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Optimizing Classroom Design with Salutogenic Approach: Thermal Comfort, Lighting, and Attentiveness

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Abstract
This study investigates optimizing classroom design by balancing thermal comfort and daylighting to enhance student attentiveness, a critical factor in educational settings. The research was motivated by the need to address the knowledge gap concerning the combined effects of thermal and visual comfort on student engagement, particularly considering gender differences, which have been underexplored in existing literature. Two identical lecture halls in Tiruchirappalli, India, were selected for the study: one with blackened windows and the other with standard windows. Field measurements of temperature, humidity, wind speed, and light levels were taken using a thermal comfort microclimate data logger and light meter, while student engagement and comfort were assessed through a questionnaire. The findings reveal that the lecture hall with standard windows provided superior visual and thermal comfort, resulting in higher levels of student attentiveness. In contrast, the hall with blackened windows showed reduced attentiveness. Additionally, gender analysis indicated that female students reported greater satisfaction with both thermal and visual comfort compared to their male counterparts. The study's implications underscore the importance of integrating both thermal and visual comfort in classroom design, highlighting that optimal daylighting is essential for maintaining student attentiveness, even when thermal conditions are consistent. Furthermore, the research emphasizes the need for thoughtful design in educational spaces to create inclusive and effective learning environments that account for gender differences in comfort perception. This study contributes to the field by providing evidence that classroom design significantly influences student engagement and satisfaction, urging designers and educators to prioritize these factors in educational settings.

Keywords*:* Salutogenic Architecture; Educational Setting; Attentiveness; User Comfort; Field Survey.

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1. Introduction

Educational environments encompass more than just the physical layout and available resources; they also include factors contributing to learning, well-being, and social connection. While many modern educational spaces prioritize quantitative aspects like daylighting and thermal comfort, qualitative elements

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such as student engagement often need to be noticed. The amenability of a learning environment significantly influences student attentiveness and participation, which factors like lighting quality and thermal comfort can influence. Thus, designing educational spaces with attention to both quantitative and qualitative elements is crucial for fostering an environment conducive to learning and student well-being.

According to ASHRAE Standard 55 (2017), thermal comfort is achieved when the environmental conditions in space keep most occupants neither too hot nor too cold, striking a balance between air temperature, radiant temperature, humidity, and airspeed. Similarly, as LEED (v4.1) standards specified, visual comfort relies on sufficient light distribution and avoiding glare. These factors work together to prevent eye fatigue and enhance mood and cognitive functioning.

The significance of individual factors such as thermal environment and natural light in prior research on cognitive performance has been well documented. For instance, H. Kim et al. (2020) demonstrated that while indoor thermal conditions may not directly impact learning outcomes, they do influence students' psychophysiological responses, subsequently affecting their cognitive load. Similarly, Porras (2020) observed that classrooms with ample natural light, typically facilitated by windows, exhibited higher academic performance than those lacking such access.

Nevertheless, a critical gap exists in the literature regarding the holistic evaluation of combined thermal and visual conditions on occupant attentiveness within educational settings. This study endeavors to address this gap through a salutogenic approach, which prioritizes the creation of environments conducive to promoting human health and well-being. By integrating thermal and visual parameter assessments, this research offers insights into optimizing classroom design to enhance student attentiveness and overall academic performance.

The study examines the impact of improved thermal comfort and lighting conditions on student focus in educational surroundings. More precisely, it answers the following research question: How can a balance be struck between qualitative attentiveness and quantitative user comfort factors in educational space design? What is the interplay between indoor ambient conditions like temperature, humidity, lighting, and attentiveness, and how can this be leveraged to enhance learning efficiency and student engagement?

The objectives of this research are to assess the impact of integrating thermal comfort and daylighting on student attentiveness within educational environments, as well as to evaluate classroom visual and thermal comfort levels featuring blackened and un-blackened windows.

This study is significant as it bridges the gap between quantitative comfort measures and qualitative aspects of attentiveness in educational settings. The findings are expected to contribute to the field in several ways. First, the study will provide new research findings on the effects of integrated thermal and visual comfort on student attentiveness, enriching environmental psychology and educational design literature with empirical data. Second, by employing the salutogenic model, the paper will offer new theoretical insights into how classrooms can be designed to foster health and well-being beyond conventional ergonomic and comfort criteria.

2. Materials and methods

2.1 Literature review

Studies have shown that cognitive performance and thermal comfort are significantly related. Thermal comfort is an essential factor that impacts productivity and personal feelings regarding thermal comfort (Bajc et al., 2018). Students who experience thermal dissatisfaction tend to lose motivation and concentration, which lowers their learning performance (Wang D. et al., 2018). Temperature is vital in high-stakes cognitive performance, potentially impacting students' careers and lifetime earnings (Zivin et al., 2020). Similarly, Lee M. C. et al. (2012) examined the relationship between thermal conditions and learning performance in an air-conditioned university through subjective assessment and objective measurement. They found that the students' thermal dissatisfaction with indoor thermal conditions strongly impacted their learning performance.

It is not only thermal comfort; adequate daylight and proper lighting also affect attentiveness in educational settings. Similarly, natural light can improve students' subjective mood, attention, cognitive performance, physical activity, sleep quality, and alertness (Shishegar N. & Boubekri M., 2016; Amalan et al., 2021). Three potential pathways are suggested for a daylight mechanism that improves human performance, increases visibility, enhances mood, and improves health. Students in classrooms with better daylighting had 7% to 18% higher scores on standardized tests than those with the least daylighting (Heschong L., Wright R. L., & Okura, S., 2002). Moreover, Heschong et al.'s work from 2002 indicated that appropriate artificial lights enhance children's concentration during class activities, particularly reading and writing assignments.

The role of individual differences in students' attention spans and engagement during class is crucial. While some students can concentrate for extended periods, others frequently experience lapses in attention. Research by Li, J., & Xue, E. (2023) suggests that teaching methods and positive learning environments involving students can help maintain their attention and increase their participation in classroom discussions. Attention wandering during lectures can also be attributed to environmental distractions, cognitive overload, and individual predispositions. Studies by Risko & Dunn (2015) and Unsworth & Robison (2017) indicate that loss of focus often occurs after prolonged cognitive effort or when stimuli cease to be captivating. In classroom settings, various factors influence attentive behavior, including thermal comfort, lighting conditions, glare, individual differences in attention span, and educators' engagement strategies. Studies by Nusrat Sharmin (2023) suggest that the factors that are out of the power of the academician are being considered uncontrollable here, and those the academician can change or affect are being considered controllable factors. Understanding how these factors interact is essential for creating a conducive learning atmosphere, allowing learners to retain information longer while actively participating.

The thermal environment is crucial in determining an individual's sense of comfort. Yet, it is only possible to satisfy some people in a given space due to differing physiological and psychological makeups. Only some people experience the same environmental conditions as comfort. The operative temperature and humidity are generally set to achieve 80% occupant acceptability. According to the predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) models, achieving general (whole body) thermal comfort with a 10% dissatisfaction rate, combined with an additional 10% dissatisfaction from local (partial body) thermal discomfort, results in a total of 20% dissatisfaction.

Specific humidity conditions, air speed, metabolic rate, and clothing insulation define a comfort zone. The range of operative temperatures (to) that provide acceptable conditions can characterize this zone or by combinations of air temperature (ta) and mean radiant temperature (tr) deemed thermally acceptable. These factors are dynamic and may vary over time. The standard, as outlined in ASHRAE 55 (2017), covers only steady-state thermal comfort. For accurate measurement of thermal parameters, the building's physical measurement positions are located at the center of each room or space, as well as one-meter inward from the wall, away from the center of each room. This ensures a comprehensive assessment of the thermal environment within a given space.

The research by Shamseldin, A., Alwetaishi, M., & Alzaed, A. (2021, March) highlights that visual and thermal comfort often have conflicting requirements. This means that recommendations to improve one aspect may negatively impact the other. Therefore, it is essential to consider how changes in thermal comfort can affect visual comfort.

Visual comfort refers to a state of mind where individuals feel satisfied with their visual environment. Daylighting in buildings aims to connect occupants with the outdoors, support circadian rhythms, and reduce dependence on artificial lighting by integrating natural and external views into indoor spaces. Achieving stable visual environments is challenging due to the significant variability in individual visual acuity, preferences, and psychological responses. Effective daylighting design considers the placement and size of windows, shading devices, and the reflective properties of interior surfaces. Daylight measurement points are critical for assessing visual comfort. Measurements should be taken at the appropriate work-plane elevation to ensure adequate task lighting. For larger spaces exceeding 14 square meters, measurements should be conducted on a maximum 3-meter square grid, as specified by the LEED v4.1 standard. This systematic approach ensures that lighting levels are consistent and sufficient throughout the space, contributing to a comfortable and visually satisfying environment for all occupants.

The research by Kong, Z., Zhang, R., Ni, J., Ning, P., Kong, X., & Wang, J. (2022) highlighted that different lighting conditions, such as natural light versus artificial light, play a crucial role in influencing visual comfort. The presence of natural light was associated with higher levels of comfort and satisfaction among students. Students reported feeling more focused and engaged in well-lit environments, which can lead to improved academic performance.

2.2 Methodology

The study methodology starts with a thorough literature review to understand existing research on thermal comfort, visual comfort, student attentiveness, and building engagement. This review identified gaps in the current knowledge and helped select an appropriate building for the study. The next step involved detailed site identification to pinpoint specific spaces within the building for data collection. Then, the research collects environmental data such as air temperature, globe temperature (Tg), relative humidity (RH), wind speed (Va), and daylight. These measurements are crucial for calculating the PMV, a key indicator of thermal comfort, and lux levels for visual comfort. Simultaneously, a questionnaire survey is conducted with the building's occupants to assess their satisfaction with thermal and visual comfort and their levels of attentiveness and engagement. These data were crucial for us to understand how different environmental conditions influence people's comfort. The analysis phase involved comparing the PMV and lux levels with their benchmark standards and correlating them with the survey results. This dual approach ensures a comprehensive understanding of the physical environment and occupant experiences. Ultimately, the study ties all this together by summarizing how comfortable it is to be in the space based on objective data and subjective experiences (Figure 1).

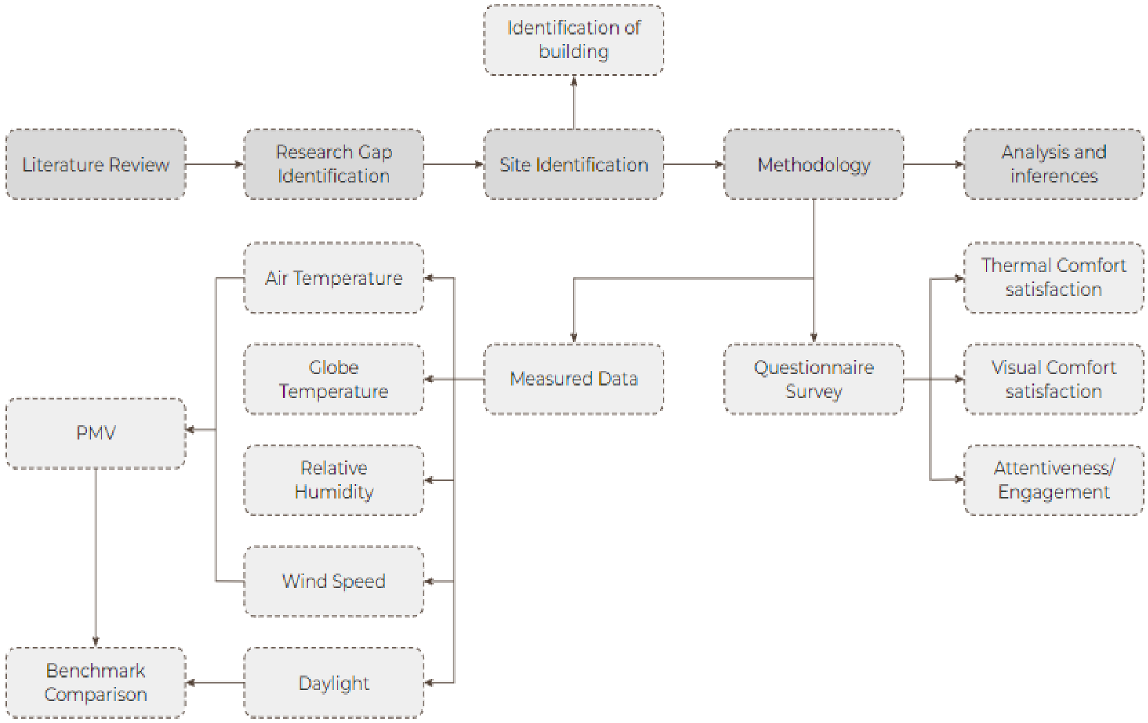

Figure 1. Study Methodology.

This study was conducted in Tiruchirappalli, Tamil Nadu, India (Latitude 10.76°N, Longitude 78.81°E), a region characterized by a warm and humid climate according to the National Building Code and classified as a Tropical Savanna climatic zone by the Köppen-Geiger system. The research focused on two identical lecture rooms of size 9.8 x 12 m on the architecture department's first floor at the National Institute of Technology Tiruchirappalli (NITT). Lecture Hall 3 (LH-3) featured blackened windows designed to prevent direct solar radiation and reduce glare, while Lecture Hall 1 (LH-1) had standard, non-darkened windows (Figure 2). The study employed observational techniques, including physical measurements and questionnaires, to gather data from these rooms to assess the impact of different window treatments on thermal and visual comfort in educational environments.

Elevation Wall A exhibits a different window-to-wall ratio among the two identical lecture halls, LH-1 and LH-3. Wall A had a total wall area of 36.4 square meters with a total window area of 14.02 square meters; this makes the WWR on Wall A 38.52%. Contrary to this, Wall B had a total wall area of 36.4 square meters and a total window area of 10.83 square meters. This resulted in a lower WWR of 29.75% for Wall B (Figure 3). The study encompassed collecting a considerable amount of data both by doing physical measurements and by conducting questionnaires in two identical lecture halls, LH-1 and LH-3, at NITT. Two separate days were selected for the conduction of physical measurements on March 27, 2024, and March 28, 2024, including morning periods between the hours of 9:30 AM and 10:30 AM, afternoon periods between the hours of 12:30 PM and 1:30 PM, and evening periods between the hours of 4:00 PM and 5:00 PM.

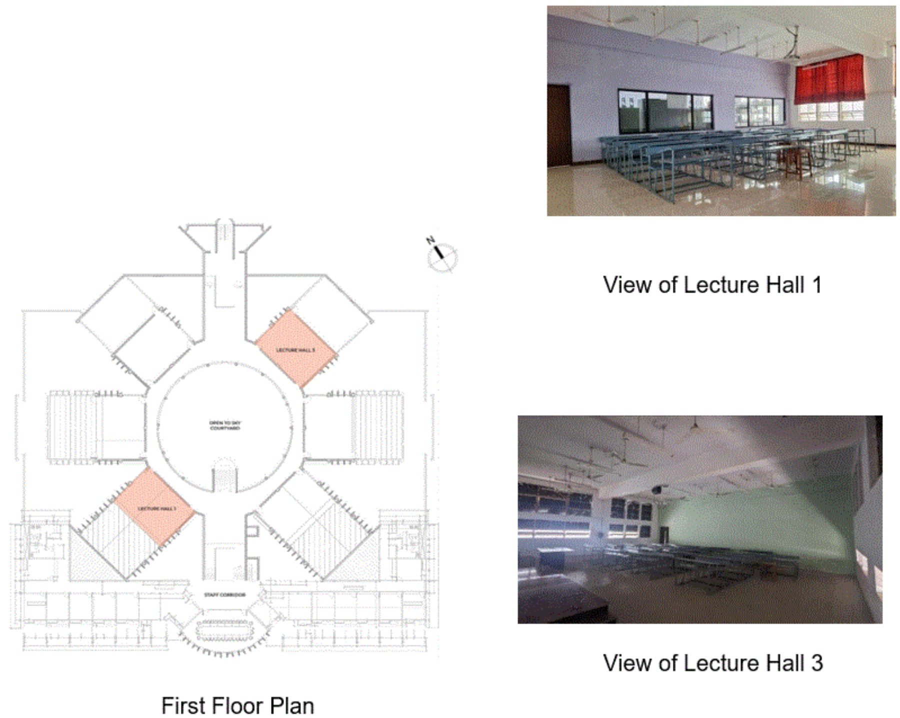

Figure 2. The first-floor plan of the architecture building shows lecture hall locations (left), the interior view of Lecture Hall 1 (right-top), and the interior view of Lecture Hall 3 (right-bottom).

The quantitative data collection employed a Delta Ohm Thermal Comfort Microclimate Data Logger to measure Ta, Tg, Va, RH, and PMV at 0.6 meters for seated occupants and 1.1 meters for standing occupants. Additionally, a light meter was used at the work plane height of 1 meter in the lecture halls to measure lux levels (Table 1). Measurements were taken at various locations within the lecture halls, following the guidelines of ASHRAE 55 (2017) and LEED, as illustrated in Figure 2. This comprehensive data collection process provided an overall assessment of the thermal and lighting conditions experienced by occupants in these spaces. In addition to physical measurements, the research team conducted a questionnaire survey targeting students who attended a one-hour lecture in their respective lecture halls. The survey collected demographic data, including name, age, and gender, to understand the diverse backgrounds of the participants. Section 2 of the questionnaire included questions on various factors such as thermal conditions, thermal sensation, causes of discomfort, daylighting provision, visual comfort, glare perception, activity level, attention span, and learning effectiveness. The responses were measured on a Likert scale from 1 to 5, where 1 indicated low satisfaction, comfort, or attention, and 5 showed high satisfaction, comfort, or attention.

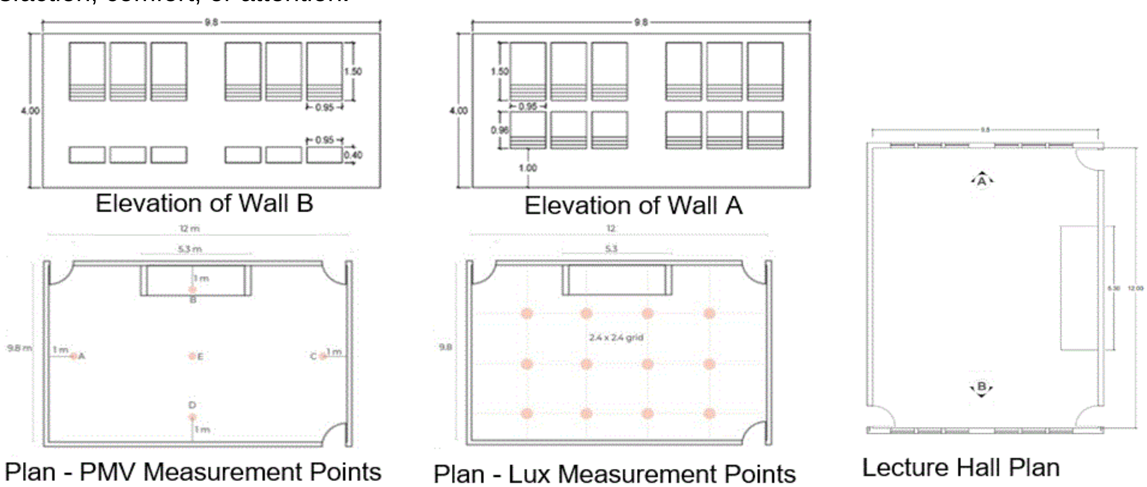

Figure 3. Plan and Elevations of the lecture halls and plans showing PMV and Lux measurement points.

Table 1: List of equipment used and their specifications

Instrument	Measured Parameter(s)	Setting Point	Accuracy	Photos
Delta Ohm Thermal comfort Microclimate Data Logger	Air Temperature Globe Temperature Wind Speed Relative Humidity PMV	0.6 m level for seated occupants and 1.1 m level for standing occupants.	Temperature: 1/3 DIN R.H.: ±1.5% (0…90%RH) / ±2% (90…100%RH) @ T=15…35 °C (1.5 + 1.5% measure) % @ T= remaining range; ± (0,05 + 5% measure) m/s	
Light Meter	Lux	Work plane level (1m)	± 5%	

A total of 209 students participated in the survey, with each session involving 30 to 40 respondents (Table 2). The rationale for combining physical measurements with a questionnaire survey was to understand how environmental factors affect students' attentiveness comprehensively. Physical measurements provided objective, quantitative data on thermal and lighting conditions, while the questionnaire survey offered qualitative insights into students' perceptions and experiences. By integrating qualitative and quantitative data, the study aimed to analyze the impact of light conditions and thermal comfort on students' attentiveness in the chosen lecture halls. This holistic approach ensured a robust analysis, capturing measurable environmental parameters and subjective human responses.

Quantitative data, such as PMV, lux levels, and temperature, were analyzed with various statistical methods. The methods used were mean, mode, standard deviations, and percentages for the two lecture halls for each of the three sessions. Qualitative data used a Likert scale of 1 through 5 to find satisfaction, comfort, and attention levels, where 1 was for low and 5 for high satisfaction. The mean, mode, relative satisfaction index, and standard deviations were subsequently obtained from this data.

Percentages of the data were calculated for each lecture hall, each session across the three days, and for different genders to ensure a comprehensive analysis. Graphical representations, including charts and graphs, were created to visualize the processed quantitative and qualitative data, allowing for a clearer understanding of the insights related to students' thermal and visual comfort and uncover deeper patterns. This provided for the structured approach to data processing and analysis to conduct a robust evaluation of the environmental condition-user satisfaction relationships. This was useful in showing how variations in thermal and visual comfort resulted in variations in student attention and overall engagement in educational settings through the correlation of quantitative metrics with qualitative feedback.

Table 2: Measurement and Survey Data Collection Schedule

Classroom	Date of Measurement	Time of Measurement	Data Recorded	Sample Size
LH-1	27.03.2024	Morning	Air Temperature (Ta), Globe Temperature (Tg), Wind Speed (Va), Relative Humidity (RH), PMV, Lux.	39
LH-3	27.03.2024	Morning		31
LH-1	27.03.2024	Afternoon		38
LH-3	27.03.2024	Afternoon		35
LH-1	28.03.2024	Evening		32
LH-3	28.03.2024	Evening		34

3. Results and Analysis

3.1 Results

This section gives the results obtained both through quantitative measurements and qualitative surveys. The formers are given by temperature, relative humidity, wind speed, PMV, and Lux levels, which help us qualify the environments studied in this research; the latter, based on survey responses, explain participants' experiences in that environment.

The physical measurements conducted in the two lecture halls, LH-1 and LH-3, revealed distinct differences in the thermal and lighting conditions. LH-1 & LH-3 have similar temperatures in the morning, followed by

LH-1 having higher temperatures than LH-3 in the afternoon and evening, with an average increase of 0.9°C in the evening (Figure 4).

In the case of RH, LH-1 is seen to have a decreasing trend from morning to evening, with morning RH at 69% and evening RH at 58%, whereas in LH-3, the RH seems to decrease and then slightly increase by evening (Figure 4). In both lecture halls, a downward slope is observed in the average wind speed from morning to evening, with the maximum wind speed of 0.68 m in the morning in LH-1 (Figure 4).

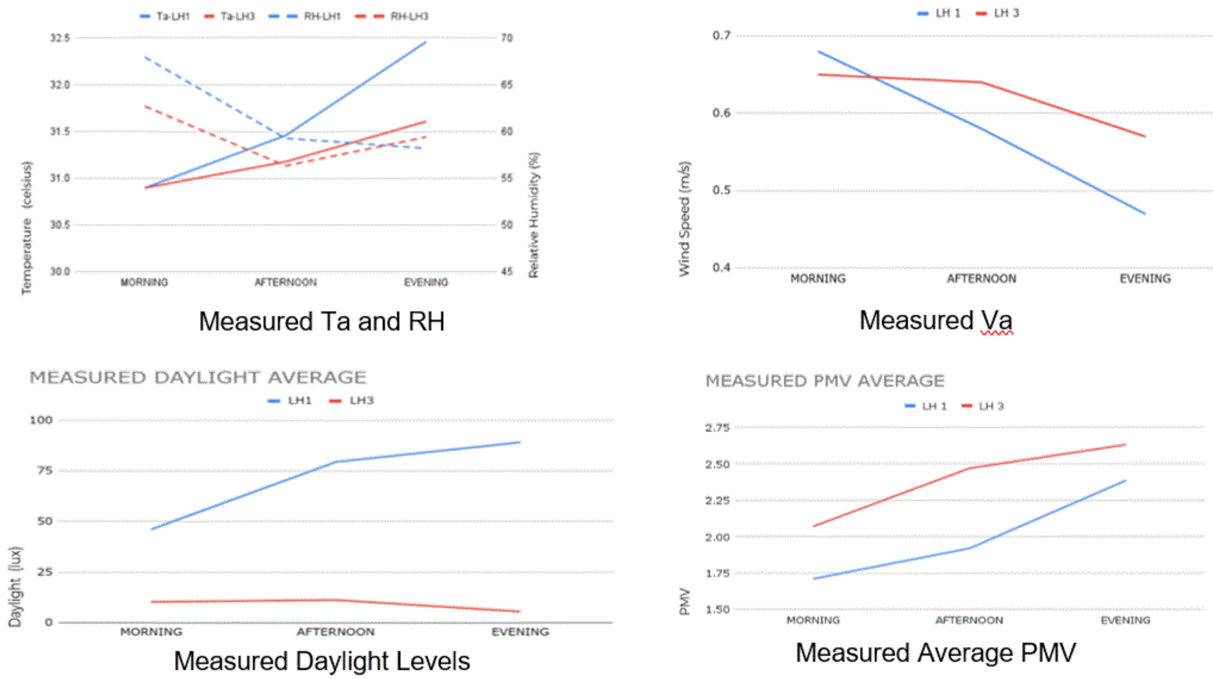

Figure 4. Measured Data of Ta, RH, Va, PMV and Daylight levels.

Concerning Mean PMV, a thermal comfort index, at all three times of measurement, it was lower in LH-1 compared to LH-3 (Table 3); this could be attributed to the orientation of both rooms concerning the sun angle in May. The lux level measurements showed a significant difference between the two lecture halls; LH-1 was well-lit, with mean lux values ranging from 46.26 to 89.23 across the day, while LH-3 had poor lighting conditions, with mean lux values between 5.63 and 11.33 only when measured during the daytime, this could be attributed to the blackening of windows in LH-3 (Figure 5). The questionnaire survey results provided insights into the students' subjective experiences in the two lecture halls (Figure 6).

Table 3: Measured PMV at various points in each lecture hall at different timeframes of the day.

Points	LH1 Morning	LH3 Morning	LH1 Afternoon	LH3 Afternoon	LH1 Evening	LH3 Evening
A	1.8	1.97	2.04	2.44	2.40	2.64
B	1.62	2.07	1.82	2.49	2.39	2.63
C	1.72	2.14	1.92	2.52	2.34	2.63
D	1.62	2.07	1.83	2.45	2.39	2.59
E	1.78	2.08	1.98	2.45	2.41	2.67

3.2 PMV Analysis

The provided PMV values offer a comprehensive lens to analyze the thermal dynamics and comfort levels within lecture halls LH-1 and LH-3 in Tiruchirappalli. LH-3, with its elongated wall oriented towards the North East, presents a scenario of heightened thermal discomfort, evident in consistently elevated PMV values across all time segments (Figure 4). Conversely, LH-1, boasting a southwest orientation, benefits from an ameliorating influence—an adjacent building strategically positioned to the southwest effectively shades it from direct solar radiation, resulting in comparatively lower PMV readings. This shading mechanism is particularly pronounced during the morning and afternoon sessions, where LH-1 consistently maintains more excellent thermal conditions than LH-3. However, despite this advantageous shading, LH-1 experiences a gradual escalation in PMV values during the evening hours, hinting at a potential waning efficacy in shading as the day progresses.

Furthermore, the intricacy deepens with the revelation that LH-3 incorporates blackened windows to mitigate heat transfer into the lecture hall. While this intervention ostensibly curtails heat ingress, it inadvertently leads to reduced daylight levels within the space. Consequently, LH-3 grapples with heightened thermal discomfort and compromised illumination levels, potentially impacting the learning environment. In the case of LH-3, where PMV values indicate overheated conditions and compromised illumination levels due to reduced daylight, occupants are likely to experience reduced attentiveness and engagement. Combining thermal discomfort and suboptimal lighting conditions can create an environment more conducive to effective learning and participation. Similarly, while LH-1 benefits from comparatively lower PMV values and potentially better daylight availability, the gradual escalation in PMV values during the evening hours hints at a potential decline in thermal comfort, which could also affect attentiveness and engagement levels, albeit somewhat compared to LH-3. The PMV values in both lecture halls indicate thermal discomfort, according to ASHRAE 55.

Figure 5. Lux data was recorded for LH 1 & LH 3 at different times.

3.3 Lux Level Analysis

The measured lux levels provide a window into the daylighting conditions within lecture halls LH-1 and LH-3 across various times of the day (Figure 4, 5). It's evident that LH-1 consistently enjoys higher illumination levels than LH-3, indicating superior daylighting. This disparity is most noticeable during the morning and afternoon sessions, where LH-1 records significantly higher lux levels. The orientation of the lecture halls contributes to this discrepancy, with LH-3's longer wall facing the northeast, receiving limited direct sunlight. Additionally, LH-3's blackened windows further diminish daylight penetration, exacerbating the disparity in illumination levels.

In contrast, LH-1 benefits from a nearby building to the southwest, which effectively shades it from direct sunlight. This strategic placement allows ample natural light to permeate LH-1, resulting in consistently higher lux levels. However, during the evening session, both lecture halls experience a relative increase in lux levels, with LH-1 maintaining its lead over LH-3, albeit somewhat.

The differing daylighting conditions underscore the impact of orientation, shading, and window treatments on interior illumination levels. While LH-1 boasts a favorable balance of natural light and thermal comfort, LH-3 grapples with compromised daylighting due to its orientation and window treatments. The above thermal and visual comfort analysis leads us to conclude that users' attentiveness and engagement responses may be more influenced by the daylight levels, given that both lecture halls have similar PMV values.

3.4 Analysis of User Thermal Satisfaction

The analysis of user thermal satisfaction (Figure 6), as gauged through Likert-scale questionnaires, provides crucial insights into the perceived comfort levels within lecture halls LH-1 and LH-3 across different times of the day. Beginning with LH-1, 38.46% of respondents expressed slight dissatisfaction with thermal comfort during the morning session, while a substantial 33.33% reported feeling neutral. This sentiment persists into the afternoon session, where dissatisfaction levels escalate significantly to 60.53%, with an additional 18.42% remaining neutral. However, there's a notable shift by evening, with only 6.25% expressing complete dissatisfaction, while 37.50% report feeling slightly satisfied.

In contrast, the thermal satisfaction dynamics within LH-3 follow a similar trajectory but with heightened dissatisfaction levels. In the morning, 54.84% of respondents report slight dissatisfaction, with 25.81% feeling neutral. These sentiments intensify during the afternoon, with 38.24% expressing slight dissatisfaction and 23.53% remaining neutral. By evening, while there's a slight decrease in dissatisfaction levels, with only 11.76% expressing complete dissatisfaction, 58.82% still report slight discontent.

Connecting these findings with the previously shared PMV values, which indicate overheated conditions in both lecture halls, reveals a consistent alignment between perceived thermal comfort and objective measurements. LH-3, characterized by elevated PMV values and compromised daylighting due to blackened windows, correlates with higher user dissatisfaction rates. Conversely, LH-1, despite experiencing overheated conditions, benefits from shading provided by the adjacent building, leading to comparatively lower dissatisfaction levels, especially during the evening session when the shading mechanism proves most effective.

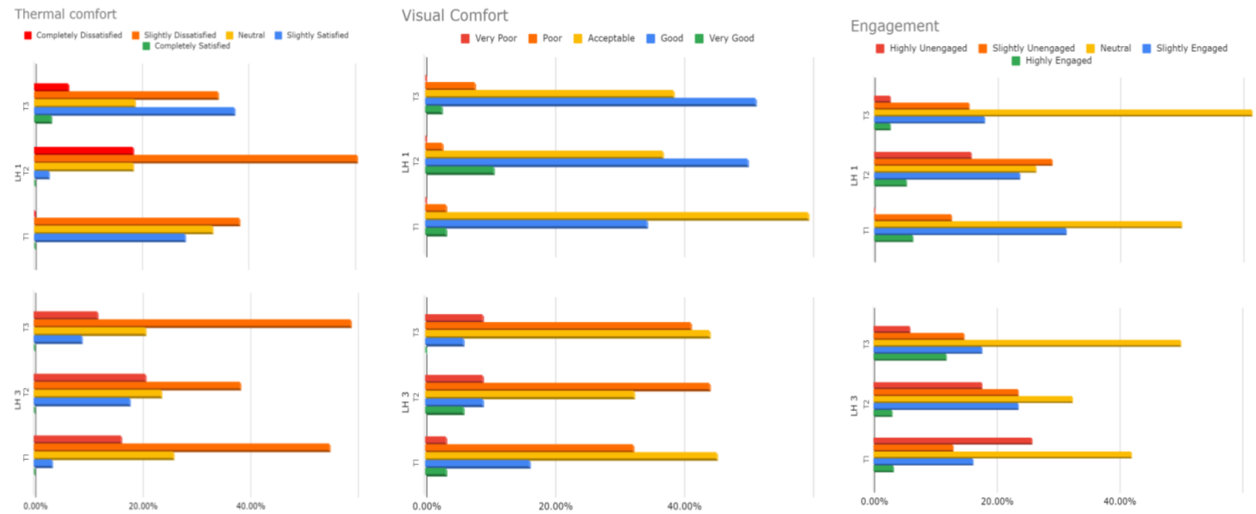

Figure 6. Results of the questionnaire survey regarding thermal comfort, visual comfort, and engagement for LH-1 and LH-3.

3.5 Analysis of User Visual Satisfaction

Analyzing user satisfaction with visual comfort offers valuable insights into the perceived quality of illumination within lecture halls LH-1 and LH-3 across different time segments (Figure 6). Beginning with LH-1, during the morning session, an overwhelming majority of respondents, comprising 89.74%, report either acceptable, good or very good visual comfort, with 51.28% rating it as good and 2.56% as very good. This positive sentiment persists into the afternoon, with 60.53% expressing satisfaction levels ranging from good to very good. Interestingly, although there's a slight decline in satisfaction levels by evening, a substantial 62.51% still rate visual comfort as acceptable, good, or very good.

Conversely, the visual comfort dynamics within LH-3 exhibit a different trend, reflecting the impact of its unique design features and orientation. In the morning session, while 48.39% of respondents rate visual comfort as acceptable or sound, 35.48% express dissatisfaction, with 32.26% rating it as poor. These dissatisfaction levels intensify during the afternoon, with a significant 53.24% rating visual comfort as inadequate or inferior. By evening, although there's a slight improvement, with only 50.00% rating it as poor or very poor, a notable 44.12% still express dissatisfaction, indicating persistent challenges in achieving satisfactory visual comfort levels.

Connecting these findings with the previously shared lux level measurements unveils a noteworthy correlation between perceived visual comfort and objective illumination levels. LH-1 consistently records higher lux levels than LH-3, aligning with the higher satisfaction rates observed among users. This disparity can be attributed to LH-1's advantageous orientation and shading mechanism, allowing ample natural light penetration, especially during morning and afternoon sessions. In contrast, LH-3, with its compromised daylighting due to blackened windows and unfavorable orientation, struggles to provide adequate illumination, resulting in lower satisfaction levels among users.

3.6 Analysis of User Engagement Levels

Analyzing user engagement levels, as indicated by Likert-scale questionnaires, provides valuable insights into the level of attentiveness and involvement of students within lecture halls LH-1 and LH-3 across different times of the day (Figure 6). Beginning with LH-1, during the morning session, most respondents, comprising 81.05%, report feeling either neutral or slightly engaged, with 61.54% expressing a neutral stance. This trend persists into the afternoon, albeit with a slight shift towards higher engagement levels, as 29.94% of respondents report feeling slightly engaged. By evening, there was a notable increase in engagement, with 37.50% of respondents expressing slight or high engagement.

In contrast, the engagement dynamics within LH-3 exhibit a different pattern, reflecting the impact of its unique design features and orientation. In the morning session, a significant proportion of respondents, comprising 41.94%, reported feeling neutral, while 38.71% expressed some level of disengagement, with 25.81% feeling unengaged. These trends persist into the afternoon, with 42.94% of respondents reporting slight or high disengagement. By evening, while there's a slight improvement, with only 20.59% expressing slight disengagement, a notable 17.65% still report feeling unengaged.

Connecting these findings with the earlier thermal comfort and visual comfort analyses unveils a nuanced interplay between environmental conditions and user engagement levels. LH-1, characterized by superior thermal and visual comfort, correlates with higher levels of user engagement, especially during afternoon and evening sessions. This positive correlation suggests that comfortable environmental conditions enhance student attentiveness and engagement. Conversely, LH-3, with its compromised thermal comfort and visual comfort due to blackened windows and unfavorable orientation, experiences lower levels of user engagement, highlighting the detrimental impact of suboptimal environmental conditions on student involvement.

3.7 Comparative Analysis of Measured Data and User Satisfaction / Engagement Levels

Analyzing the relationship between mean user visual satisfaction and measured lux levels unveils intriguing insights into the impact of environmental factors on perceived comfort within lecture halls LH-1 and LH-3 (Figure 7). Commencing with the lux levels, LH-1 consistently exhibits higher average illumination across all three times than LH-3. For instance, during the morning session, LH-1 records an average lux level of 46.26, significantly surpassing LH-3's 10.39 lux. This disparity persists throughout the day, with LH-1 maintaining higher lux levels during the afternoon (79.55 vs. 11.33 lux) and evening (89.23 vs. 5.63 lux) sessions. Connecting these lux measurements with the mean visual comfort questionnaire results further elucidates the relationship between illumination and user satisfaction. In LH-1, where lux levels are notably higher, the mean satisfaction level for visual comfort consistently exceeds that of LH-3 across all times. During the morning session, LH-1 achieves a mean satisfaction level of 3.49, compared to LH-3's 2.84. This trend persists into the afternoon and evening sessions, with LH-1 boasting mean satisfaction levels of 3.68 and 3.38, respectively, while LH-3 lags with mean satisfaction levels of 2.57 and 2.47. These findings underscore the pivotal role of adequate illumination in fostering user satisfaction with visual comfort. The substantially higher lux levels in LH-1, facilitated by its advantageous orientation and shading mechanism, correlate with higher mean satisfaction levels among users. In contrast, the compromised daylighting conditions in LH-3, attributed to its blackened windows and unfavorable orientation, coincide with lower mean satisfaction levels, underscoring the adverse impact of suboptimal lighting on perceived comfort.

Figure 7. Comparison of measured lux levels with user satisfaction on visual comfort (left); Comparison of PMV levels with user satisfaction on thermal comfort (center); Comparison of lux levels with user response on engagement (right).

Analyzing the relationship between user thermal comfort satisfaction and measured PMV levels sheds light on the prevailing conditions within lecture halls LH-1 and LH-3 (Figure 7). Beginning with the PMV levels, LH-1 consistently maintains lower average PMV levels compared to LH-3 across all three times. For instance, during the morning session, LH-1 records an average PMV of 1.71, whereas LH-3 registers a higher PMV of 2.07. This trend persists throughout the day, with LH-1 exhibiting lower PMV levels during the afternoon (1.92 vs. 2.47) and evening (2.386 vs. 2.632) sessions.

Connecting these PMV measurements with the mean thermal comfort questionnaire results provides valuable insights into user satisfaction. In LH-1, where PMV levels are comparatively lower, the mean satisfaction level for thermal comfort tends to be higher than that of LH-3. During the morning session, LH-

1 achieves a mean satisfaction level of 2.9, whereas LH-3 records a lower level of 2.16. However, this trend reverses during the afternoon, with LH-1 exhibiting a lower mean satisfaction level of 2.05 than LH-3's 2.37. By evening, LH-1 again surpasses LH-3 in mean satisfaction levels, with values of 2.97 and 2.26, respectively.

These findings highlight the significant impact of PMV levels on user thermal comfort satisfaction. Lower PMV values in LH-1 correspond to higher satisfaction levels among users, indicating a more comfortable thermal environment. Conversely, higher PMV levels in LH-3 coincide with lower satisfaction levels, indicative of thermal discomfort. Optimizing thermal conditions to maintain lower PMV values is crucial for enhancing user comfort and satisfaction within educational environments.

Analyzing the relationship between user engagement and measured lux levels in lecture halls LH1 and LH3 provides insights into the influence of lighting conditions on student participation (Figure 7). LH1 consistently maintains higher average lux levels than LH3 across all three times. For instance, during the morning session, LH1 records an average lux level of 46.26, significantly higher than LH3's 10.39 lux. This trend persists throughout the day, with LH1 exhibiting higher lux levels during the afternoon (79.55 vs. 11.33 lux) and evening (89.23 vs. 5.63 lux) sessions. Connecting these lux measurements with the mean user engagement values reveals exciting patterns. In LH1, where lux levels are consistently higher, the mean user engagement tends to be elevated. For example, during the morning session, LH1 achieves a mean user engagement level of 3.03, while LH3 records a lower level of 2.58. Similarly, LH1 maintains higher mean user engagement values during the afternoon and evening sessions than LH3. This suggests that the superior lighting conditions in LH1 positively influence student engagement, fostering a more conducive learning environment.

In contrast, LH3, with its lower lux levels, corresponds to lower mean user engagement scores. Despite minor fluctuations in engagement levels throughout the day, LH3 consistently records lower engagement levels than LH1. This underscores the importance of adequate lighting in promoting active participation and attentiveness among students. Overall, the analysis underscores the significant role of lighting conditions in shaping user engagement within educational settings. Higher lux levels, as observed in LH1, contribute to increased user engagement, while lower lux levels, as seen in LH3, may hinder student participation.

3.8 Gender-wise Analysis of Thermal and Visual Comfort Satisfaction

Comparing gender-wise satisfaction levels based on thermal and visual comfort in lecture halls LH1 and LH3 reveals intriguing insights (Table 4). The data indicates that females generally report higher thermal and visual comfort satisfaction than males. Regarding thermal satisfaction, females exhibit a 71% satisfaction rate in LH1 and 69% in LH3, while males display a 29% satisfaction rate in LH1 and 31% in LH3. Similarly, for visual satisfaction, females report a 69% satisfaction rate in LH1 and 71% in LH3, whereas males show a 31% satisfaction rate in LH1 and 29% in LH3. Cumulatively, the aggregate satisfaction for females across both comfort aspects stands at 70%, significantly higher than the 30% recorded for males. These findings align with existing research suggesting differences in how men and women perceive and respond to environmental stimuli. Studies indicate that women are often sensitive to visual cues and details, contributing to their greater visual comfort in various lighting conditions (Emory University Health Sciences Center, 2004; BioMed Central Limited, 2012).

Table 4: Comfort levels of male and female population

Gender	Percentage of Thermal Satisfaction			Percentage of Visual Satisfaction		
	LH 1	**LH 3**	**Cumulative**	**LH 1**	**LH 3**	**Cumulative**
Female	71%	69%	70%	69%	71%	70%
Male	29%	31%	30%	31%	29%	30%

4. Discussions

In light of these insights, strategic interventions are imperative to optimize thermal comfort and environmental quality within both lecture halls. For LH-3, measures to augment daylighting while preserving the efficacy of heat reduction strategies merit exploration. This could entail integrating alternative window treatments or daylight redirection systems to offset the diminished daylight levels. Conversely, for LH-1, leveraging the existing shading mechanism while augmenting ventilation and passive cooling strategies could enhance thermal comfort without compromising daylight availability. The juxtaposition of orientation, shading, and daylighting interventions underscores the multifaceted nature of environmental design considerations in educational spaces. By judiciously navigating this intricate interplay, stakeholders can endeavor to cultivate environments prioritizing occupant comfort, productivity, and well-being.

5. Conclusions

The comprehensive analysis of user responses, encompassing thermal comfort satisfaction, visual comfort satisfaction, and engagement levels across different times of the day within lecture halls LH-1 and LH-3, yields profound insights into the multifaceted dynamics shaping the learning environment. Examining the PMV values alongside user satisfaction data reveals a consistent trend of overheated conditions within both lecture halls, signifying a pervasive discomfort experienced by students. This discomfort is further corroborated by the Likert-scale questionnaire responses, wherein many student's express dissatisfaction with thermal conditions, particularly during the afternoon sessions. Notably, while LH-1 benefits from a shading mechanism that moderates thermal conditions to some extent, LH-3's blackened windows, while intended to mitigate heat transfer, inadvertently exacerbate discomfort, highlighting the pivotal role of environmental design in mitigating thermal stress.

Delving deeper into the analysis, the lux level data unveils a pronounced discrepancy in daylighting between the two lecture halls, with LH-1 consistently enjoying higher levels of natural light throughout the day. This divergence in daylighting levels aligns with user responses regarding visual comfort satisfaction, where LH-1 outperforms LH-3 across all time segments. The influence of daylighting on student experiences is underscored by the parallel trends observed in engagement levels, with LH-1 demonstrating a more balanced distribution of engagement across different times of the day than LH-3. The correlation between visual comfort, daylighting levels, and student engagement highlights the crucial impact of environmental stimuli on cognitive processes and active participation. Gender-based analysis shows that females typically report higher satisfaction with thermal and visual comfort compared to males, supporting existing research on gender differences in environmental perception. This study provides valuable evidence that classroom design significantly affects student engagement and satisfaction, urging designers and educators to prioritize these elements in educational environments. The findings underscore the complex interaction between ecological factors, user satisfaction, and gender dynamics, emphasizing the need for thoughtful design to create inclusive and effective learning spaces. Research could further explore the relationship between environmental distractions, cognitive overload, and individual predispositions in attention wandering during lectures. This could help educators develop strategies to mitigate these factors and promote sustained attention and engagement. Further research in this area could explore the effectiveness of specific interventions that optimize classroom conditions to enhance attentiveness and academic performance.

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Conflicts of interest

The Authors declare that there is no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors/s.

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