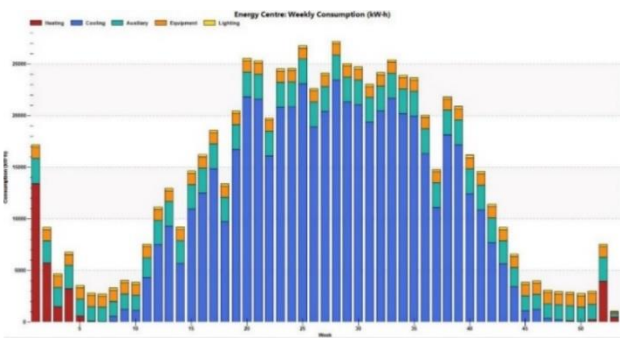


Figure 3 - Energy breakdown

Figure 4 shows the weekly energy breakdown, here equipment load has service spaces (corridor lift), Hot Water Consumption energy within it. A peak of cooling load in the months of March, April May, June, July, Aug, Sep, and peak of cooling load in the months of Dec, Jan is observed.

ECM which will reduce the predominant loads (Cooling & Heating) will result in a higher energy reduction.



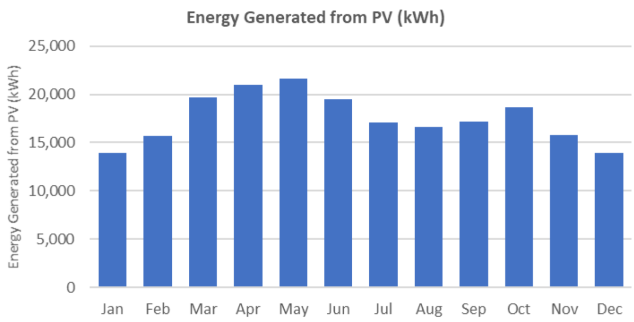


Figure 4 - Monthly energy Consumption (kW-h), Figure 5 - Rooftop PV generation

Renewable Potential (Photovoltaic generation)

To calculate Rooftop PV potential 80% of rooftop area is considered and for each month solar radiation of the surface (kWh/m^2) is calculated. 18% is chosen as the efficiency of the PV panel as per present technology. Figure 5 shows the PV generation for each month.

For the base case, the rooftop PV can offset 28% of the total building EUI, as per the generation if the EUI gets less than 26 (kWh/m^2.year) then the building becomes net-zero.

To calculate Rooftop PV potential 80% of rooftop area is considered and for each month solar radiation of the surface (kWh/m^2) is calculated. 18% is chosen as the efficiency of the PV panel as per present technology. Shows the PV generation for each month. 18% is chosen as the efficiency of the PV panel as per present technology. Shows the PV generation for each month.

Compliance check for the base case

The compliance for ENS of the apartment building is checked using the compliance check tool for ENS code (Version 1.6). The following are the details used and results from the tool.

Table 7 - Project Information

Project Name	Faculty Housing (Ashoka University)
State	New Delhi
City	New Delhi
Climate	Composite
Latitude	>= 23.5° N
Total No. of Residential Blocks	1

Table 8 - Dwelling Unit Details

S/No.	Type of Dwelling Unit	No. of Units	Carpet Area (m^2)	Total Area (m^2)
1	1 1BHK (Type 01)	47	50.0	2350.0
2	2 1BHK (Type 02)	14	54.0	756.0 3
3	2BHK	14	115.0	1610.0
4	3BHK	10	170.0	1700.0
Total carpet area (m^2)				6416.0

ENS Compliance Results

Table 9 - ENS results

S/No.	Requirement	Calculated	Criteria	Status
1	WFR_{op}	11.08	12.5	Non-Compliant
2	VLT %	80	27	Compliant
3	U_{roof}	1.8	1.2	Non-Compliant
4	RETV	20.25	15	Compliant

Observations

- WFR_{op} requirement got non-compliant status which will suggest that window wall ratio of the building should be increased, which is addressed above by daylight options.
- U_{roof} requirement also got non-compliant status where the U-value of the roof should be less than or equal to 1.2, which suggests having a roof assembly with insulation as an option.
- RETV for the base case not following the Eco-Niwas Samhita compliance, U-value of the wall & window can be further brought down to reduce energy consumption and to get ENS compliance.

Results from the climate analysis

Environmental parameters chart

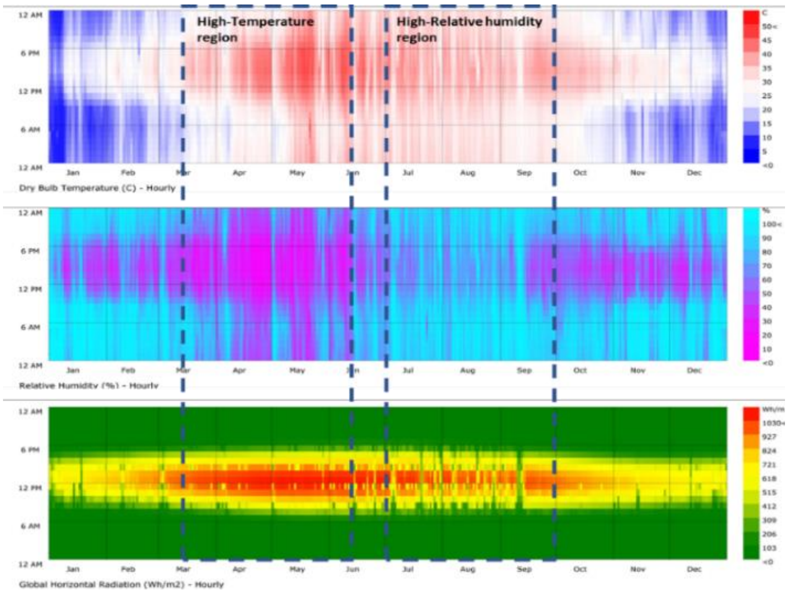


Figure 6 - Environmental Parameters DBT, RH & GHR,

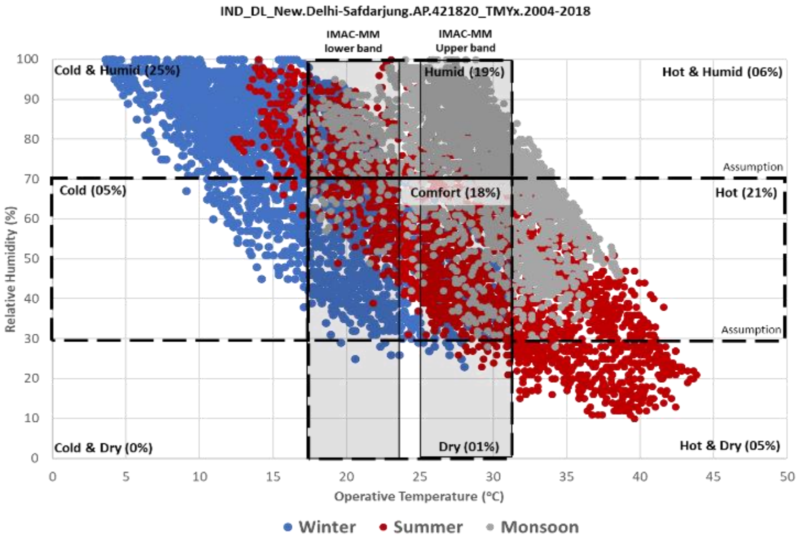


Figure 7 - Climate Categorization

Climate Categorization

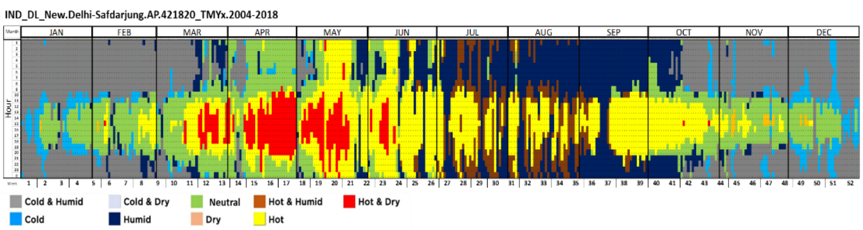


Figure 8 - Heat map showing the distribution of each mode

Observations

Table 10 - shows four major modes, percentage (%) during occupied hours, the required process to bring those modes to comfort bands, and the potential strategy by which it can be done.

Table 10 - Percentage of each mode during occupied hours & potential strategy

NO	MODE	%	REQUIRED PROCESS	POTENTIAL STRATEGY
1	Cold & Humid	25	Heating & Dehumidification	Electric heating coil, DX heating system
2	Hot	21	Sensible Cooling	Indirect Evaporative cooling
3	Humid	19	Dehumidification	Humidistat control, DX cooling system
4	Neutral	18	NIL	Mixed mode, DAOS
5	Hot & Humid	6	Cooling & Dehumidification	Indirect Evaporative cooling, DX system
6	Cold	5	Heating	Electric heating coil
7	Hot & Dry	5	Cooling & Humidification	Direct Evaporative cooling
8	Dry	1	Humidification	Direct Evaporative cooling
9	Cold & Dry	0	Heating & Humidification	Electric heating coil

Indian Model for Adaptive Model (IMAC)

IMAC mixed-mode buildings neutral temperatures were calculated using the IMAC assistant.

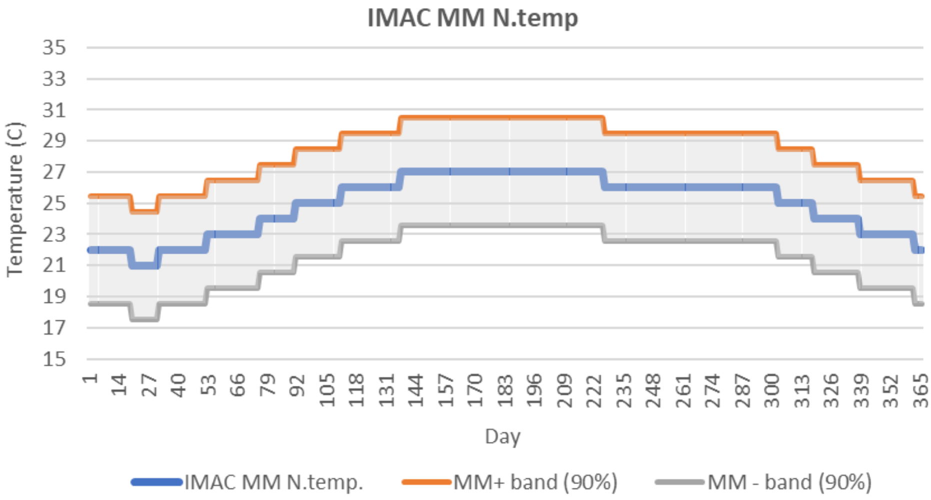


Figure 9 - IMAC Neutral temperatures and 90% acceptability bands

Limitation

As the internal temperature in a room is based on several local factors the study on climate will only help to understand/capture the main ECM's and thermodynamic process required in that climate, a specific room indoor environmental metrics (Operative temperature (OT), Relative humidity (RH) will be observed to access proposed ECM's)

Results of the Sensitivity analysis

Standardized regression coefficient (SRC)

To understand the sensitivity of main components specific to the cooling load, heating load, and total site energy analysis is done via standardized regression coefficient (SRC). The below graphs shows the sensitivity of each component.

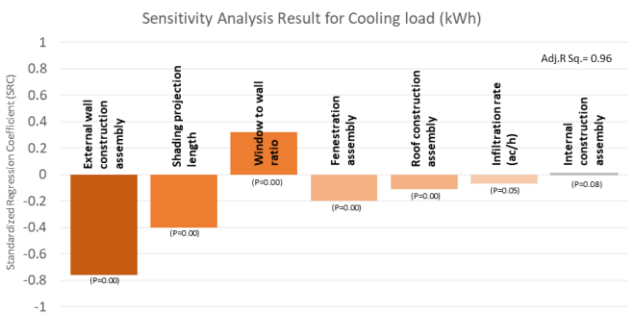


Figure 10 - SRC for Cooling load,

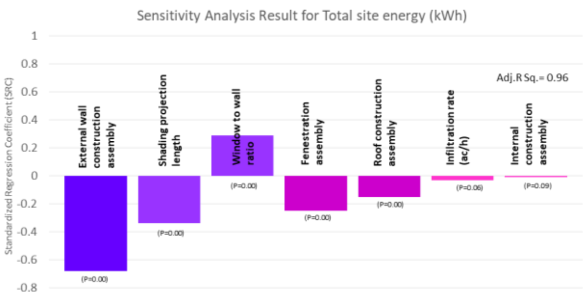


Figure 11 - SRC for Total site energy

Observations

- External Wall construction assembly has the maximum effect on both cooling and heating load followed by shading projection length for cooling load and fenestration assembly for the heating load.
- For total site energy window to wall ratio (WWR) is also contributes to maximum effect.
- Roof construction assembly has shown a medium effect on cooling and heating loads whereas internal partition construction assembly and infiltration rate have shown the least among other components.

Further, to understand the sensitivity of window opening percentage to comfort hours as per IMAC 90% acceptable range the sensitivity analysis for comfort hours (hr) vs Window Open (%) is analyzed.

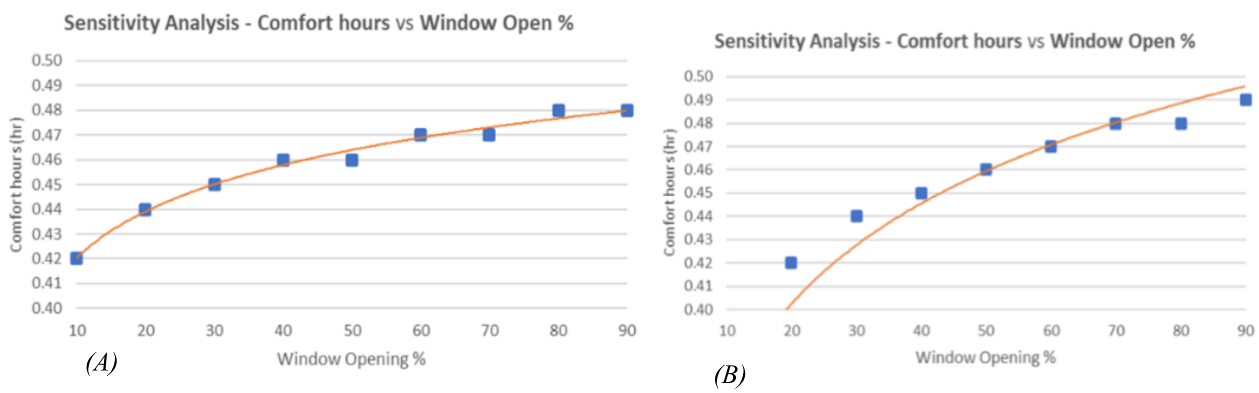


Figure 12 - Sensitivity analysis window opening %

Two text rooms A & B which are facing east, and west were chosen to do the analysis and it is observed that as the window open % increases comfort hours are also increasing. From this study, all the windows were replaced with the casement windows with mosquito mesh resulting in an effective 70% opening of windows.

The ECM's from the climate and sensitivity analysis used in different design stages

Table 11 - ECM's used at diff. design stages

Option	Discerption
Base case	Base case
Design stage 01	Basecase + IMAC
Design stage 02	Basecase + IMAC + Shading
Design stage 03	Basecase + IMAC + Shading + Natural ventilation
Design stage 04	Basecase + IMAC + Shading + Natural ventilation + Envelope optimisation
Proposed design	Basecase + IMAC + Shading + Natural ventilation + Envelope optimisation + 5-star PTAC system

Energy savings and incremental costs of individual ECM's

<u>Reduction of EPI and comparison of incremental cost</u>

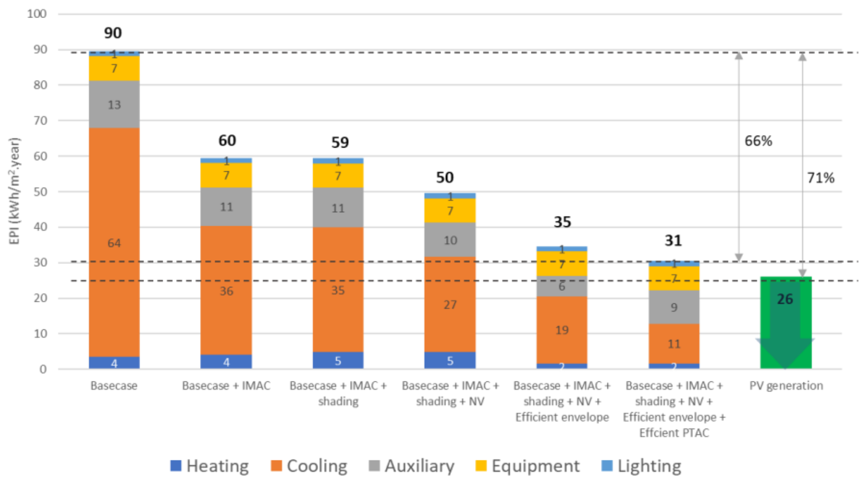


Figure 13 - Reduction of EPI

Table 12 - Incremental cost for diff. cases

Option	**Discerption**	**Incremental cost (₹)**
Base case	Base case	0.00
Design stage 01	Basecase + IMAC	0.00
Design stage 02	Basecase + IMAC + Shading	59,736.00
Design stage 03	Basecase + IMAC + Shading + Natural ventilation	0.00
Design stage 04	Basecase + IMAC + Shading + Natural ventilation + Envelope optimisation	-16,34,446.2
Proposed design	Basecase + IMAC + Shading + Natural ventilation + Envelope optimisation + 5 star PTAC system	4300 per ton
ENS case	Basecase + AAC block (exterior wall) + efficient roof assembly	-29,70,555

Unmet hours at each design stage

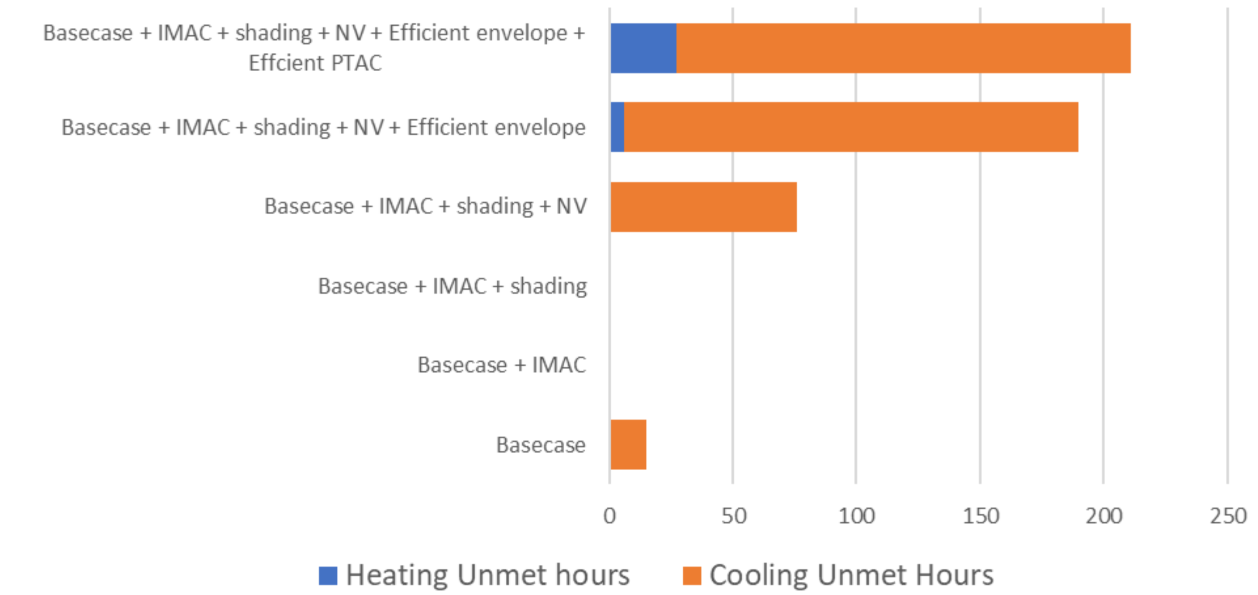


Figure 14 - Unmet hours

Parametric study on Eco-Niwas Samhita compliance cases

Parametric analysis of ENS Compliance cases

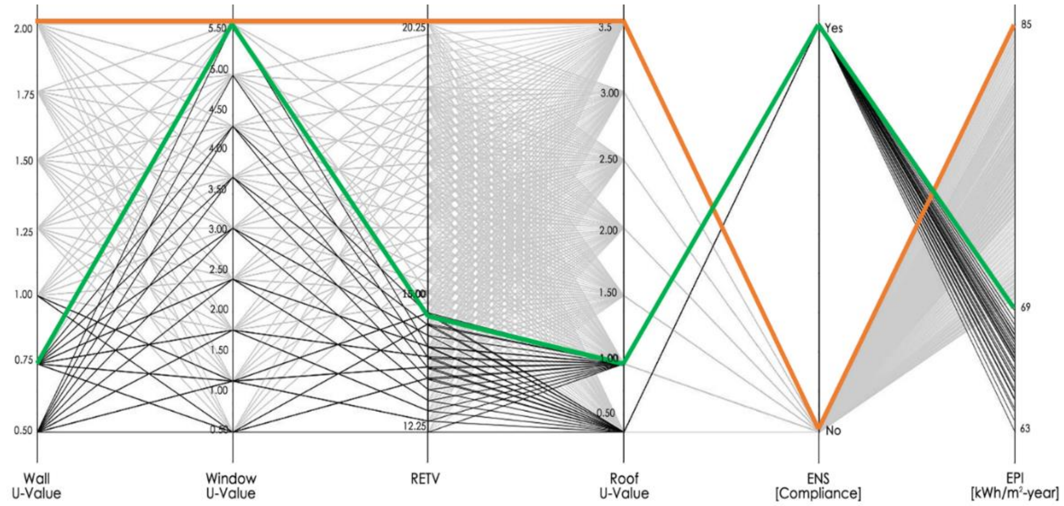


Figure 15 - Parametric analysis of ENS Compliance case

Building as usual case
One of the ENS compliance case (with AAC block used in exterior walls as the only change)

Note: Window U-value is changed and SHGC is kept constant for the analysis.

Observations

- The ENS compliance case with a low payback period is found and this case has the EUI range of 69 to 72 (19% reduction from BAU case) with savings from day 01 as the incremental cost is also less than BAU and has higher efficiency.
- The BAU case has the RETV of 20.25, by changing exterior wall assembly to AAC block the RETV came to 14.98 and just meets the ENS compliance of 15 RETV
- U-value of the wall and roof have a major impact on the RETV as the WWR in this building is at 18%.

Proposed case ECMS's and respective Internal rate of return (IRR) (for 20 years)

Table 13 - IRR for diff. cases

Option	Discerption	IRR (%)
Base case	Base case	-
Design stage 01	Basecase + IMAC	-
Design stage 02	Basecase + IMAC + Shading	60.89%
Design stage 03	Basecase + IMAC + Shading + Natural ventilation	-
Design stage 04	Basecase + IMAC + Shading + Natural ventilation + Envelope optimisation	26%
Proposed design	Basecase + IMAC + Shading + Natural ventilation + Envelope optimisation + 5-star PTAC system	46%
ENS case	Basecase + AAC block (exterior wall) + efficient roof assembly	30.98%
Renewable	Roof top PV	46.13%

Table 14 – Payback period for diff. cases

Option	Discerption	Payback period (years)
Base case	Base case	From Day 01
Design stage 01	Basecase + IMAC	From Day 01
Design stage 02	Basecase + IMAC + Shading	1 year 9 months
Design stage 03	Basecase + IMAC + Shading + Natural ventilation	From Day 01
Design stage 04	Basecase + IMAC + Shading + Natural ventilation + Envelope optimisation	From Day 01
Proposed design	Basecase + IMAC + Shading + Natural ventilation + Envelope optimisation + 5-star PTAC system	0years 2 months
ENS case	Basecase + AAC block (exterior wall) + efficient roof assembly	From Day 01
Renewable	Roof top PV	2years 4 months

Conclusion

The Net-Zero Energy Potential and main outcomes are as follows.

- After applying three different identified internal profiles (low-mid-high consumption) the BAU case EUI is in the range of 92 to 88.
- ECM's - IMAC MM 90% temp. setpoints, shading, NV, efficient envelope, efficient PTAC system were identified as the energy conservative strategies.
- After all ECM's were applied one upon another the EUI is in the range of 37 to 31 (66% reduction from BAU case). Which gives a payback period of 8 months.
- A 73kWp of rooftop PV is installed which offset 26 kWh/m2-year EUI with a payback period of 2.1 years
- The ENS compliance case with a low payback period is found and this case has the EUI range of 69 to 72 (19% reduction from BAU case) which payoff from day 01.
- AAC Blocks is identified as a very effective ECM as it has lesser construction cost and higher energy efficiency than BAU case.

Further discussion

- Efficient central HVAC systems like VAV, VRF will further reduce the EUI to reach Net-zero energy building.
- Renewable systems like Building integrated photofloods (BIPV) will also offset the required EUI to reach Net-zero energy building.
- As the study is conducted for a specific building, the same study can be done for typical residential building layout types and in different cities to further increase the study of net-zero energy residential buildings.

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Annexure 1

Envelope constructions

Table 15 - Envelope construction costs

Constructions	**U-value**	**Cost/m²**
BAU-Wall (10mm cement plaster + 230mm brunt brick + 10mm cement plaster)	2.19	2400
Autoclaved aerated concrete (AAC) block wall with plaster on both sides	0.70	2000
150 mm RCC Roof [RCC slab]	3.27	1800
White reflective tile; 40mm PUF insulation; 150mm RCC slab	0.73	2650
AIS Solar Control Glass – 6 mm (Spring)	5.70	886
AIS 6 mm (Solar Control Glass) - 12 mm (Air Gap) - 6 mm (Clear Glass) (Spring)	2.80	1926
AIS 6 mm Double Low-E Glass – 12 mm Air Gap – 6 mm Clear Glass (Clear Vivid)	1.60	2264
AIS 6 mm Low-E Glass – 12 mm Air Gap – 6 mm Clear Glass (Green Essence Plus)	1.80	2100