Evaluation of students' perceptions and thermal comfort in London

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Abstract. A thermal comfort field study was conducted in a lecture room involving 44 participants to investigate occupant perception and thermal comfort, as well as compare it with other 37 lecturer theatres. All buildings are located in a temperature climate region of the UK. Additionally, objective measurements including dry-bulb air temperature, relative humidity, and subjective responses concerning thermal sensation, thermal preference, and air velocity were additionally collected. Through Hobo measurement and a questionnaire survey in the site lecture room, we present the association linking thermal comfort and seating location. A similar tendency can be found through the comparison between the AMV values of all lecture theatres and PMV ones, which could be explained by the fact that occupants have a very limited physical adaption to their surroundings in the lecture room. Furthermore, the level of thermal comfort of the occupant sitting in the back (higher seats) is lower than that of the occupant sitting in the front row (lower seats).Through a statistical contrast of the level of thermal comfort among individuals seated at the back and front in all lecture theatres, it was illustrated that the occupants at the back were warmer compared to those at the front, and the decreased level of thermal comfort of occupants could be found in many lecture theatres. Overall, in the relationship between thermal comfort and seat position, thermal comfort has a close association with the front seat, which comprises greater comfort in contrast to the rear seat.

Keywords. Thermal comfort, seat position, indoor air temperature, PMV, AMV
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1. Introduction

Due to increased occupant density inside classrooms and the detrimental impact that an insufficient thermal setting may have on students' performance and learning, providing comfortable conditions for educational buildings has always been critical [1]. This study focuses on the thermal environment in conjunction with certain connected factors such as indoor air quality and movement. In modern countries, more than 90% of people spend their time inside [2]. Students spend more daytime at school than in any other building other than their homes, emphasising the need to provide acceptable interior temperature conditions inside these institutions. As a consequence, lecture theatres' interior thermal comfort is critical, as it has a significant influence on the degree of thermal comfort experienced by students, especially those situated at the back due to the buoyancy effect [3].

The purpose of this research is to examine the thermal comfort levels of naturally ventilated lecture rooms. To accomplish this goal, numerous effective strategies, such as objective methodologies and subjective analyses, are required for the physics A1/3 lecture room, and further verification is accomplished through comparison with the other 37 lecture theatres. First, a questionnaire survey was conducted to assess the student's thermal perception, while physical parameters including air temperature and relative humidity were monitored and recorded using HOBO loggers. Students are required to mark their specific seat position, and two HOBO loggers are situated at the front and back of the lecture theatre, respectively. Following that, the predicted mean value (PMV) is calculated using physical data and the Fanger model, and then compared to the actual mean vote (AMV) obtained by surveys.

2. Literature review

Thermal comfort can be described as a state of mind or satisfaction that is impacted by human behavioural, psychological, physiological, and a large number of other factors [4]. Thermal perceptions are different among individuals even though they are exposed to the same environment. Developing knowledge of thermal comfort plays an important role in providing a satisfactory indoor environment for people, suggesting or improving standards [5] as well as reducing energy consumption of buildings [6]. According to a previous survey, compared with visual and auditory comfort, occupants focus more on thermal comfort and indoor air quality [7]. Furthermore, according to a research [8], building energy consumption accounts for around 40% of global energy consumption and over 30% of carbon emissions, with a substantial part of this being used to achieve thermal comfort. Consequently, the optimal use of energy should strictly conform to the requirements for thermal comfort, and it is essential to carry out a comprehensive assessment of the thermal comfort factors.

2.1 thermal comfort approaches

Heat balancing and adaptive models are the two main methods for thermal comfort. Heat balance employs data from climate chamber experiments, which is best characterised by the Fanger model, while the adaptive models are primarily based on data from field research of occupants in buildings.

The heat balancing method was developed by Fanger using a steady-state heat transfer model in a climate chamber with controlled climatic parameters [9]. The closing insulation and metabolic rate of participants are determined and standardised in these studies when they are exposed to different thermal environments. Participants use the ASHRAE seven-point scale of thermal sensation to report how hot or cold they feel under the indicated thermal condition (-3 cold, -2 cool, -1 slightly cool, 0 neutral, +1 slightly warm, +2 warm, and +3 hot). Fanger's model states that the human body's thermoregulatory system is able to respond physiologically, such as sweating and shivering, to any thermal imbalance with the surrounding environment. This heat balance can make people maintain constant internal body temperature and achieve a neutral thermal sensation [10].

Fanger developed the Predicted Mean Vote (PMV) index to evaluate whether a certain environment could be accepted by a large group of people [11]. Over one thousand subjects in the climate chambers are required to give their thermal perception based on the seven-point scale sensation in ASHRAE. The mean of all subjects' responses is found to give a mean vote under the given thermal condition. Fanger combined PMV with the thermal physiological properties of humans at a given activity level and their thermal balance with the specified environment [12]. The PMV equation is complicated and, to be brief, it is a function of two personal parameters (activity level M in W/m^2 and clothing level I_{cl} in clo) as well as four environmental parameters (air temperature ta in °C, mean radiant temperature t_{mrt} in °C, air velocity v in m/s and relative humidity/vapor pressure pa in kPa). Therefore,

$$PMV = \int(M, I_{cl}, t_a, t_{mrt}, v, pa) \quad (1)$$

Some researchers developed a method for calculating thermal comfort indices based on six parameters in accordance with ASHRAE Standard 55-2013 [13]. Predicted Percentage Dissatisfied (PPD) is another index that predicts the percentage of people who responded ±2 and ±3 on the seven point sensation scale using the PMV. It was noted based on a study that those who answered ±1 and 0 were considered to be comfortable [11].

Previous studies assessed the accuracy of comfort theories based on Fanger's model through a few field studies and demostrate that, in naturally ventilated buildings, the calculated PMV consistently underestimates the actual mean vote (AMV) [14-18]. According to a research, the application of the heat balance model led to an inaccurate assessment of thermal comfort because it failed to account for human thermal adaptation ability, including physiological and behavioural variation and psychological effects [17].

2.2 Influence factors of thermal comfort

The effect of air temperature on human thermal comfort and performance has been extensively studied. It is generally agreed that too high or too low temperatures can have a negative impact on occupants' performance [19-20], but for the comfortable range of the inside temperature, there are some different opinions. Some research insisted that the range should be within the comfort zone [21-22], whereas others contended that improved thermal comfort could be obtained by the air temperature being outside the comfort zone dependent on specific performance tasks and environmental conditions. Some researchers put forward a correlation between them that a 2% decrease in thermal comfort could be caused by 1 ℃ increase in temperature [23-24]. In addition, indoor air temperature has an indirect impact on air quality, and the lower the temperature, the better the air quality is perceived [25]. Indoor air quality is primarily described by the CO2 concentration.

Indoor air velocity is another factor influencing occupants' thermal comfort. The research confirmed that thermal comfort levels with elevated air velocity are equal to or greater at warmer temperatures than those without it at cooler temperatures [26]. Furthermore, some research has proposed that elevated air speed has a positive impact on the perceived air quality in spaces with high temperature [27-28]. Based on a research, high temperature and high concentration of pollution may be mitigated by increasing air flow toward the face [29]. Consequently, the strategy of supplying room air with high speed and keeping a high indoor temperature with less supply of outdoor air can be energy efficient during the heating period without reducing the indoor thermal comfort and air quality [29]. However, it is challenging to achieve this strategy in a lecture theatre with various breathing levels and high occupancy density.

3. Methodology

3.1 Object of the study

Through literature surveys, research documents relevant to the assessment of students' thermal adaption to the lecture theatres with special architectural geometry have not received much attention. In the lecture theatres, the seats are placed on a slope, and non-uniform environmental conditions can result from the different height levels. The purpose

Figure 1. Physics A1/3 lecture theatre in UCL

of this research is to obtain a better understanding of the varying levels of thermal comfort in lecture theatres, taking into account the occupants' sensation. This is to be achieved through a combination of objective and subjective approaches.

The main object of study is the Physics A1/3 Lecture Theatre (Figure 1), with comparison to the results of the other 37 lecture theatres in UCL for further verification. Physics A1/3 is a small-sized lecture theatre with increasing seat height. It is located on the fourth floor of the building and surrounded by several adjacent rooms. The main features of the lecture theatre are summarised in Figure 2.

All lecture theatres were studied during the lesson time from October 28th to November 24th, 2019 and indoor thermal comfort was investigated during the winter period in this report. The lecture theatres are located in central London. According to the CIBSE Guide A, London has a temperate maritime climate which is mild and humid all year round. The annual average temperature is over 11 °C, and the temperatures in winter are equal to or exceed -3 °C for 99.6% of the year.

Number of seats	53
Floor area (m^2)	76
Space height (m)	3.5
Volume (m^3)	266
Number of windows	4

Figure 2. Main features of the case study

3.2 Subjective approach

A total of 44 questionnaires were conducted in the classroom during the lecture break, which was one hour after the lecture began, in order to allow students to adjust to the environment. Students in Physics A1/3 are unable to change their environmental conditions through accessible control systems, which are driven by centrally controlled mechanical systems. Students have to sit at their desks with a certain degree of limitation on adjusting their activity or clothing level during the lecture time, but their physical actions are free during the break. The adaptive actions of occupants were not considered during the field campaign, but they could act before the start of the questionnaire survey.

The questionnaire content used in the research topic can be divided into four main categories: - General information: individual seat position, gender, clothing level - Thermal comfort: thermal vote based on Fanger seven-point scale and thermal preference - Indoor air movement/quality - Concentration level The actual mean vote (AMV), thermal preference as well as the correlation between all of these results are deeply investigated in this research.

3.3 Objective approach

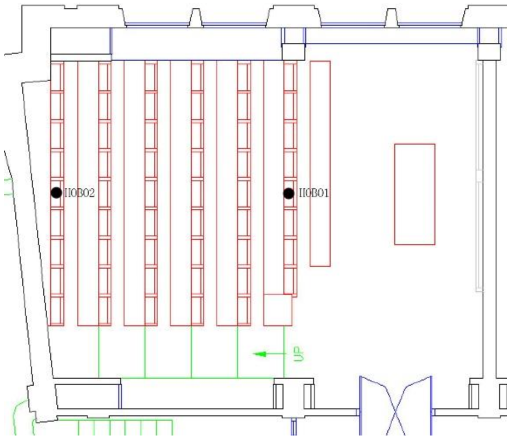

Figure 3. The location of two HOBOs

Two HOBOs in the occupied zone monitored thermal-hygrometric parameters in the space to ensure an accurate assessment of human exposure to thermal comfort (Figure 3). One HOBO was located in the middle of the first row (one of the lowest seats) and the other one was in the middle of the last row (one of the highest seats). The HOBOs were launched half an hour ahead of measuring, with the consideration of their response time and the HOBO specifications being:

- Dry-bulb air temperature: measure range from -20° to 70°C, accuracy ± 0.35°C from 0° to 50°C

- Relative humidity: measure range from 5% to 95% RH, accuracy ±2.5% from 10% to 90% RH

Subsequently, a mean value for clothing insulation level was obtained from all surveys, which resulted in average values for temperature and humidity in the indoor environment. All seated students have a metabolic rate of 1.0 MET. The PMV comfort zone's still air conditions (0.2 m/s) are closely matched by the indoor air velocity in many situations. Through the use of the CBS Thermal Comfort Tool, the PMV comfort index was calculated.

4. Results and analysis

4.1 Descriptive results

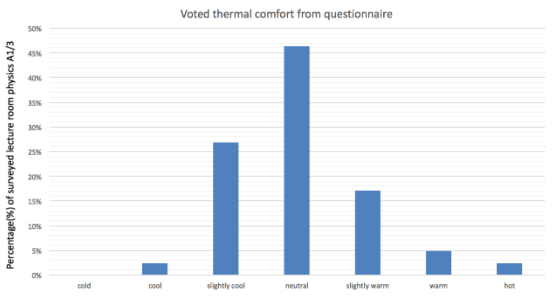

Figure 4. Voted thermal comfort percentage in Physics A1/3 Lecture Theatre

Figure 4 and Figure 5 illustrate the difference in thermal comfort between students in physics A1/3 and all lecture theatres. Thermal comfort was rated using a questionnaire. According to Fanger's definition of thermal comfort, -1 to 1 is the satisfaction range of indoor thermal environment; consequently, satisfaction with thermal comfort accounts for 90% of the total, with an average indoor temperature of 21.95°C and an average air humidity of 65.625 %, in line with ASHRAE Standard 55-2013. The predicted percentage of dissatisfied (PPD) has a proportion of 10%, which is remarkably similar to the estimated number in Figure 4. When comparing the physics A/13 lecture theatre (Figure 4) to the other lecture theatres (Figure 5), it becomes clear that the residents of physics A1/3 prefer a colder environment. Additionally, the discontent rate for all lecture theatres was 20%, which is higher than the dissatisfaction rate for the physics A1/3 lecture room.

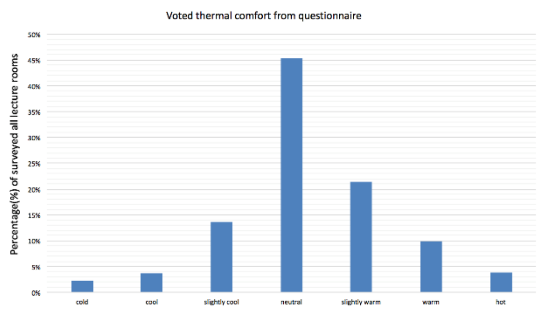

Figure 5. Voted thermal comfort percentage for all Lecture Theatres

4.2 Comparison between PMV and AMV

The Fanger PMV is a widely used indicator for evaluating occupant thermal comfort that has been used in international standards such as ISO 7730 [30], ASHRAE 55 [31], EN 15215 [32], and Chinese Standard [33]. It is based on the steady state heat balance principle and predicts the mean value of a large group of people's votes on the 7-point thermal sensation scale (cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2), hot (+3)) based on six inputs (air temperature, mean radiant temperature, air speed, humidity, metabolic rate, and clothing insulation) [9]. Figure 6 shows the relationship between PMV and AMV , where the black line indicates a benchmark based on Fanger's research in the environmental chamber, each dot in the figure represents the mean value of PMV and AMV of each lecture rooms. The results showed that the PMV and AMV of all lecture theatres reveal little fluctuation when compared with the benchmark. PMV can be calculated based on the calculation procedure showed in ISO 7730. AMV can be calculated by value obtained from the questionnaires. London features a temperate oceanic climate, located in the United Kingdom (51°30 N, 0°39 W), generally featuring mild summers and cool but not cold winters, with a relatively narrow annual temperature range and few extremes of temperature [34]. Therefore, this minimal fluctuation can be regareded as the thermal adaptation generated by the past thermal experience of a long time spent living in a specific region with a stable thermal comfort environment. Additionally, for students who prefer to be cooler or warmer, the PMV has several pitfalls that must be presumed to have a similar metabolic level. Appropriate cooling or heating of the room is acceptable throughout the winter or summer, which enables buildings to save massive amounts of energy.

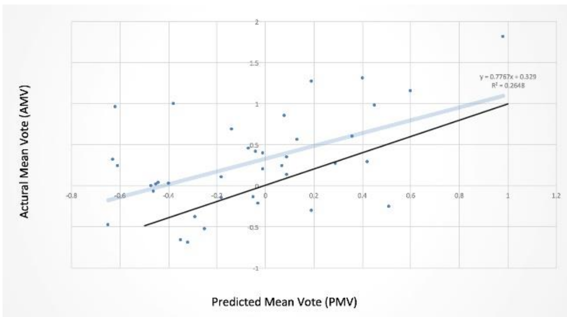

Figure 6. Comparison between PMV and AMV of all surveyed lecture theatres

4.3 Air movement difference between seat positions with various height levels

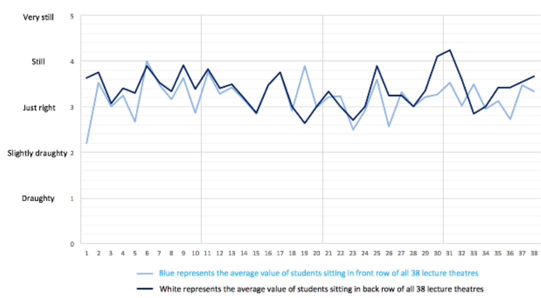

Figure 7. Voted about air movement satisfaction from students sit at the front and back respectively

Figure 7 showed all 38 lecture theatres, with students seated in the front demonstrating more air movement and satisfaction than those seated in the back, with the exception of a few classes due to the following causes: 1. The interior structure of the house - as a consequence of the internal construction of the house, which includes windows at the back of the class, the back air velocity is fast, resulting in a higher level of satisfaction for students in the rear compared to the front. 2. Gender differences in air movement; women perceive it as higher, while men perceive it as more frail, and when completing the questionnaire, the women seated in the back are comparatively many, which explains why certain rooms have a higher level of satisfaction in the back than in the front. However, the common consensus is that students placed in the front enjoy better ventilation, which results in higher thermal comfort than students seated in the back row in theatres.

4.4 Thermal comfort difference between seat positions with various height levels

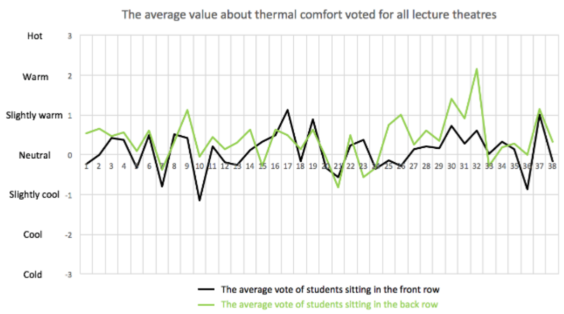

Figure 8. All lecture rooms average thermal comfort evaluation of different position

Figure 8 showed each classroom has a unique code, and the black line represents the thermal comfort trend for students situated in the first row of the 38 lecture theatres, while the green line represents the tendency of students placed in the rear. The line's substantial volatility reflects the decreased thermal comfort shown in the figure closer to the average. Overall, the black line is more stable than the green line, indicating that students situated in the front row experience more thermal comfort than those seated in the rear row. Unexpectedly, 13 lecture theatres demonstrate that students situated in the rear are more comfortable than those seated in the front, owing mostly to the back's lower temperature in comparison to the front, which might be attributed to the open system of natural ventilation.

5. Conclusion and limitation

Through a statistical comparison of thermal comfort levels between students situated in the back and front of all lecture theatres, it was determined that those seated in the rear were warmer than those in the front and had reduced thermal comfort in the majority of lecture theatres. In times, as a consequence of the significantly reduced temperature, thermal comfort may be compromised at the front. Thus, seat position and thermal comfort are strongly related to the front seat, which provides more comfort than the back seat. The back seat comfort, on the other hand, may be improved. Increasing the ventilation at the rear might be an effective strategy, since thermal comfort and air velocity are inextricably linked, and an adequate amount of interior ventilation can improve students' focus by enhancing their comfort. Additionally, when comparing PMV and AMV to Fanger's benchmark, it can be observed that the two have similar tendencies with little variation. This is mostly attributed to London's temperate oceanic climate, which has relatively stable temperature conditions. This will result in occupant thermal adaptation, generated by long-term thermal experience in a particular location with a consistent thermal comfort environment, which is in line with Fanger's experiment condition.

The purpose of the study was to examine the relationship between thermal comfort and seat position employing statistical analysis. This study excludes gender issues, since the male to female ratio is 3:1, and preferably, the male to female ratio should be 1:1 to get more precise data result. The relationship between sitting position and thermal comfort seems to be quite close in average, and the relationship between thermal comfort and seating position is evaluated using three variables: indoor air quality, indoor air velocity, and indoor air temperature. Additionally, the AMV values for all lecture rooms were compared to the PMV values and found to have similar tendencies, since the students in the lecture theatres had significantly limited physical adaptation to their environment. Nonetheless, an average absolute error exists between the two sets of numbers, which might be the consequence of an imperfect method of estimating the amount of clothing and a greater variation in individual opinion. Thus, it is suggested that 13 scale values be used to precisely scale the PMV to 0.5 increments.

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Data access statement:

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.