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Evaluation of Thermal Discomfort and Non-refrigerant-based Cooling Methods as Mitigation Measures in Indian School Buildings

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Highlights

- Thermal comfort of students has been assessed.
- Impact of evaporative coolers on improving thermal comfort has been investigated.
- Recommendations have been provided to shift policy focus towards designing school buildings considering thermal comfort.

Abstract

The atmospheric temperature of the Indian subcontinent is rising steadily, with maximum and minimum temperatures increasing by up to 0.9º C and 0.5º C, respectively. Heat waves are becoming more frequent, posing a threat to vulnerable communities, including students, leading to changes in school schedules or closures in northern India. Unfortunately, thermal comfort assessment in Indian schools has received limited attention to date. To address this, a study was conducted in Ajmer (Hot and Dry climate) to evaluate thermal discomfort caused by heat stress in schools. The study investigates the relationship between students' thermal comfort and indoor/outdoor thermal conditions and the effectiveness of low-energy cooling technology, such as ceiling fans and evaporative coolers, in mitigating thermal discomfort during heat stress conditions. Data collection and evaluation have been conducted before and after the deployment of evaporative coolers to gauge their effectiveness in improving the thermal comfort of the students. A Simulation-based approach is adopted post-deployment of coolers to quantify the improvement in thermal comfort. The study aimed to provide insights into the benefit of adopting effective cooling technologies for improving the indoor classroom environment for students and enabling policymakers to assess indoor thermal conditions and choose suitable technologies to help mitigate heat stress in schools.

The results show that low-energy cooling technology, like evaporative air coolers, helps in bringing down the indoor temperature to a thermally comfortable range for the students. In addition, this study established that there is a need to focus on thermal comfort while developing the school infrastructure, as it helps in improving the students' learning cognizance, attendance ratio and physical well-being.

Keywords: Thermal Comfort, Heat stress, Low-energy cooling techniques, Evaporative Air Coolers.

Introduction

India is one of the largest and most populated economies in the world, with its average temperature being projected to rise by ~4.4°C by the end of the 21st century—which would result in extreme heat stress, with devastating impacts on human health and energy security [1]. Incidentally, it has been estimated that an increase in surface temperature and humidity will intensify the heat stress across India, particularly over the Indo-Gangetic and Indus River basins [1]. Thus, wider access to cooling is necessary in order to bring benefits to human development, health, well-being, and economic productivity. With around 4 trillion-person cooling degree days [2], coupled with a lack of access to cooling and thermal comfort, rising temperature, rapid population growth, and urbanization will not only amplify heat stress but will also fuel the demand for space cooling. According to the India Cooling Action Plan (ICAP) 2019 [3], India has one of the lowest access to cooling, with per capita space cooling energy consumption at 69 kilowatt-hours (kWh) compared to the world average of 272 kWh [4]. Access to affordable and sustainable cooling for attaining thermal comfort is no longer considered a luxury but, rather, a necessity for meeting the larger environmental goals as well as enhancing the overall quality of life, productivity, and well-being [4]. Various studies have also indicated that India's rapidly changing climate will have a severe impact on the heat stress situation within the entire ecosystem. Particularly, children are identified as one of the vulnerable groups and are adversely impacted by rising heat stress in the absence of adequate thermal comfort infrastructure put in place in the schools [1].

Need for Thermal Comfort in India's Academic Institutions

As per the Unified District Information Systems for Education Plus (UDISE+) 2019-20 report by the Ministry of Education [5], India has more than 15,00,000 lakhs (1.5 million) schools, from which 11,16,932 lakhs schools are managed by the government, and 3,37,499 are managed by private entities. However, none of the reports (inclusive of the one mentioned above) or policies focusing on India's education sector encompasses thermal comfort as one of the key priorities for the school infrastructure, as shown in Figure 1. Thus, it can be said that thermal comfort in India's academic sector has never been prioritized, while it can provide multiple benefits. Moreover, India's policy and regulatory framework do not bestow information on the associated benefits of providing access to thermal comfort for children in academic institutions; this area has been least focused on. However, there have been persistent attempts in the literature to understand the existing thermal scenario in academic institutions and emphasize the need for ensuring thermal comfort in the former to address the heat-related challenges for this age group. In particular, the literature highlights the number of studies that have assessed thermal comfort through field surveys in educational buildings globally [6] [7]. A number of these are focused on assessing the thermal environment in classrooms compared to common thermal comfort standards. Also, most of the studies conclude that students' thermal preferences are distinct from the comfort range prescribed in the standards. This wide disparity in thermal neutralities underlines the need for micro-level thermal comfort studies. In the Indian context, for instance, a study by Jindal A [8] conducted in 2015-16 investigated thermal comfort in naturally ventilated classrooms of three government residential schools located in the composite climatic zone of India and also assessed students' thermal perceptions. The study concludes that the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) adaptive thermal comfort model is an adult-based standard and was developed for the pan-global thermal environment. The same cannot be applied to children and teenagers in the regional climatic context of India. Also, the study highlights the need to segregate the data of the middle and secondary-class students and determine the differences between their thermal comfort acceptability range. These findings can provide guidelines for architects to design thermally comfortable and energy-efficient schools without compromising occupant comfort.

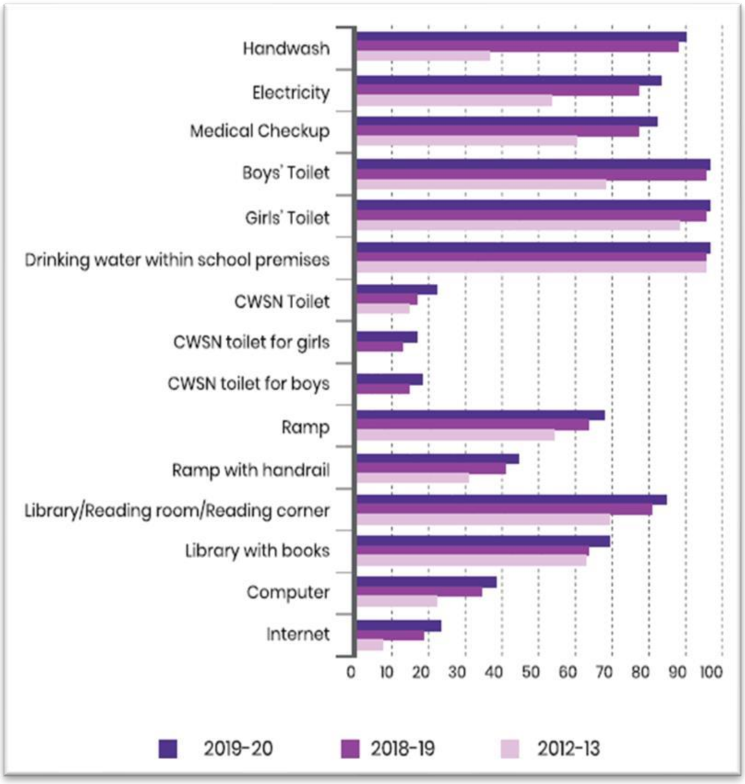

Figure 1: Percentage of Schools Having Specific Infrastructure Facility 2012-2020 [5]

Therefore, to substantiate the assessments on the subject of thermal comfort range in schools as well as the thermal comfort perception of students across different age groups, we have based our analysis on simulation-based exercises and field survey of selected schools in the districts of Rajasthan (Ajmer), to determine actual thermal conditions and thermal comfort perceptions.

Achieving thermal comfort in the academic sector is vital to bring about systemic changes on multiple fronts, ranging from increased attendance to enhanced quality of education and improved quality of life. In addition, it can also help in creating equal exposure opportunities and attending school for women as they are disproportionately impacted by heat stress, more so during the menstruation period. Furthermore, bringing the students closer to using evaporative air coolers (EAC), a Non-GWP refrigerant-based space cooling solution to achieve thermal comfort in the constantly warming world, can lead to wider adoption of energy-efficient space cooling appliances—leading to Thermal Comfort for a Billion Lives (TCBL).

Therefore, with the recommendations of the 'Decoding Evaporative Air Coolers (EAC)' report [4] being the foundation stone, the AEEE team has collaborated with Symphony Ltd. to take forward the Supporting Affordable Heat Action for Resilient Academic Institutions Programme (SAHARA)

Programme, a programme initiated to Supporting Affordable Heat Action for Resilient Academic Institutions. The project envisions providing access to thermal comfort for children in India's academic institutions, which is the most under-looked area.

Thermal Comfort Scenario in Indian Academic Institutions – A case study of Ajmer

In order to understand the on-ground reality of heat stress, a school located in the Ajmer district of Rajasthan has been selected (shown in Figure 2) to assess the thermal comfort of students during heat stress conditions and evaluate the effectiveness of EAC in improving the thermal comfort of students. Indoor and outdoor temperature and humidity of the classrooms were measured before the deployment of the evaporative coolers. The survey was conducted to gauge the thermal perception of the students in the classrooms. The indoor environment of the classrooms post-deployment of EAC has been evaluated through simulations. The climatic condition of the region is dry and hot, with dry bulb temperature typically varying between 23 to 41°C. The subsequent section details the methodology adopted while executing the analysis.

Characteristics of the classrooms

The school building considered for the study has three classrooms and a hall on each floor. The layout of the classrooms and the cross-section of the wall and roof assemblies are shown in Figure 2. The school has an ancient building at the time of British rule converted to a school and made of stone masonry.

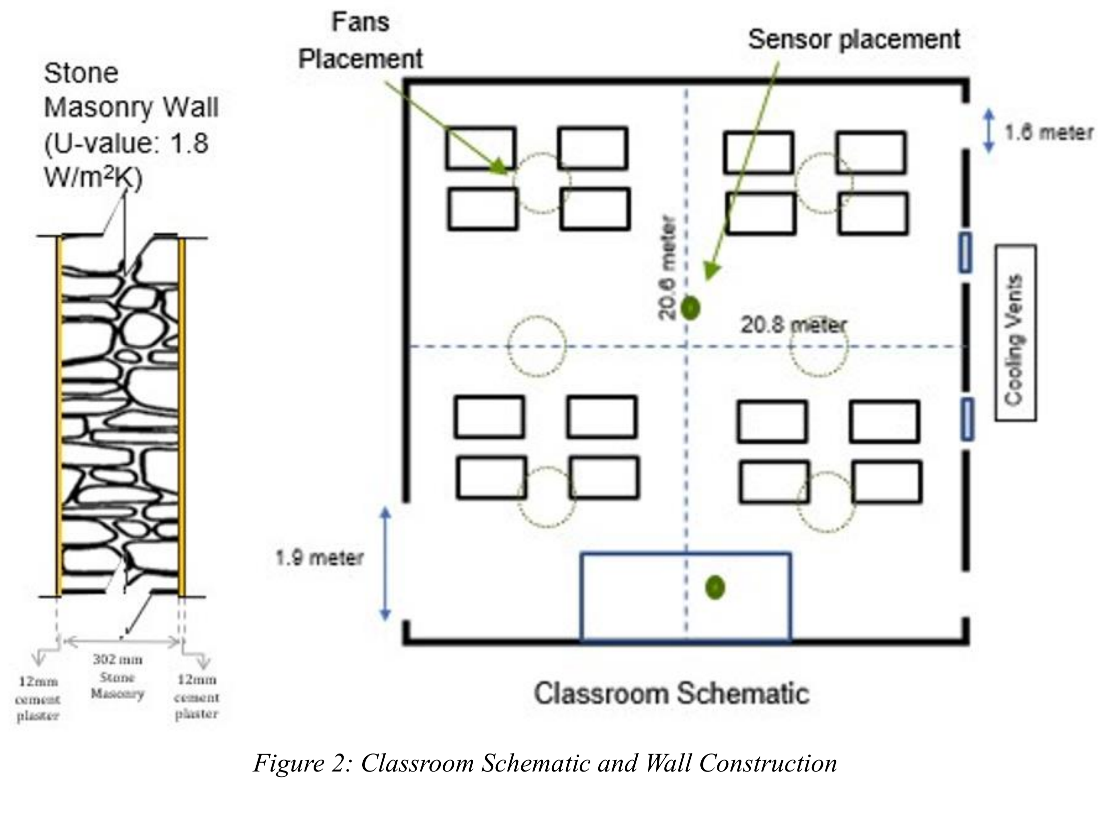

Figure 2: Classroom Schematic and Wall Construction

Table 1 shows the thermal properties of the construction materials used in the school building.

Table 1: Thermal Physical Properties of the Building Components

Building Components	Description	Thermo Physical Property
External Walls	The wall comprises stone masonry and cement plaster; the total thickness of the wall is 0.32m	U value – 1.80W/m^{2}K
Internal Walls	The wall comprises burned brick and cement plaster; the total thickness of the wall is 0.20m	U value – 1.62W/m^{2}K
Floor	The floor is made up of single-layer cast concrete with a thickness of 0.125m	U value – 4.31 W/m^{2}K
Roof	The roof is made up of single-layer cast concrete with a thickness of 0.125m	U value – 4.31 W/m^{2}K
Window	The window has been installed with clear glass 5 mm	U value – 1.960 W/m^{2}K

Results and Discussion

Thermal performance analysis of the classroom

Temperature and humidity of the classrooms were measured between 5th April 2023 to 28th April 2023 before deploying the EAC in the classrooms. Temperature and humidity data were recorded at intervals of 1 hour with HTC-1 digital thermometer (accuracy ± 1 ℃, mention accuracy for humidity). Figure 3 shows the placement of the sensors in the classrooms.

Figure 3: Placement of the sensor for collecting the real time data

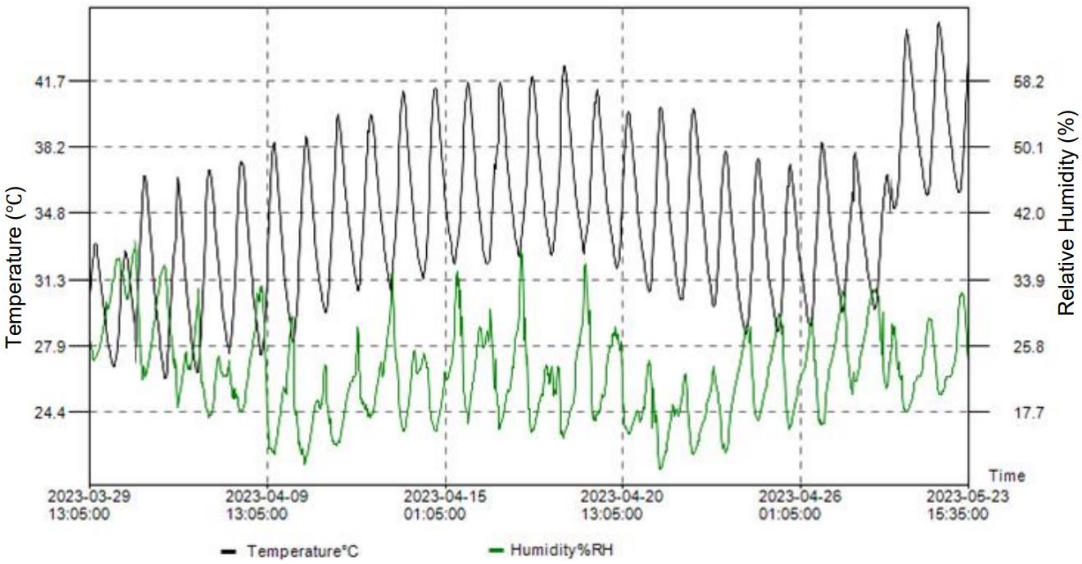

Figure 4: Indoor experimental temperature and relative humidity for the peak summer

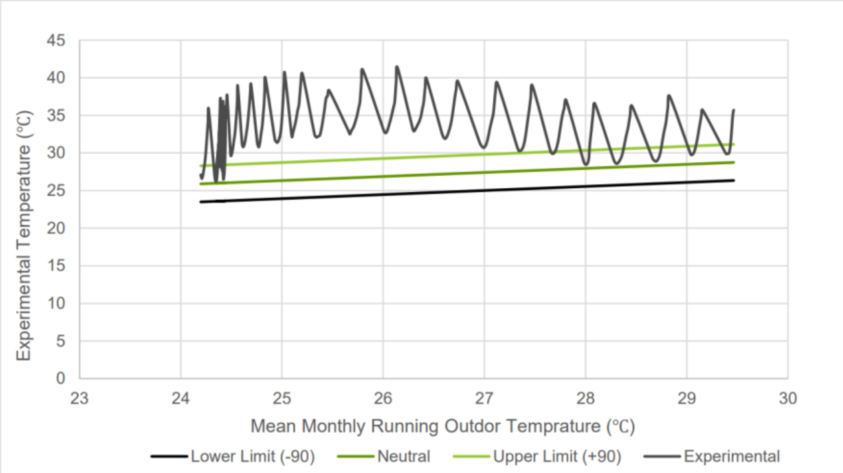

Figure 5: The outdoor running temperature with fans and natural ventilation

Figure 4 shows the temporal variation in the classroom's temperature and relative humidity in the month of April. It can be observed from the figure that relative humidity is low, which offers potential for evaporative cooling in the classrooms. Figure 5 shows the plot of the classroom's temperature with the IMAC thermal comfort band [9]. It can be observed from the figure that 188 hours are out of the thermal comfort band from the total occupied hours of 207, while school is typically running in two shifts from 7:00 am to 4:00 pm, according to the school principal.

Evaluation methodology of Post deployment of EAC

To analyze the thermal properties of classroom post deployment of EAC, the measured data of air temperature and humidity has been used in equation (1) to calculate the effective air temperature after deployment of EAC. In order to calculate the effects of evaporator air coolers on the thermal comfort of the classrooms within the schools, the team calculated the wet bulb temperature using the following equation [10].

Tw = T * arctan [0.152 * (Rh + 8.3136) ^(1/2)] + arctan(T + Rh%) - arcta.n(Rh - 1.6763) + 0.00391838* (Rh)^(3/2) * arctan(0.0231 * Rh) - 4.686 (1)

Where,

Tw = Wet Bulb Temperature

T= Experimental Indoor Temperature

Rh = Relative Humidity

The saturation efficiency was considered to be 70% to calculate the temperature reduction after operating the EACs. Some assumptions were also considered while executing the analysis to formulate the results.

Thermal performance analysis

Figure 6 shows the plot of air temperature with the IMAC thermal comfort band. It can be inferred from the figure that nearly none of the points were crossing the upper limits of the IMAC model out of the total occupied hours 207 falls. This showcases that in hot and dry climatic conditions, Evaporative Air Coolers (EACs) can play a major role in meeting the thermal comfort requirement of the school.

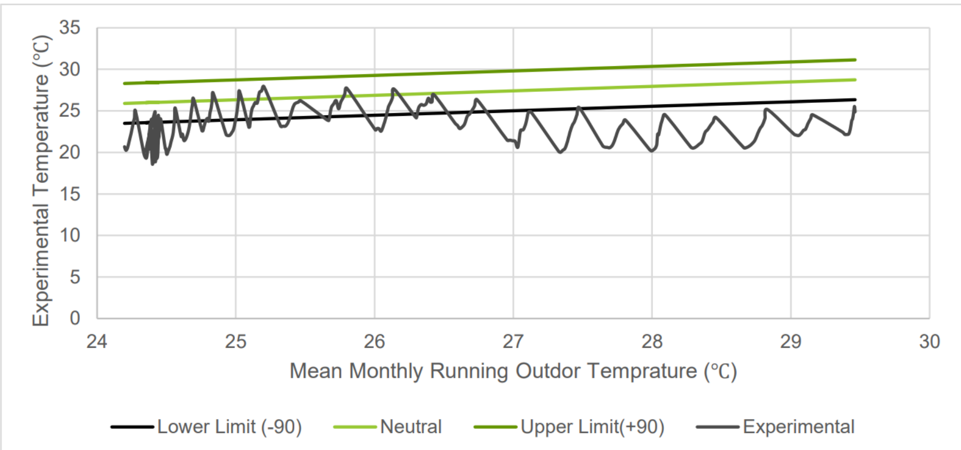

Figure 6: The outdoor running temperature with Evaporative Air Coolers

Figure 7 demonstrates a remarkable reduction in the number of discomfort hours experienced in classrooms, ultimately reaching zero. This compelling evidence solidifies the effectiveness of EACs as a viable technology for schools throughout Rajasthan. By highlighting this significant improvement, it becomes evident that EACs can play a pivotal role in facilitating a systemic shift toward adopting more efficient cooling solutions in the region. This is especially relevant in a place like Rajasthan, where traditional evaporative cooling is a suitable and viable solution due to various factors. Consequently, widespread adoption of EACs can unlock equitable access to cooling solutions for all, aligning with the broader objective of ensuring thermal comfort for billions of lives.

The findings emphasize the necessity for including a provision in the UDISE data to monitor the thermal comfort parameter in Indian schools. By doing so, we can address a crucial and often disregarded issue, granting much-needed access to cooling solutions for a vulnerable community, specifically students. This step is of utmost importance in ensuring that the well-being and comfort of students are prioritized, as thermal comfort significantly impacts their ability to learn and thrive. By incorporating the tracking of thermal comfort into the UDISE data, we can shed light on this critical aspect and pave the way for effective interventions and policy changes to improve the learning environment for students across the country.

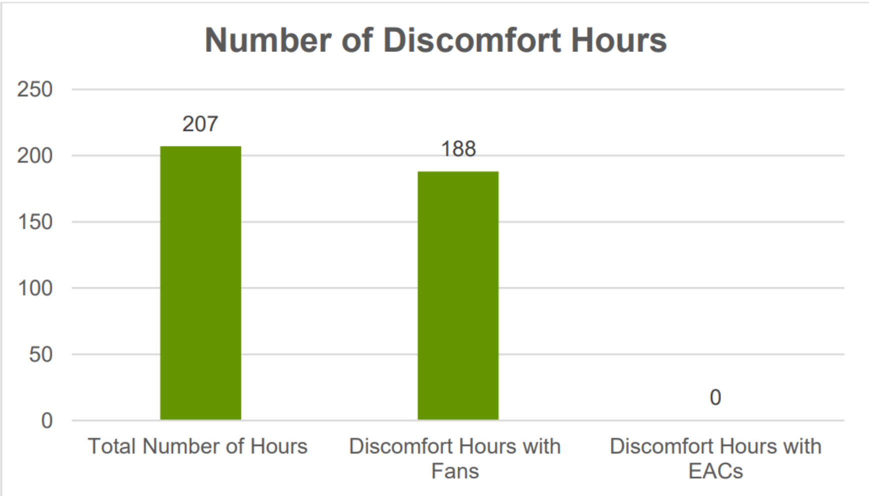

Figure 7: Reduction in Thermal Discomfort Hours Fans vs EACs

Thermal comfort perception of students

A descriptive cross-sectional survey research design was used to assess the students' comfort level pertaining to thermal cooling in schools and the impact of usage of energy appliances on electricity consumption. The sample comprises students from classes IX to XII and not from Primary classes because higher age group students are able to discuss school infrastructure and respond better about their comfort and concentration level during the summers.

A stratified random sampling technique was used to select the schools to collect responses from the students. The survey deals with the students who were initially asked about their profile, like gender, and then their comfort level with the cooling environment in schools and the impact on their comfort and concentration.

The survey findings are shown in Figure 8, where 261 respondents, including students, teachers, and administrative staff of the schools, have responded to the need for thermal comfort in the classrooms and awareness regarding the subject of energy efficiency. The students' response exhibited a bias towards their school, stemming from the deep sense of pride they harbour for their institution. However, it's essential to acknowledge and address the error in their responses. Thus, to negate the error, In addition to the students, it's important to consider the perspectives of the teachers and administrative staff, who also operate within the same premises and are subject to the same set of challenges and discomforts.

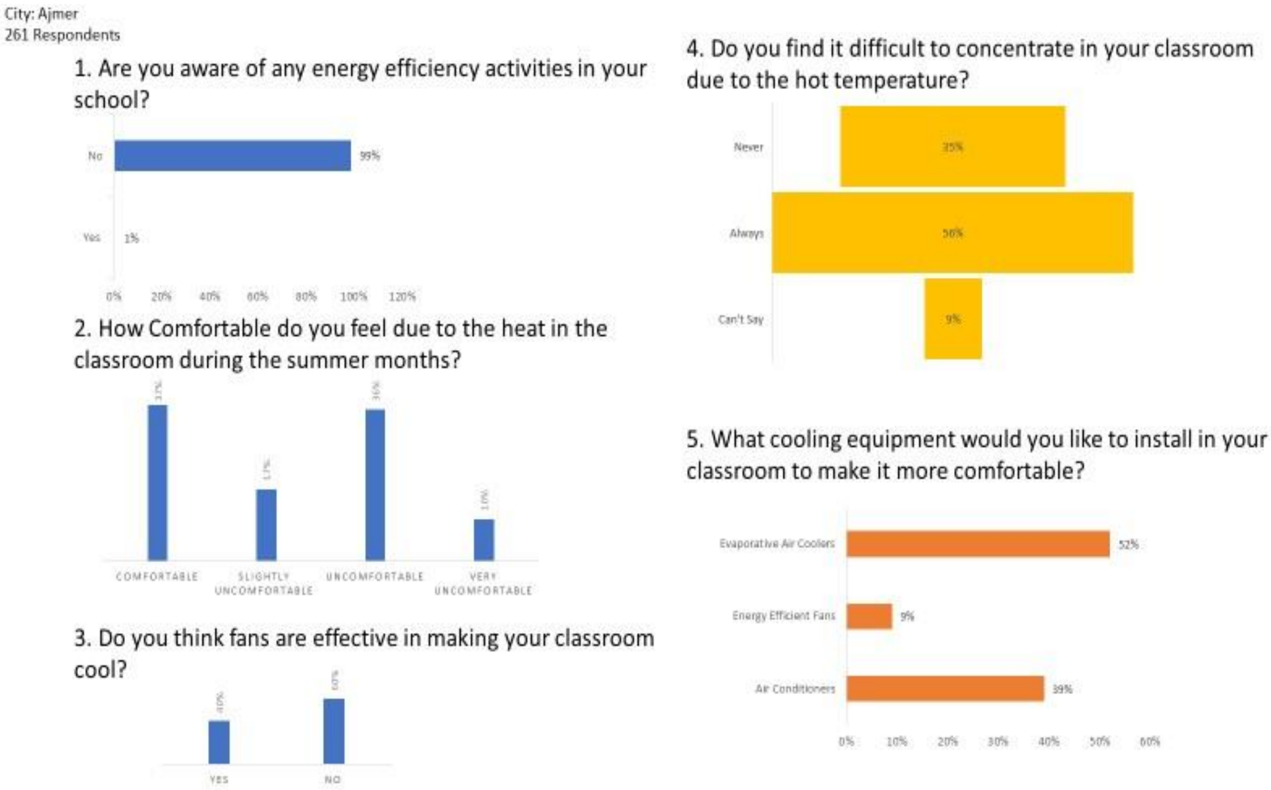

Figure 8: Survey Findings with Emphasis on Thermal Comfort and Energy Efficiency in Schools

The survey results indicate that a significant proportion, specifically 60% of the respondents, perceive fans as inadequate in meeting the requirements for thermal comfort. Additionally, an impressive 52% of respondents recognize evaporative air coolers as a viable and effective solution for addressing the thermal comfort needs in classrooms. These findings highlight the growing demand and recognition for such technology in educational settings. As a result, there is an ever-increasing need for the implementation of advanced cooling technologies like evaporative air coolers in classrooms. By embracing these solutions, educational institutions can ensure a conducive environment for optimal learning and enhance the overall well-being of students.

Recommendations

Institutionalizing thermal comfort in Indian academic institutions requires a collective effort of multiple organizations from different ministries and associations. Since the context of thermal comfort is multidimensional and traverses across wide sectoral stakeholders, therefore the institutional mapping has been done in three categories:

1. **Educational Infrastructure –** To achieve a wider goal of thermal comfort for all citizens, the Ministry of Education can create a thermal comfort scenario mapping across Indian classrooms, identifying areas that require cooling interventions and paving the path for the creation of green schools. Based on the data collected, the Ministry can thus prepare guidelines for the education sector and may include the same as recommendations under the Nation Education Policy (2020), which already recommends improving the infrastructure of India's academic institutions to boost the overall quality of education.
2. **Energy Security –** The increase in the demand for electricity is one of the priority concerns for the Ministry of Power (MoP). According to the India Cooling Action Plan (ICAP) [3], there will be an eight-fold increase in the overall cooling demand, which will result in a surge in electricity consumption in the future. It is not sustainable to meet this demand by relying solely on-air conditioning technologies. Therefore, it is essential to focus on deploying other non-refrigerant cooling technologies in various sectors, including schools. The Ministry of Power should work towards promoting the use of such technologies to meet the growing cooling demand while minimizing the environmental impact and reducing the strain on the electricity grid.
3. **Climate Mitigation & ICAP Recommendation –** According to recent projections [3], the demand for refrigerants is expected to increase by a staggering 6.5 times in the coming years. In light of this concerning trend, it is crucial for the Ministry of Environment and Forest Climate Change to take proactive measures, such as deploying energy-efficient cooling solutions in multiple schools. This initiative holds immense potential in providing the masses with access to cooling technologies that produce no greenhouse gas (GHG) emissions. Considering that schools in India serve various purposes, ranging from hosting elections to organizing boot camps in rural areas, the widespread

adoption of Evaporative Air Coolers (EACs) can drive a systematic change in meeting the thermal comfort needs of the masses.

Conclusion

This study establishes that Evaporative Air Coolers (EACs) have a pivotal role in meeting schools' thermal comfort requirements. The comprehensive data collection and evaluation conducted in a school in Ajmer, Rajasthan—a region characterized by hot and dry climatic conditions—clearly demonstrate a remarkable reduction in thermal discomfort hours upon deploying EACs in classrooms. The findings of this study provide compelling evidence of the effectiveness of EACs in creating a more comfortable learning environment for students. By adopting this technology, schools can effectively mitigate the challenges posed by harsh climatic conditions, ensuring that students can focus and thrive in a conducive setting.

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Moreover, this paper places significant emphasis on providing recommendations to key stakeholders in the domains of Educational Infrastructure, Energy Security, and Climate Mitigation. The stakeholders to whom these recommendations are directed include the apex authorities of the Ministry of Education, the Ministry of Power, and the Ministry of Environment and Forest Climate Change. By addressing these stakeholders, the paper seeks to foster collaboration and encourage proactive measures in addressing the thermal comfort needs of educational institutions. It highlights the importance of integrating energy-efficient cooling solutions into educational infrastructure, ensuring the security of energy resources, and promoting climate mitigation efforts.

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