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Evaluation of thermal comfort in University Classrooms of Pakistan

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Abstract

In the present research work, the thermal comfort of an educational building in a semi-arid climate of Lahore, Pakistan has been analyzed based on the PMV-PPD method using a subjective scale in terms of acceptability, neutrality, and preference, considering the impact of gender. Firstly, this study examine how the temperature affects occupants' (male and female) comfort levels in current university classrooms during the winter and summer. Secondly, how occupant behavior affects thermal comfort, productivity, and health well-being to determine how future buildings should be designed to accommodate gender preferences. Thirdly, the study recommends retrofitting approaches for building systems that satisfies inhabitants' thermal requirements, to meet economical and energy efficiency needs. This study revealed that females were more affected by winter conditions while males were more affected by higher temperatures in summers which is the longest season of the year. In both seasons, males found a frequent impact of thermal comfort, due to which more productivity loss was observed in them in comparison to females. In winter, females were more affected form SBS, and in summer, males showed more symptoms of getting affected by SBS. The overall percentage saving in energy consumption was found 27 % for considered Building compared with retrofitted simulated model of building systems. It is suggested that a well-insulated indoor thermal environment is the need of the hour for classrooms in university buildings to improve the thermal comfort conditions, productivity and health conditions of the occupants for both seasons.

Keywords: Thermal Comfort; Building Occupants; Building Performance; Productivity; Sick Building Syndrome

1. Introduction

The economic development and well-being of a nation are significantly influenced by environmental and energy challenges. The buildings and building construction sectors account for nearly 40% of global energy consumption and contribute around 33% of greenhouse gas emissions [1]. With the rapid growth of the population and the increasing need for energy-consuming appliances such as air conditioning in emerging countries, the energy demand for buildings is projected to continue to climb [2]. Many cities throughout the world have set targets to enhance energy efficiency and cut greenhouse gas (GHG) emissions, aiming to mitigate the environmental impact and achieve long-term sustainable development. In modern societies, people spend a substantial portion of their time indoors, approximately 20 hours per day [3]. This high energy consumption is primarily driven by the need to maintain a comfortable indoor thermal environment, making it one of the most pressing global challenges [4]. Therefore, accurate quantifying of building energy consumption has become a prominent concern. Achieving a significant reduction in energy consumption, targeting a range of 50-90% over the next 30 years, is crucial for resource conservation [5].

In order to enhance energy consumption forecasting and attain improved energy efficiency, professionals from academic and industrial domains have directed their focus toward identifying prospects for energy-saving interventions, particularly within individual buildings [6]. Numerous factors exert influence on the energy consumption of buildings, encompassing climate conditions, the integrity of the building envelope, the efficiency of building equipment, the effectiveness of operation and maintenance practices, occupant behavior, and the quality of the indoor environment [7, 8]. Among these, occupant behavior has been highlighted by several studies as a crucial element affecting building energy demand, which explains the reason for the large gap between current and predicted energy demands [9].

One of the numerous elements that affect occupant happiness is indoor environmental quality (IEQ). A high IEQ value is essential since it influences the inhabitants' health and mood [10] as well as the building's energy efficiency and consumption [11-13]. Educational buildings are special types of buildings with the prime objective of providing a conducive environment to promote teaching and learning [14-17]. In the context of educational buildings, which exhibit heterogeneous spatial usage, diverse social and geographical contexts, and cultural dimensions, achieving thermal comfort has garnered considerable attention from researchers [18, 19]. Given that students spend approximately 30% of their time in classrooms, the classroom environment directly affects their physical and mental health, as well as their learning performance and concentration [20-23]. Therefore, the thermal environment plays a pivotal role in classroom design, aiming to enhance concentration and learning efficiency [24]. Consequently, there is a pressing need to propose practical and effective solutions tailored to achieving comfort in classrooms [25].

In general, occupants have a considerable level of autonomy when it comes to ensuring indoor comfort. They are empowered to customize the heating temperature set point and duration, open windows strategically during the activation of heating and cooling systems, optimize the use of shading elements, and engage in various activities in different areas of the building, thereby promoting a pleasant and personalized environment [26]. These actions and interactions with the environment have a considerable impact on the energy demand and energy-saving performance of buildings [27]. Therefore, it can be inferred that indoor thermal comfort and occupant behavior have a profound impact on building energy consumption, and they are equally important as the implementation of innovative energy-efficient technologies [28]. A survey showed that, compared with visual, auditory comfort, and indoor air quality, thermal comfort is more important for building occupants [20].

Over the past three decades, there has been extensive research conducted on the relationship between thermal comfort, student performance, well-being, and indoor environmental parameters such as acoustics and lighting in educational buildings [29]. Classrooms, in particular, have higher occupancy density compared to other workplaces, with four times the density of office buildings. The non-conductive thermal environment in classrooms can significantly impact occupants, with studies showing that high classroom temperatures can reduce performance levels by up to 30% and increase the likelihood of absenteeism by 1.28 times compared to students in low-exposure environments [30]. Conversely, a healthy learning environment improves test scores, reduces absenteeism, and enhances the productivity of both teachers and students [31]. Many countries rely on natural ventilation in educational buildings, with only around 12% utilizing mechanical or hybrid ventilation. Researchers worldwide have dedicated substantial efforts to theoretical analysis, simulation, and experimental validation in the field of thermal comfort assessment [5]. China leads in

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terms of the number of publications on thermal comfort assessment, with contributions also coming from South Korea, Japan, India, and Brazil [32].

The most important factors to consider when designing interior spaces are pleasant temperature sensations, excellent work performance, and a low incidence of sick building syndrome (SBS). Research showed that guys performed better at work, were more comfortable, and had a lower frequency of SBS than females in chilly conditions. It was discovered that the balanced ideal temperature ranges for males and females, respectively, were 17.3-22.0 °C and 18.5-20.8 °C, with fewer than 30% of all subjects displaying chilly feelings, poor job performance, and overt SBS symptoms [33]. It was also found that hotness feelings from male and female students differed significantly ($p < 0.001$). For female students, the neutral temperature was one degree higher than for male students[34]. The optimal indoor temperature for high performance of office duties is 25.8 °C, and when the temperature was 22.0–26.0 °C, workers' productivity did not significantly decline[35] [36] [37]. Additionally, when the temperature rose above 28.0 °C, the workers' performance was significantly reduced [37].

While evaluating students' thermal perceptions and behavioral adjustment in NV university classrooms the findings show that pupils are well accustomed to the severe summer temperatures[38]. The assessment of insulation provided by students' apparel revealed that for male and female students, respectively, the mean clothing insulation values were 0.60 clo and 0.72 clo. Seasonal variations were found to be quite distinct [39]. The ANN model's input parameters included gender, season, gender, indoor and outdoor air temperature, radiant temperature, the temperature at 6 a.m., and running mean temperature. When the model specified in the ASHRAE-55 Standard was used, only 32% of the projected values deviated by less than 0.1 clo from the actual value, as opposed to 50% of the anticipated values [39]. When assessing the thermal environment using the PMV-PPD approach, body motion and air movement have a significant influence on the insulation provided by clothing and must be taken into account. A mere 15% error in metabolic rate estimation crosses the upper limit (0.3 scale units) of the accuracy of PMV [40].

Energy conservation in buildings is often viewed as a trade-off between energy costs and occupant well-being. To promote a good indoor thermal environment, it is essential to further investigate student health and wellness outcomes, indoor satisfaction, and cognitive performance using larger sample sizes [41]. It is the moral responsibility of building consultants to create conducive

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environments that prioritize occupant comfort rather than merely building for survival. However, limited knowledge exists in this domain, and further studies can significantly contribute to resolving the energy crisis within the building sector [42]. Fanger's idea developed via climate chamber tests to claim that an individual's metabolic rate, clothing insulation, and surroundings could all be taken into account when determining thermal comfort[39].

To conduct a study on classroom environments, inspired by Fanger's groundbreaking idea concerning thermal comfort, incorporating factors such as an individual's metabolic rate, clothing insulation, and the overall surroundings. By analyzing these objective assessment parameter, it will aid in how students' thermal comfort is affected in classroom settings. In the widely used ASHRAE 55 and ISO 7730 standards for assessing indoor environments, thermal comfort is now described as "the condition of mind which expresses satisfaction with the thermal environment." Table 1 shows the comparison of these factors between ASHRAE 55-2017 & ISO 7730.

Table 1 Comparison between ASHRAE 55-2017 & ISO 7730

Environmental Parameters	ASHRAE 55-2017	ISO 7730	Thermal Comfort
Humidity	30% to 60%	30 to 60%	Maximum
Air Temperature	20°C to 23.5°C (68°F to 74.3°F)	20°C to 27°C (68°F to 81°F)	Maximum
Radiant Temperature	20 to 25 °C (68 to 77 °F)	20 to 25 °C (68 to 77 °F) [1]	Maximum
Air Velocity	0.15 m/s to 0.25 m/s	0.15 to 0.25 m/s	Maximum
Clothing insulation (Summers)	0.5 to 1.0 clo (for sedentary activities)	0.5 to 1.0 clo (for sedentary activities)	Maximum
Metabolic rate	1.0 met	1.0 met [1]	Maximum

Occupants' perspective in thermal comfort assessment is of primary concern, it is necessary to understand in-depth concerns of key energy-saving mechanisms to conserve resources. Occupant's perspective is changed taking into account their gender. Although there are various standards available on thermal comfort but these international standards are inadequate[43] for climatic conditions in Pakistan and this area is under explored yet. Previous studies depicts indoor environment impacts thermal comfort of occupants and they live in dynamic thermal environment.[44]

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Hence, this research had analyzed in detail thermal indoor environment of classrooms from the view point of gender differences through subjective assessment and energy optimization in case study building. Since, Pakistan is going through sever energy and economic crisis to conserve resources for extreme climatic conditions this research can help to find roadmap to reduce this crisis.. Moreover, such studies help to design energy efficient and occupant friendly building in terms of reduced energy bills. The climate change has severely affected Pakistan's economy consequently, high inflation is experienced by the local masses. Pakistan has not yet established a standard unified database for thermal comfort assessment and improvement in existing building performance like developed countries to cater its energy demands. Considering the differences in cultural contexts on perception, preference, and acceptance of building occupants in different countries and regions the trends are variable. Thus, it is the need of the hour to assess thermal comfort in buildings to facilitate researchers, which is valuable for architects, engineers, and the construction industry to move forward for the development of the energy-efficient building. The detail of the research objectives to be achieved in this study is as follows: i) Investigate occupant's thermal comfort in extreme summers and winters through subject assessment to understand existing thermal environment of classrooms. ii. Analyze the occupant behavior (males and females) influencing thermal comfort needs, productivity, and health well-being in existing conditions iii) Suggest optimized retrofitting techniques to make existing classrooms comfortable enough to satisfy the occupants thermal needs, considering energy-efficient and cost-effective building design for future as well.

2. Methodology

The field study employed a comprehensive methodology encompassing experimentation and questionnaire surveys to assess the indoor thermal perception of students. The methodological workflow developed for this study is visually depicted in Fig. 1, outlining the systematic approach utilized in the research process. First of all, a wide scale literature review was done focusing on relevant books, journal papers, and conference papers using the appropriate keywords e.g. thermal comfort, PMP, and PPD methods, etc. focusing on the recent research by taking into account the last 10 years data. Based on a strong literature work subjective assessment survey was conducted in May and June for summer 2022 and Dec, and Jan 2022 for winter. Out of these only linear geometry classrooms were selected with the natural ventilation system. Then, a case study building is selected on the basis of available site information, visual survey and objective assessment in classrooms. Mean

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values of temperature indoor and outdoor, humidity, air velocity for calculation of PMV and PPD percentage with help of CBE calculator [45, 46]. Subjective Assessment questionnaire was analyzed and compared on the basis of gender preferences. (Previously gender preferences in this region was not calculated before).

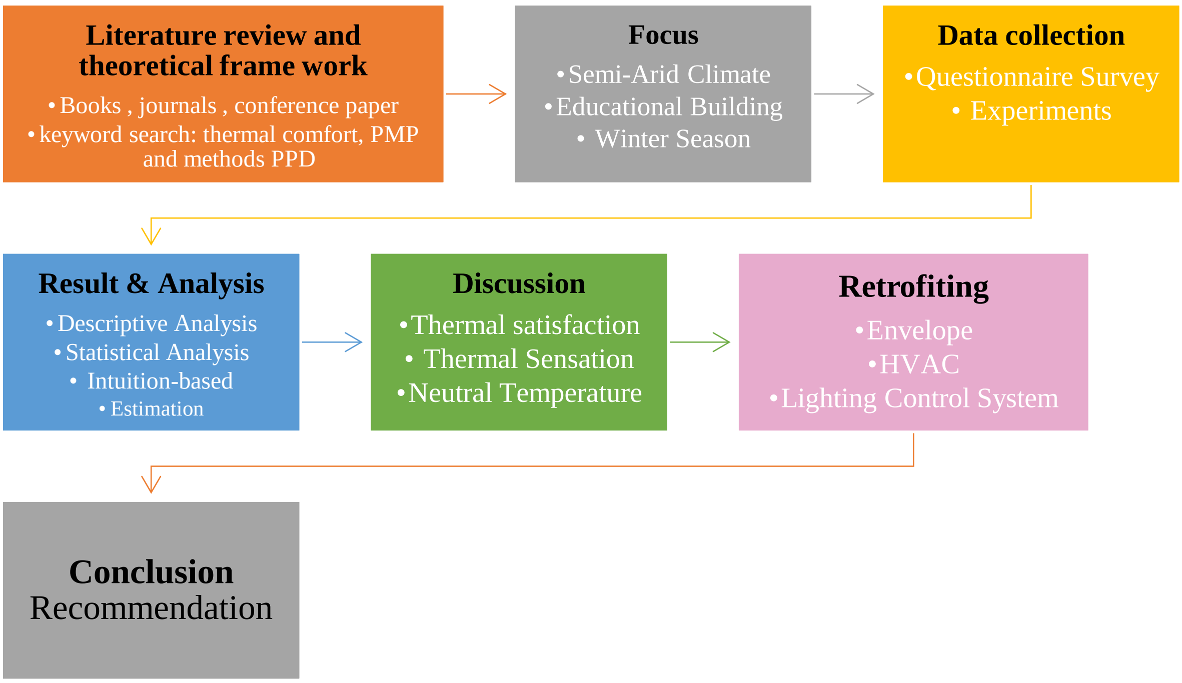

Figure 1 Methodological Workflow of thermal comfort assessment

In the next stage, retrofitting techniques were identified at the possible retrofitting areas keeping in mind environmental conditions, economically viable solutions, and eco-friendly. The priority given for the selection of retrofitting techniques was maximum energy saving, literature review, and availability of indigenous materials. Retrofitting is proposed for the Envelope, HVAC and lighting control system and a comparison of the simulated model before and after retrofitting is made for improvement in the thermal comfort of occupants after energy analysis on Green Building Studio, Dialux, and Hap. At the final stage, an analysis of results was conducted and conclusions were deduced through comparative analysis for better energy performance.

2.1.Data Collection

Site Analysis: The field investigation was performed from (May-June, 2022) and (Nov. to Dec., 2022), at the University of Engineering and Technology, which is located in Lahore, Pakistan for summers and winters respectively. Lahore, the cultural capital of Pakistan, stands as one of the country's largest cities, bustling with a population of over 11 million people, making it a vibrant metropolis. As presented in Table 2 a hot semi-arid climate, Lahore experiences scorching outdoor temperatures in summer (usually above 30 °C) and mild winters (usually less than 20°C), located in the northeastern part of Pakistan (N 31° 34' 46.7256", E 74° 21' 15.6564").

Table 2: Climatic Conditions at Lahore

City	Yearly Mean Temperature	Avg. Yearly Humidity	Avg. Solar Radiation	Avg. Sunshine Hours per year	Avg Yearly Wind Speed	Climate Type
-	°C	%	kWh/m^2	hrs./year	mph	-
Lahore	24.3	58.5	1900-2200	3035	5	semi-arid

2.2.Questionnaire Design:

In this study, both subjective evaluations and objective physical measurements were used for assessment of thermal comfort. The questionnaire was designed on the basis of the parameters and relevant indicators taken from the literature review. The design of the questionnaire adhered to the guidelines outlined by ASHRAE-55 for the assessment of thermal comfort. The questionnaire responses were distributed into the following six sections to evaluate personal factors, building information, thermal comfort its impact on preference, sensation, acceptance, productivity, ventilation and health conditions shown in Table 3.

Table 3 Scales for subjective assessment

	Thermal comfort Scales	Thermal Sensation Vote	Thermal Preference Vote	Thermal Acceptance Vote	Airflow Acceptance Vote	Productivity Effect Vote	Productivity Rate Vote
	TC overall	TSV	TPV	TAV	VAV	PEV	PRV
-3	Extremely Comfortable	Cold	Much Cooler	-	-	Very Frequently	-
-2	Comfortable	Cool	Cooler	Acceptable	Acceptable	Frequently	Much Less Than Normal
-1	Slightly Comfortable	Slightly Cool	Slightly Cool	Slightly Acceptable	Slightly Acceptable	Occasionally	A Little Less Than Normal

0	Neither	Neither	Neither	Neither	Neither	Neither	Normal
1	Slightly Uncomfortable	Slightly Warm	Slightly Warmer	Slightly Unacceptable	Slightly Unacceptable	Rarely	A Little More Than Normal
2	Uncomfortable	Warm	Warmer	Unacceptable	Unacceptable	Very Rarely	Much More Than Normal
3	Extremely Uncomfortable	Hot	Hot	-	-	Never	-

2.3. Experimental Setup:

Various types of instruments were utilized in the objective experimental measurements to measure the environment variables such as outdoor and indoor temperature, humidity, and air velocity for both seasons. Table 4 below provides a general overview of the measurement equipment.

Figure 2 Experimental Setup

Table 4 Information of Instruments for Objective assessment of Thermal Comfort

No	Parameters	Instrument	Range	Accuracy
1.	Temperature	Wireless Weather station (RF-104)	Temp range:-5°C to 55°C remote sensor: -30°C to 80°C	±1°C
2.	Air Velocity	Digital Anemometer AM - 4826	0.4-30 m/s with 0.1 resolution	±2%
3.	Relative Humidity	Wireless Weather station (RF-104)	20% to 95%	±5%

The occupants' responses to a thermal comfort survey were collected alongside physical measurements of the environmental variables. The Fig. 2 shows the physical measurements setup and Fig. 3 shows position of devices in classroom plan. While Fig. 4 depicts the conduction of the survey in progress in 840 sq. m. class on the first floor of Automotive Department the case study building.

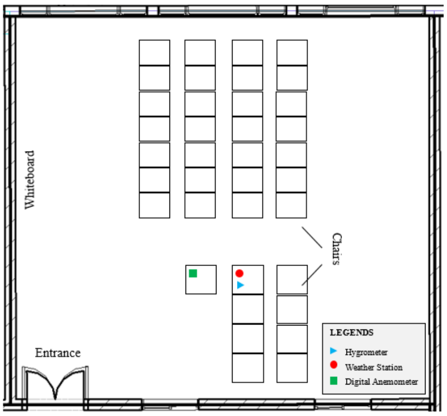

Figure 3 Plans of Classroom selected for experimentation

The view of the case study building façade presents that wall to window ratio (WWR) of the wall on the North is comparatively more than other walls due to large windows on the façade.

Figure 4 The physical measurements and the conduction of the survey was carried out in Automotive Department-

2.4.Case study of the Automotive Department, UET Lahore, Main Campus

The field study was carried out at UET Lahore's Automotive Engineering Department. The department, which was built in 2012–2013, has 1189 square meter land area. A simplified layout plan of the Automotive Department at University of Engineering and Technology Lahore is shown in Fig. 5. A football ground to the north, a mechanical department to the west, a science museum to the south, and a graveyard to the east surround the Automotive Department. The rationale behind choosing the Automotive Engineering Centre was of paramount significance. The primary reason for selecting this facility lies in the fact that it was established before the implementation of the Building Energy Codes of Pakistan (BECP). Consequently, these codes were not considered during the initial phases of design, planning, and construction. Following a thorough site visit, it was identified the

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need for modifications in various fundamental aspects of the structure and building services to align with current energy efficiency standards. To enhance the overall energy performance of the building, implement techniques and strategies aimed at optimizing energy utilization. This endeavor will provide invaluable insights into the effectiveness of these interventions and their potential impact on energy consumption and sustainability within the facility.

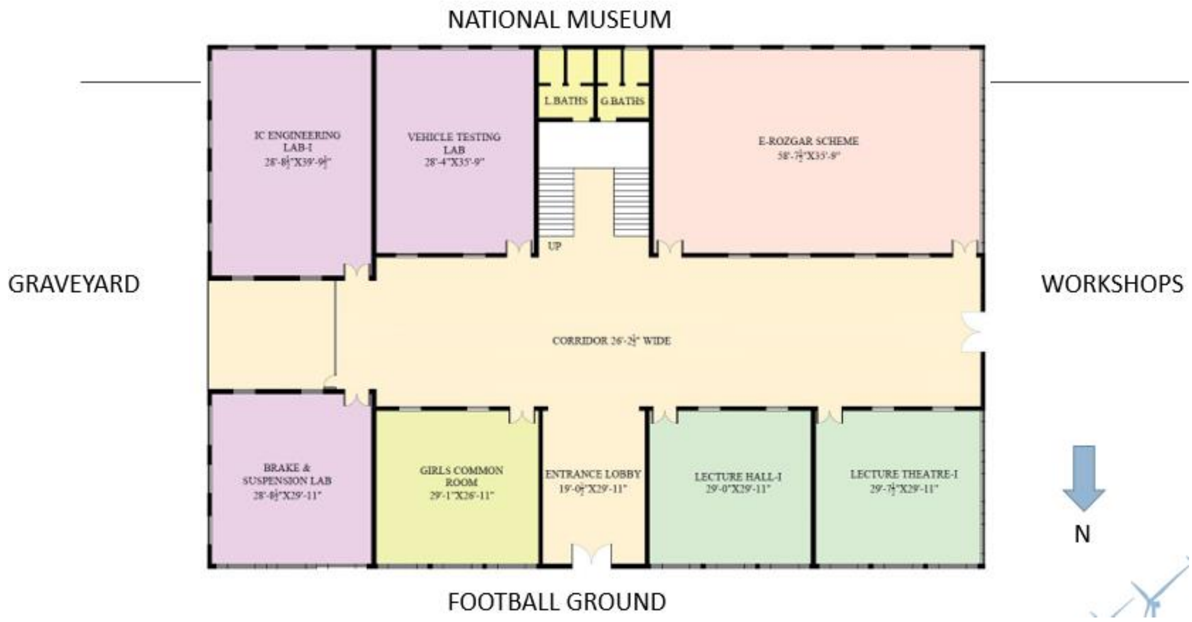

Figure 5 Layout of Automotive Department at University of Engineering & Technology, Lahore, Pakistan

The Department comprised of two floors, featuring a total of eight classrooms. The distribution includes two classrooms on the first level and an additional six on the second floor. Notably, the classrooms' orientation is arranged in a manner where the longer facades are directed towards both the north and south. Given the significance of classroom orientation in the field study assessment, careful consideration of this aspect is imperative. Moreover, Table 5 represents valuable details pertaining to the department's spatial arrangement and structural characteristics, assisting in making informed decisions regarding the suitability of this location for our study.

Table 5 Building Information

Building parameters	**Description/value**	**Building parameters**	**Description/value**
Orientation	Long axis facing north-south	Total glazing area	368.6 m^2
Location	UET Lahore, Pakistan	Window to wall ratio (WWR)	0.58

Project type	Existing	Operating schedule	8AM – 8PM (260 days)
Each floor height	9.15 m (2- storied)	Project Cost	8 Crore Rupees.
Plot area	6903 m^2	Duration of Construction	2012 – 2013
Total exposed area of walls	640m^2	Material of Construction	Bricks, RCC

3. Results and Discussion

The Center for the Built Environment (CBE) Thermal Comfort Tool is for thermal comfort calculations and visualizations that comply with the ASHRAE 55–2017, ISO 7730:2005, and EN 16798–1:2019 Standards results are shown in Fig. 5 for winter and Fig. 6 for summer. The Predicted Mean Vote (PMV), Standard Effective Temperature (SET), adaptive models, local discomfort models, and dynamic predictive clothing insulation shown in Table 6 for winters and Table 7 for summers are among the primary thermal comfort models that are included in it.

3.1.Experimentation for winters:

The measured values for PMV and PPD are deviating from the ASHRAE-55 standard. A PMV (predicted mean value) between -0.5 to + 0.5 as depicted in Table 6 it is evident that that values are lying in uncomfortable range with cold sensation while for PPD if 20% of the respondents are dissatisfied its again on percentage predicted dissatisfaction is more than standard values its 30% in one case but overall the dissatisfaction is higher from objective measurements taken for PMV-PPD values. Similarly, the psychometric charts in Fig. 6 also represents relationship between operative temperature and humidity.

Table 6 Measured and calculated Environmental Parameters from CBE calculator [45, 46]

Predicted Mean Vote	**Predicted % dissatisfied**	**Cooling Effect**	**Air Speed [m/s]**	**Standard Effect Temperature**
PMV	PPD	CE	VR	SET
-2.31	88.5	1.26	0.3	17.2
-1.76	64.9	1.51	0.4	19.1
-1.09	30	0.88	0.3	21.3

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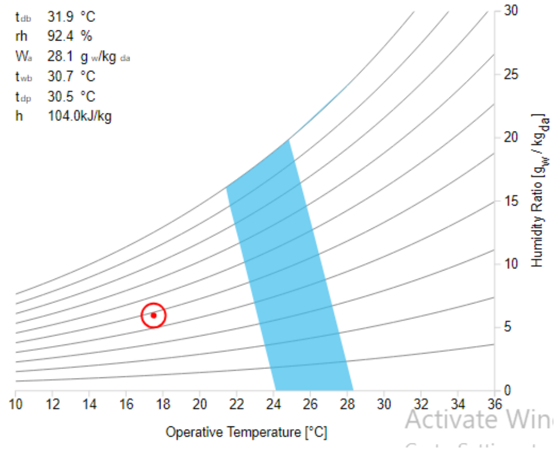

Figure 6 Psychometric Chart for thermal comfort

3.2.Experimentation for summers:

Since the PMV value lies between 2 and 3 as shown in Table 7 is extremely high and it is clearly seen that occupants had felt warm and hot sensation in their current indoor environment. While for PPD the calculated percentage lies between 70-99 which is also a very high rate of dissatisfaction in current settings this calls for immediate action especially in summer season to improve building indoor temperature for the occupants. Similarly, the psychometric chart in Fig. 7 between operative temperature and humidity also depicts uncomfortable conditions and deviation from the standard values.

Table 7 Measured and calculated values through CBE calculator for summers [45, 46]

Predicted Mean Vote	**Predicted % dissatisfied**	**Cooling Effect**	**Air Speed [m/s]**	**Standard Effect Temperature**	**LEED**
PMV	PPD	CE	VR	SET	COMPLIANCE
2.04	78.4	2.76	1.1	30.7	FALSE
2.96	98.9	2.4	0.7	34	FALSE
3.32	99.9	2.69	0.8	34.5	FALSE

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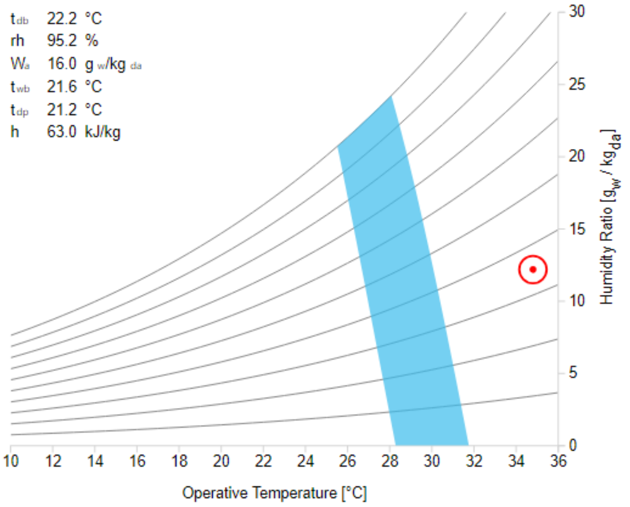

Figure 7 Thermal Comfort Tool results for summer

3.3.Subjective Assessment for winters and summers

Thermal comfort round the year: Overall thermal comfort level throughout the year of males in 38.9% while 25.1% female respondent's casted votes in comfortable range round the year. On contrary only 19.6% of the male respondents and 14.6% of the females voted in uncomfortable range which depicts that overall inclination of the comfort votes was in comfortable range that is about 64% from both genders.

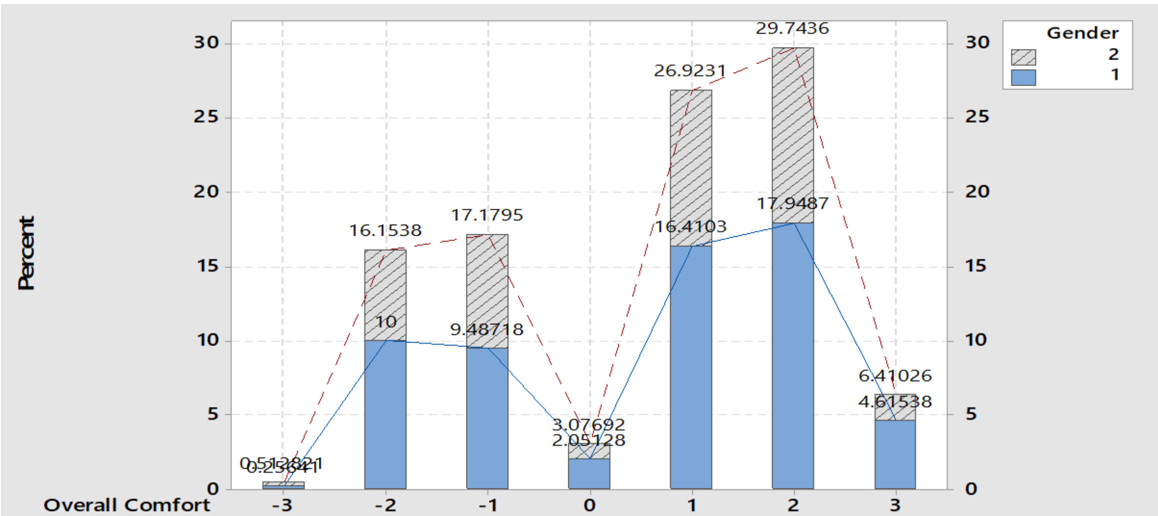

Figure 8 Typical Comfort Level [Scale: -3 Extremely Uncomfortable; -2 Uncomfortable; -1 Slightly Uncomfortable; 0 Neither; 1 Slightly Comfortable; 2 Comfortable; 3 Extremely Comfortable]

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Although, ASHRAE -55 standard states any building comfortable when 80% of the respondents voted in comfort range. This shows a similar trend of thermal comfort level for both genders. The overall thermal comfort from males and females both in general, is in comfortable range round the year as depicted in Fig.8.

3.3.1. Subjective Assessment for winters (right here – right now)

Sample size and Demographics: This study employs a methodology centered on questionnaire surveys to investigate and evaluate the thermal comfort experienced by occupants. The questionnaire survey facilitates the segregation of subjective and objective variables. Objective variables include gender, age group, and occupation, while subjective variables encompass the votes and health-related categories provided by the occupants. During the peak winter period and peak summer period in Lahore, Pakistan, and a comprehensive questionnaire survey was conducted in December 2022 across diverse classrooms out of which Automotive department of UET Lahore was selected for physical experimentation and interviews.

The study surveyed 262 participants in winters about personal factors like gender, age, and activity levels. A balanced representation was found, with 57.6% females and 42.7% males. 91.2% were aged 18-25, with a vibrant 18-25 age group. It reveals that 12.9% of respondents had lived in Lahore for over a year, while 20.5% have stayed for 1 to 9 years. The majority, 66.2%, have a long-standing relationship with the city, having lived there for 10 to 25 years or more, indicating strong acclimatization to the city's unique environmental characteristics. In December, 57.4% of people wear heavy clothing, while 23.2% and 19.0% wear medium and light clothing respectively.

The clo value was calculated as heavy 1.0 clo, medium 0.96 clo, and light 0.74 clo. Students' activity level was mostly limited to sitting during class hours. The study found that 82.5% of individuals are engaged in sedentary behavior, with 3.8% walking, 12.9% standing, and 0.4% reclining. The metabolic rates associated with these activities were 1.1 MET for sitting, 1.4 MET for standing, 1.7 MET for walking, and 2.2 MET for reclining. About 28.9% of students responded to a questionnaire about their classroom thermal comfort before 12 p.m., with a significant focus on the afternoon. 16.3% of responses were recorded in the evening, and 11.0% were recorded at after noon. This understanding can help optimize thermal conditions in educational settings.

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*Thermal Comfort at present***:** When both genders were asked about their current feeling of comfort level overall 25% of the males and 38% of the females were found comfortable. On other hand, 18% of the males and 19% of the females were feeling uncomfortable at a lower temperature inside the classroom. This infers that 63% of the respondents voted in comfortable range while female respondents found to be more comfortable. However, at present 37% of the respondents were uncomfortable with similar trend of uncomfortable level felt by the both genders.

Thermal Sensation Vote at Present: The bar chart as shown in Fig. 8 presents an insightful depiction of thermal sensation votes cast by occupants at the present indoor thermal environment. It reveals both genders exhibit a similar trend in their voting behavior. Notably, a substantial majority of the votes were registered in the cold range, indicating that the occupants were predominantly experiencing a sense of coldness within the premises. It was found, approximately 6% of male occupants expressed a preference for warmer conditions, while nearly 3.83% of the votes fell within the natural range. However, from the prevailing trend emerged, a sudden surge of approximately 13.41% in the number of sensations reported in the slightly cool range. This surge coincided with a minor decline in the overall number of votes, reaching 11.9%. Ultimately, the figure illustrates a continuous decline in sensation votes associated with cold feelings in the current indoor conditions with 7.9% votes. Turning to female occupants, around 10% expressed a desire for warmer temperatures, while 6% remained neutral, indicating an absence of strong warmth or coldness. Notably, a significant increase of approximately 16.86% was observed in sensation votes favoring slightly cool conditions, while a gradual decline of approximately 14.94% was witnessed in the overall response rate.

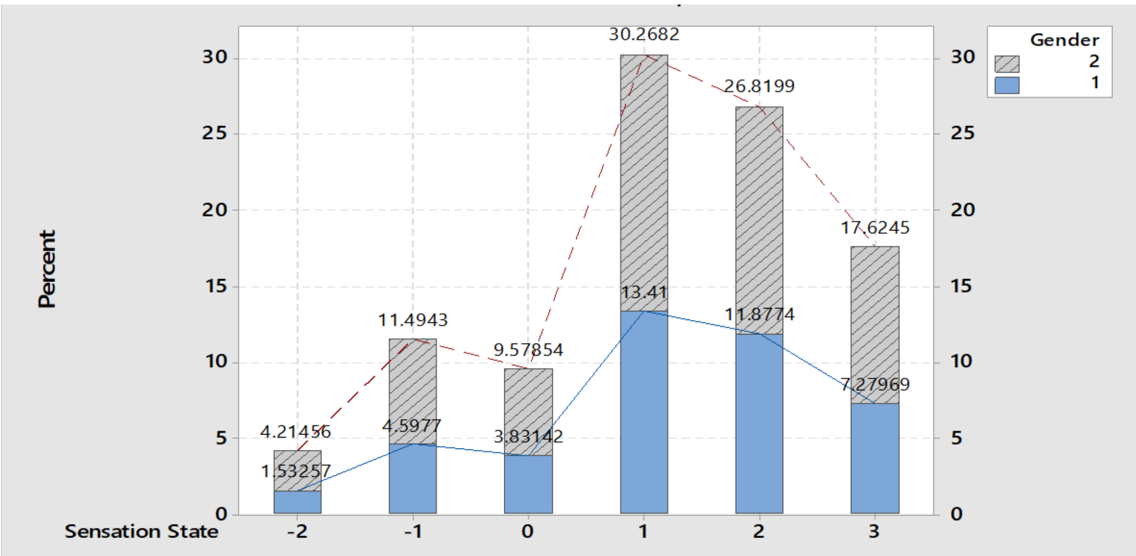

Figure 9 Gender Wise Chart of Sensation State [Scale: -3 Hot; -2 Warm; -1 Slightly Warm; 0 Neither; 1 Slightly Cool; 2 Cool; 3 Cold]

Thus above Fig 9 concludes with a marginal decrease of 10.34% in the response rate for indoor sensations. Accordingly, thermal sensation votes in right-here right-now survey about 39.8% of the males and 29.7% of the females were feeling warm. However, 8.5% of the male respondents and 7% of the females were feeling cold. This points out that males were more sensitive towards sensation of higher temperatures in comparison to females.

Thermal Preference Vote at present: The preference votes provide valuable insights into their immediate temperature preference perception. Overall, a majority of the occupants expressed a preference for a higher temperature than the current one, indicating a prevailing inclination towards a warm range. This preference trend appears to be consistent across both genders, reinforcing its significance. So, about 20.3% of the males and 26% of females preferred much warmer temperatures in comparison to males. While less than 2% of the male and female respondents preferred cold temperature. Approximately, 23% of the males and 29% of the female occupants voted for no change in the current condition. This presents that current conditions are in a satisfactory range of occupants with a similar trend for both genders.

Thermal Acceptance Vote at Present: The overall trend initially showcases a steady flow of votes falling within an acceptable range, followed by a subsequent decline in the number of occupants who express a neutral stance for both genders. However, as an abrupt upward trend line indicates a rise in votes denoting unacceptable conditions, eventually tapering off towards the end. Delving into the

Fig. 10 responses of female occupants, the trend line exhibits a consistent and steady flow of votes for both an acceptable range, accounting for approximately 14.6%, and a slightly acceptable range, constituting around 12.3%. However, there is a decline to 10% in votes indicating a neutral stance.

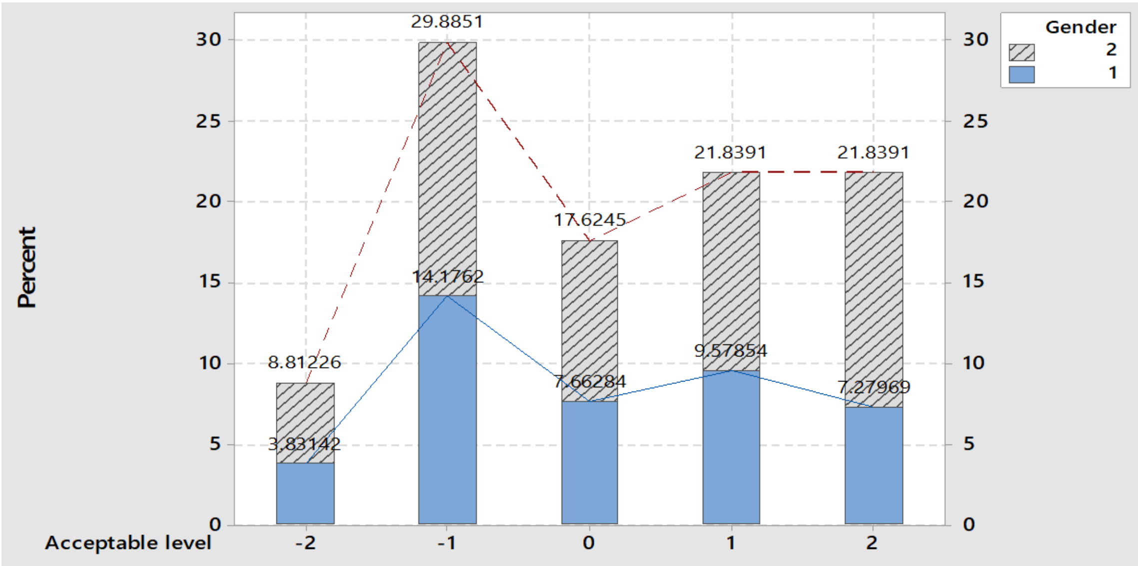

Figure 10: Gender-Based Chart of Acceptable Level [Scale: -2 Unacceptable, -1 Slightly Unacceptable, 0 Neutral, 1 Slightly Acceptable, 2 Acceptable]

Thereafter, a sudden surge of growth, measuring approximately 15.71%, becomes apparent for slightly unacceptable conditions, which subsequently drops to a mere 3.81% for conditions deemed for completely unacceptable. In the case of male occupants, the graph maintains a consistent pattern, with an acceptable range comprising approximately 9.6% of votes. This is accompanied by a declining trend of 7.6% of occupants expressing a neutral stance. Interestingly, over 14.1% of male respondents registered a sense of slight unacceptability in the conditions, while the number of votes for completely unacceptable conditions experienced a reduction of almost 3.8%. It could be seen that about 16.9% of the respondents the males and 26.9% of the females voted in the acceptable range, while 18% & and 20.7% of the males and females respectively voted in the unacceptable range. The rest of the occupants voted in the neutral range. This shows that females were more adaptable to lower temperature conditions as compared to males.

Airflow Acceptance Vote: The bar chart as shown in Fig.11 provides a notable distinction between genders, with 7.28% of males and 13.79% of females finding the airflow comfortable. The trend line reveals perceptions, with 9.89% of males and a peak of 20.69% of females considering it slightly acceptable. Particularly, discomfort levels are higher among females, with 21.84% finding it slightly uncomfortable and 11.49% uncomfortable. These findings highlight the complexity of occupant experiences and the importance of airflow optimization for enhanced comfort and satisfaction [5].

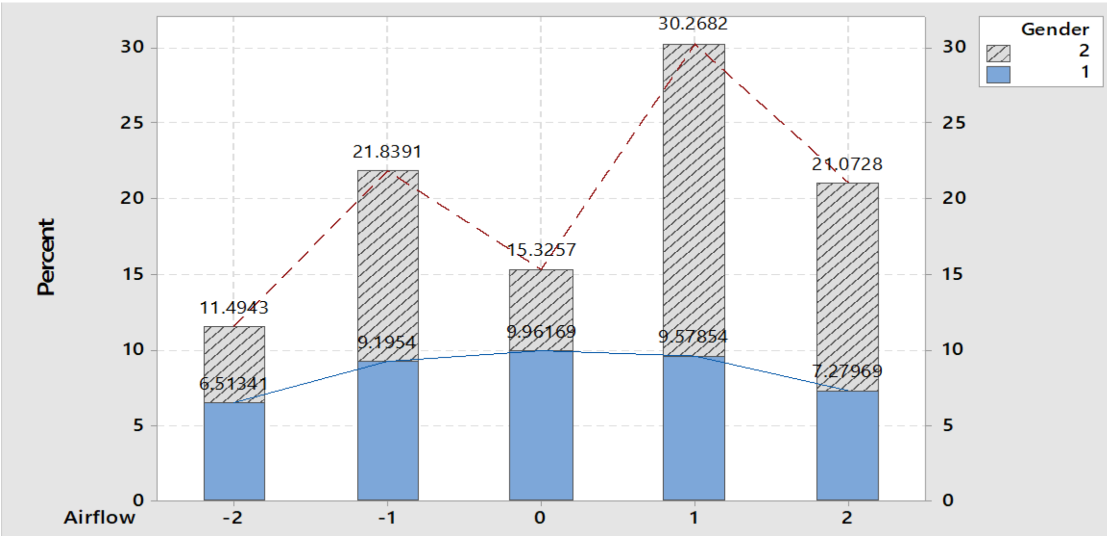

Figure 11 Airflow in Classrooms [Scale: -2 Unacceptable, -1 Slightly Unacceptable, 0 Neither, 1 Slightly Acceptable, 2 Acceptable]

Impact of Productivity: About 35.6% of the male respondents and 21.8% of the females found frequent impact of thermal comfort on their productivity level. On the other hand, 24.1% of the males and 15.7% of the females found themselves occasionally impacted from thermal environment. It means that male respondents were more frequently effected from thermal comfort conditions and lost productivity level [32]. [33]. The Fig. 12 depicts is graphical illustration.

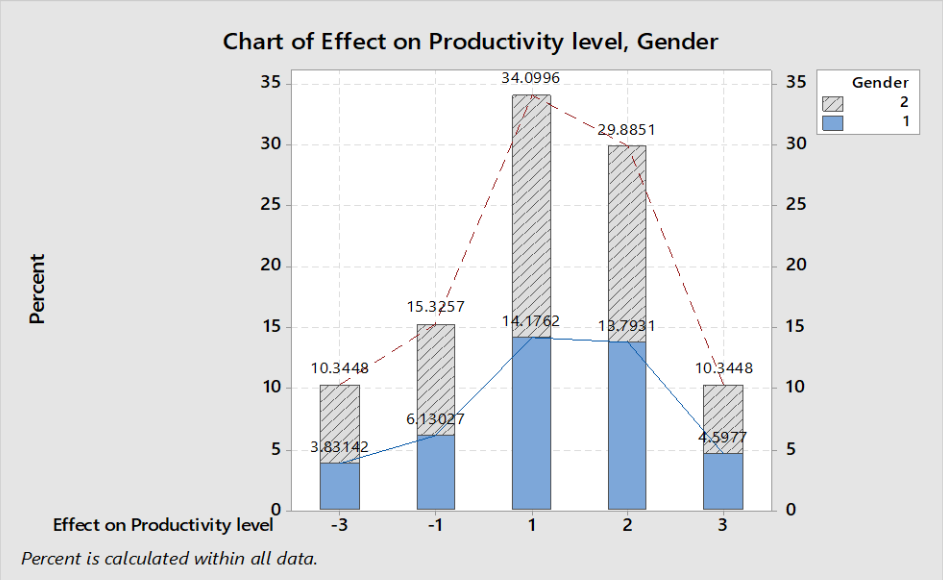

Figure 12 Productivity level [Scale: -3 Very Frequently -2 Very Frequently, -1 Occasionally, 0 Neither, 1 Rarely, 2 Very rarely 3 never]

Sick Building Syndrome: Sick building syndrome was used to evaluate the health conditions of the occupants in the building. The significance of health conditions cannot be overruled for classrooms. It was investigated that 40.5% of students reported no SBS symptoms, 19.5% experienced headaches due to inadequate ventilation, temperature control, or lighting. 10.3% experienced a stuffy nose, while 21.4% experienced tiredness and difficulty concentrating due to cold temperatures. 6.5% experienced dry eyes, throat, or rashes [33]. These findings highlight the need to address indoor environmental factors to improve student well-being and academic performance during winters. Moreover, it was found that 27% of the males and 32.3% of the females got effected from the SBS in the buildings while 15.6% of the males and 24.8% of the females felt no health issues in the building. Thus, females had shown more symptoms of SBS as compare to males [33].

3.3.2. Subjective Assessment for summers (right here – right now)

Sample size and Demographics: The respondents were questioned about the following personal characteristics pertaining to gender, age, and duration of stay, attire, and levels of activity. A total of 397 replies, including information on personal variables, were received. 60.2% of the respondents were male, compared to 39.8% of female respondents. 92% of the respondents are in the 16 to 25 age range. More than half of the students have lived in Lahore their entire lives, and 33% of them are

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from the Punjab province. The remaining students are from other provinces. Nearly 72.3% of respondents to the study, which was conducted in May and June, wore light apparel, while 22.4% and 5.3% wore medium- and heavy-weight items. During class hours, about 77.83% of the students were responding, although their activity was confined to sitting. According to the survey, approximately 44.4% of buildings were built in the last 5 to 15 years, 23.4% in the last 25 years, 7.7% in the last 40 years, 8.3% in the last 75 years, and 16.3% in the last 100 years or more. Around 51.2% of the structures were made of reinforced concrete, and 48.8% of the buildings were made of masonry. One of the crucial factors affecting the thermal comfort of a building's interior is building orientation. A total of 29% of the buildings faced east, compared to 20% and 13% of the buildings that faced north and south, respectively. Since the west is thought to be the hottest direction in Lahore during the day. Additionally, it was discovered that the higher the floor level, the less thermal comfort there was.

Thermal Comfort Votes at Present: Thermal comfort votes in right-here right-now survey 22.9% males and 13.5% voted in comfortable range for summers in their current classrooms. On the other hand, only 38.1% of the male’s respondents and 25.5 % of the females voted in uncomfortable range. This shows that males were more uncomfortable in comparison to females in current settings. Here, 63.5% of the respondents voted in uncomfortable range and only 36.4% of them voted in uncomfortable range from both genders. Overall, the trend depicts that males felt more uncomfortable due to high indoor temperature in comparison to females.

Thermal Sensation Votes at Present: The Fig. 13 illustrates percentages of thermal sensation votes by building occupants in right here. Right-now survey in summer. The overall trend of responses was found in warm range in their current indoor classrooms.

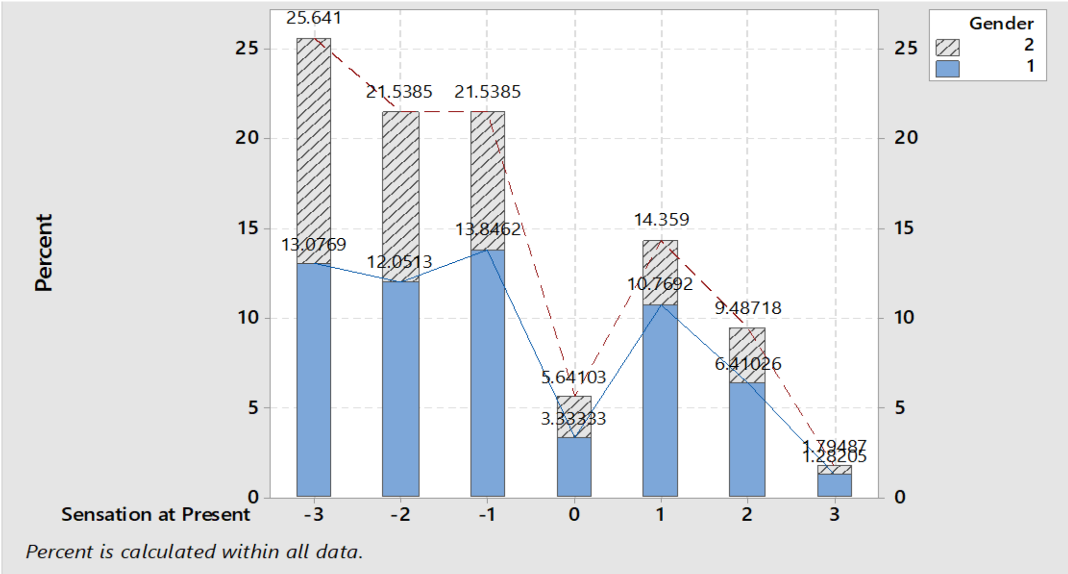

Figure 13 Gender Wise Chart of Sensation State [Scale: -3 Hot; -2 Warm; -1 Slightly Warm; 0 Neither; 1 Slightly Cool; 2 Cool; 3 Cold]

The trend for both genders shows similarities with slight variations. About 7 % female respondents voted in cold range. Then a sudden decline was observed approximately 2-3% for the responses that showed no change in present thermal conditions. While the response rate rose up to 7.6% & 9.5 % for slightly warm respectively. In addition, the graph trend remained almost steady for warm range sensation. Afterwards an upward response trend was voted for the hot sensation which was almost 12.6 %. For male respondents 12.6 % casted thermal sensation votes in cold range in current location. While only 3.3 % responded with no change in current conditions. On the other side, the upward trend was observed for response rate in slight warm approximately 13.8 % and slight decrease was found in warm range about 12.0 %. Then figure ended at thermal sensation with 13.0% votes for hot conditions with gradual increase.

Thermal Preference Votes at Present: Most of the voters preferred more cooling compared to current temperature indoors with similar trend observed for both genders as shown in Fig. 14. Female voters preferred much cooling temperature about 14.5 % then current conditions and the 13.01% preferred cooler temperature. A downward trend for thermal preference response rate about 6.1 % was observed for slightly cool temperature and in the end of figure a sharp downward response rate was found for no change 1 %.

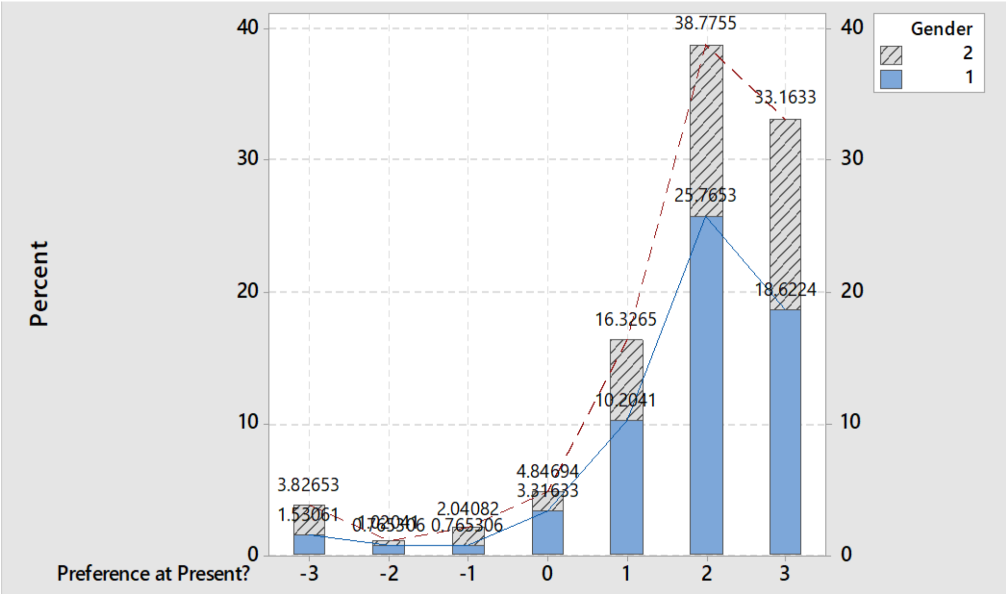

Figure 14 Gender-Based Chart of Preferred Current State [Scale: -3 Much Warmer, -2 Warmer, -1 Slightly Warmer, 0 Neither, 1 Slightly Cooler, 2 Cooler, 3 Much Cooler]

A negligible number of votes were found casted in warm range. Almost 18.6% of the male respondents preferred much cooler temperature than existing. When most of temperature almost 25.2 % preferred cooler temperature. A visible sudden decline in thermal preference votes were observed for slightly cool temperature by only 10.2 % respondents. The 3 % respondent, wants no change in their current indoor temperature. Furthermore, a negligible response rate was found for warm range. So, about 54.6% of the males and 33.7% of the female respondent's preferred cold temperature. Thus, it depicts that males preferred lower temperature as compare to the females in existing conditions [34].

Thermal Acceptance Vote at Present: This Fig. 15 depicts thermal acceptance response rate in summer. Maximum of the respondents voted in acceptable range for current indoor thermal environment. In the trend for both genders were almost same with few fluctuations. The thermal acceptance response rate at present. For females was about 7.6 % and 13.04 % acceptable and slightly acceptable range respectively. Almost 1.7 % females wanted no change in current situation. However, an upward trend was found almost 7.7 % and 8.9 % for unacceptable range. A steady straight-line trend was observed by male respondents for slightly acceptable range and acceptable which was about 17.1 and 17.4 % respectively.

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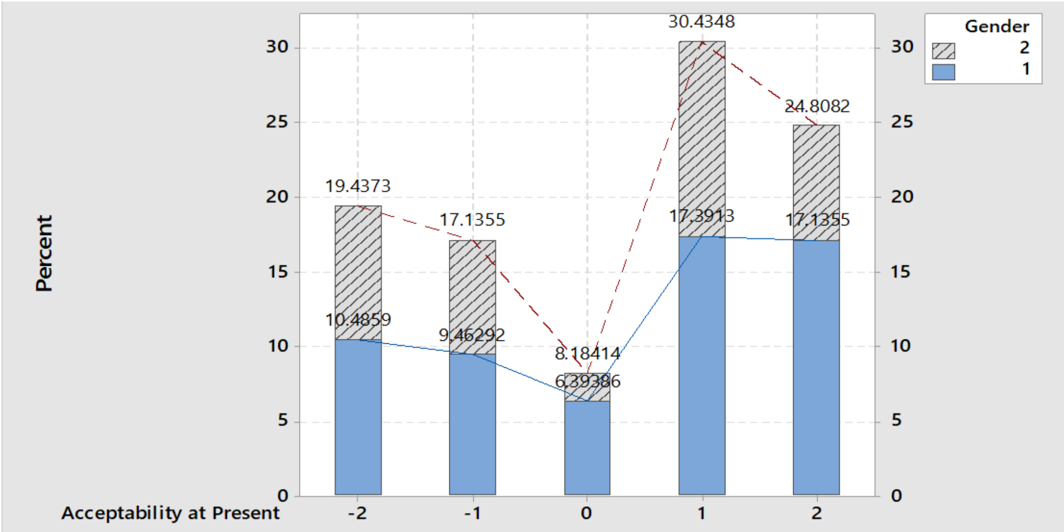

Figure 15 Gender-Based Chart of Acceptable Level [Scale: -2 Unacceptable, -1 Slightly Unacceptable, 0 Neutral, 1 Slightly Acceptable, 2 Acceptable]

A sudden decline was found for no change response rate almost 6.4 %. Therefore, a gradient rise was observed for slightly unacceptable and with steady trend it was approximately 9.5 % and 10.5 % respectively. So, approximately 34.5% of the respondents of the males and 20.7% of the females voted in acceptable range, while 20% & 16.6% of the males and females respectively voted in unacceptable range. Rest of the occupants voted in neutral range. This shows that males were more adaptable to higher temperature conditions as compare to males.

Air Flow Acceptance: The Fig. 16 illustrates the airflow acceptance of building occupants in summers. Most of female respondents about 15.64 %, and 8.72 % felt that air flow is slightly acceptable and acceptable in classrooms during summers. The neutral respondents found overall 37.4% % has neither air flow acceptance nor unacceptable. On the other hand, about 7.6 % & 3.3 % felt slightly unacceptable and unacceptable. A quiet similar trend was observed for both genders. For male respondents about 21.8 % and 15.9 % casted votes in range of slightly acceptable and acceptable air flow in classrooms. It was observed that 17.9 % and 15.6 % considering productivity rate occasionally and frequently respectively. 7.6% male respondents remained neutral. While 7.2 % & 8.2 % male responses were observed in a range where airflow is slightly unacceptable and unacceptable during summers in classrooms of university.

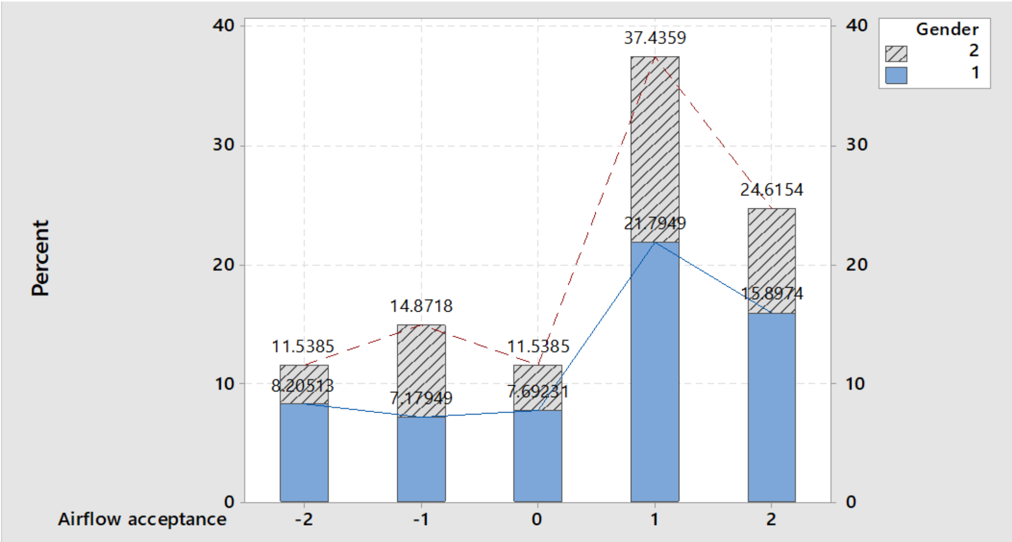

Figure 16 Airflow in Classrooms [Scale: -2 Unacceptable, -1 Slightly Unacceptable, 0 Neither, 1 Slightly Acceptable, 2 Acceptable]

Impact of Productivity: The impact of thermal comfort on productivity rate of building occupant is of great significance. Overall, the respondents found a frequent impact of temperature comfort in indoors on their productivity rate. A quiet similar trend was observed for both genders. Most of female respondents about 6.6 %, 17.4 % and 8.4 % felt that the productivity rate was impacted very frequently, and occasionally by indoor temperature conditions. On contrarily negligible trend was observed for neutral respondents. On the other hand, 6.6 % of the response rate were casted in rare, impact productivity on performance due to temperature conditions. For male respondents 12.5 % casted votes in range of very frequent temperature on performance due to thermal comfort it was observed that 17.9 % and 15.6 % considering productivity affect frequently and occasionally respectively. Negligible respondents remained neutral. While 14.0% responses were observed in rare impact on productivity due to temperature constraints in classrooms.

The productivity rate of building occupants in summers. Most of female respondents about 6.5 %, and 15.13 % felt that productivity rate was less than the actual by indoor temperature conditions. Overall, the respondents found neutrally for 44.3 % has no thermal comfort effect in indoors on their productivity rate. On the other hand, about 1 % of the response rate were casted in rare, where productivity rate more than the actual. A quiet similar trend was observed for both genders. For male respondents about 17.7 % and 8.2 % casted votes in range of less productivity rate than the actual. It

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was observed that 17.9 % and 15.6 % considering productivity rate occasionally and frequently respectively. 29.2% male respondents remained neutral. While 4.3% & 1.5 % negligible male responses were observed in rare manner where productivity rate is more than the actual. Both genders' thermal comfort in educational facilities is significantly impacted by productivity. An individual's degree of contentment with their work environment rises when they are productive because they are more focused and invested in their tasks. As a result, thermal comfort may be significantly impacted by decreased productivity, which can lead to more stress and dissatisfaction. Uncomfortable conditions for both male and female occupants may result from poor productivity's impact on temperature control systems' upkeep. For everyone to be comfortable in educational buildings' thermal environments, it is crucial to maintain ideal productivity levels. Thus, it was found 44.6% of the male respondents and 32.4% of the females found frequent impact of thermal comfort on their productivity level. On the other hand, 14.1% of the males and 6.6% of the females found themselves occasionally impacted from thermal environment. Moreover, the rise in fan speed increase the performance level of the students.[47] It means that male respondents were more frequently affected from thermal comfort conditions and lost their productivity level. [37]

Sick Building Syndrome: The sick building syndrome conditions of the building occupants shown in figure 20 were found on higher side in males as compare to females that is 19% and 14% of the respondents felt tiredness and lack of concentration respectively. About 30% of the found no impact of the sick building syndrome. Around 11% of the male respondents and 9% respondents felt headache. About 5% felt eye aching and dry throat and only 3% were facing running/stuffy nose. About 9% were facing other issues relevant to sick building syndrome. This indicates that about 70% of the respondents were somehow affected physical from symptoms of sick building syndrome in the classrooms. It was found that 40.8% of the males and 20.9% of the females got effected from the SBS. This infers that more symptoms of SBS were found in males in comparison to females during summers. The physical and mental health of occupants is highly influenced by indoor temperature and effects their learning ability [20-23].

3.4.Energy Optimization of Case Study Building through retrofitting of Building Envelop and its services

As existing energy consumption of automotive building is on higher side and already Pakistan is already facing energy short fall. Following retrofitting techniques were proposed, analyzed and then compared to reduce energy consumption and improve building performance level.

For Building Envelop, insulation on roof and walls and Double-Glazing windows on all wall except East orientation can reduce energy losses due to building envelop [26]. Weightage taken from literature as per impact of parameter chosen (56.3%). For HVAC, VRF system is introduced for Heating and Cooling of building instead of traditional system (42%). For Lighting System, LED lighting is introduced in replacement of conventional lighting fixtures which in turn not only improve building Performance but also enhance Resource Efficiency of building (26.5%).

In the Automotive department to improve building performance by retrofitting HVAC, and Lighting systems through simulation on Green Building Studio, Hap Analysis, and Di*a*lux software respectively. The energy model simulated for the 'Automotive Engineering Centre' case-study building which provides energy consumption and building performance through a simulation model. An energy model was developed to identify energy savings areas and inform decisions about energy efficiency measures. The Table 8 presents U and R values for baseline model.

Table 8 U & R-value of Baseline Automotive Model

Sr.	Parameter	Material	U value (W/m^2 K)	R-value (W/m^2 K)
1.	Walls	Brick 9"	2.5902	0.3861
2.	Roofs	Concrete 10"	0.9784	1.221
3.	Windows	Single Glazed Reflective Glass	6.7018	0.1492
4.	Doors	Plywood	2.1946	0.4557

For Building Envelop, by providing 4-inch insulation on south and west walls and 3 inch on roof with low-e double glazing on all walls except east, we can get almost 21.97% gain in energy savings in Building Envelope. So building envelope retrofitting is an effective measure to reduce operational cost.

Existing HVAC system is split system. Retrofitted system is Variable refrigerant flow (VRF). The overall Peak Cooling Load of the Building is reduced from 1,395,397 BTU/hr to 1,052,937 BTU/hr which shows about 24.54% of Cooling Load Saving. The overall Peak Heating Load of the Building is reduced from 290,907 BTU/hr to 238,464 BTU/hr which shows about 18.03% of Heating Load Saving.

The Existing lighting system consists of fluorescent tube lights and energy savors, Total energy consumption per year is 13449.6 kWh and total energy wastage is 4529.52 kWh. Selected building does not satisfy with ILER standards ratios so there is huge amount of energy wastage. 19-watt LED bulbs in Labs, Classrooms, and corridors, 12-watt LED bulbs in Toilets and Storage Rooms are installed. Students spend about 30% of their time in classrooms so an optimized day lighting and energy performance plays critical role.[48] Therefore, classroom Design decisions in architecture like geometry, shallow plan buildings, wall to window ratio, orientation and other passive design strategies[49] are vital factors that effects students and building energy consumption in long term. In addition, its considerable impact is evident on student's health and learning ability.

4. Conclusion:

These findings shed light on the satisfaction experienced by occupants within the current university classroom's microclimate in both seasons, i.e., summers and winters. It was found that the vast majority reported that university classrooms effectively caters to the diverse thermal needs of its occupants for extreme winters about 25% of the males and 38% of the females were found comfortable in right here and right now survey. However, occupants' discomfort was evidently visible during the extreme summer season only 38.1% of the male's respondents and 25.5 % of the females voted in uncomfortable range. Moreover, it was evident that females were more affected by winter conditions while males were more affected by higher temperatures in summer. In both seasons, males found a frequent impact of thermal comfort on their productivity and it resulted in more productivity loss in males as compare to females. In winter, females were more affected from SBS, and in summer, males showed more symptoms of getting affected by SBS. Based on the dissatisfaction level of the building occupants from PPD and PMV values and subjective assessment, it is apparent that the current thermal comfort assessment calls for improvement in the indoor building thermal environment. In this regard, it could also be inferred that the PMV-PPD method showed a bit higher side dissatisfaction as compared to subjective assessment. The PPD value on average calculated was about 91% for the summers and almost 61% for the winters. However, overall, the dissatisfaction level of both genders was quite higher for the summer season than the winter. According to climatic conditions, summer is the longest season in Lahore(6-8 months), and immediate action is needed to overcome huge energy consumption to achieve thermal comfort.

Since dissatisfaction level in summers is high, there is an urgent need to improve the indoor thermal environment of the classrooms. Therefore, retrofitting existing classrooms is suggested for the case study building automotive department, UET, Lahore. The existing model of the case study had been compared with the retrofitted techniques to make the building suitable to improve energy performance. After the retrofit, almost 18.03% of the total heating load decreased. Using the Efficient Lighting System reduces the overall total annual energy consumption from 13499.6 KWh/annum to 10591.2 KWh/annum after retrofit, saving 21.54% energy. Overall %age saving (Acc. To weightage) after retrofitting all building systems is 27.407 % for the Automotive Building in UET, LHR.

5. Recommendations

Further studies can address the cost-effective measures in the short term and long term. Support other retrofit strategies in the market and study their cost-effectiveness in the long term. Thermal comfort assessment in perspective of occupants and focusing indoor environment quality. Additionally, larger samples at different climatic zones can verify results statistically for the preferences of both genders in more depth. Other different types of buildings can also be studied since the scope of this study was limited to naturally ventilated university classrooms. Also, age and activity level variation are important variables and can be studied in future research to investigate thermal comfort assessment of different genders.

Statements of author’s contribution

All authors contributed equally in the preparation of this manuscript.

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Declaration of Conflicting Interests' statement

The Author(s) declare(s) that there is no conflict of interest.

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