Global Warming and its Effect on the Overheating within Educational Building in London

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Abstract. Global warming increases in spring and summer temperature as well as the high percentage of glazing feature of educational building are resulting in high thermal gain and indoor air temperatures. As a result of this occupant tend to adjust their seating to overcome this internal heat island effect resulting in an overload on the air conditioning, if present, in different zones. This research aims to bridge the gap between energy performance of buildings and occupants' habitual adaptive behaviour in educational buildings. Data, indoor and outdoor temperatures, from a representative educational building in the City of London were collated and analysed. The building fabric thermal performance for the case study building was modelled and simulated by using the Integrated Environmental Solutions (IES) software suite. The findings revealed that different parts of lecture rooms have reached temperature which are beyond the acceptable limit during the summer and even when mitigating actions were used such as air movement fans and opening of the windows the overheating was still significant. This was difficult to pick in the modelling and was only picked in the actual data monitored.

Keywords: Climate Change, Energy Efficiency, Energy Simulation, Indoor Air Quality, Overheating

1 INTRODUCTION

Educational buildings form an important part of the built environment and have significant importance in our societies as they deliver education and a place to deliver innovative research and practices that support the sustainable development and incentivise economic growth. At the same time educational buildings, classrooms, laboratories, and equipment-education infrastructure - are crucial elements of learning environments in schools and universities. However, educational building stock has been documented to use more energy per floor area both in terms of embodied energy (EE) and operational energy use (OE).

Gul and Patidar (2015) set out a pilot study to analyse the relationship between the patterns of electrical energy consumption and user activities in a university building [1]. This study focused on the electricity consumption of an academic building at Heriot-Watt

University in Edinburgh, Scotland. The study was conducted on using an online questionnaire survey which has been sent both to students and staff. Additionally, semi-structured interviews were conducted with key management members across the campus. This approach was used to provide a comprehensive understanding of the building's daily usage, operation, and management. Building Energy Simulation (BES) analysis was conducted at 30-minutes intervals to investigate fluctuations in electrical consumption which has been caused by the number of people entering the building or room activities. The study found that the activities of building users, particularly students, had a small influence on the electricity consumption of the building. The primary source of electrical consumption was identified as the pre-set heating/cooling systems of the building which has been operated by a Building Management System (BMS) controlled by the University Estates department. This system did not consider room activity or occupancy status. However, it was highlighted that detailed information on occupancy patterns could help the management team redesign control strategies to improve the building's energy performance.

Masoso et al. (2010) revealed the significant amount of wasted energy in commercial buildings in Botswana and South Africa during non-occupied hours. The study points out that this waste during non-working hours was only a fraction of the waste caused by poor occupants' behaviour, which also led to high energy being wasted even during working hours [2]. Advanced energy auditing technology was utilised to conduct an energy audit on six randomly selected commercial buildings for base case scenario development. Electricity consumption data was recorded on sub-hourly basis, and energy consumption was classified into categories such as heating, ventilation and air conditioning (HVAC), plug load (office equipment), and lights. The investigation of the university building in Botswana showed that 64% of energy use was attributed to the Heating Ventilation and Air-Conditioning (HVAC) system, 22% to plug load, and 14% to lighting. Additionally, it was found that during non-working hours, energy use accounted for 59%, which was 18% higher than the energy use during working hours, indicating great potential for energy savings. Across all six buildings, the air conditioning systems are the largest energy consumers, followed by equipment left unnecessarily on at the end of the day (mainly computers), and then lighting. As a result, the study recommends that more attention should be given to addressing energy wastage caused by poor occupants' behaviour.

Gallacho´ir et al. (2007) conducted benchmarking analysis on a case study at University College Cork in Ireland, analysing the use of simple performance indicators and how additional data and new metrics can significantly improve the understanding of energy trends, particularly in assessing building energy performance [3]. The study highlights the importance of accurately visualizing both measured and predicted energy performance of a building. The study emphasises the need for proficient use of a building management system (BMS) to obtain precise actual energy performance data for individual buildings. In addition, the study suggests using a precise whole building energy simulation tool that can accurately replicate the building's dynamic thermal behaviour to forecast its performance. It also highlights the importance of having detailed data at a sub-sectoral level for comparing performance and making informed energy policy decisions.

Pasandi, et al (2024) conducted a study on comprehensive review of tools and applications which were used to analyse the feedback interaction between building operation and energy and urban microclimate. The study classified tools and applications related to

Urban Building Energy Modelling (UBEM) and Urban Climate Modelling (UCM), focusing on the combination of these tools through Multi-Domain Urban Scale Energy Modelling (MD-USEM) to facilitate reliable information exchange between urban microclimate and building energy models. Additionally, the study reviewed a total of 1,752 studies, primarily from reputable sources such as Elsevier, Springer, Taylor & Francis, and peer-reviewed conference proceedings [4]. A systematic review adopting a meta-analysis approach was used to define the statistical aspects of studies in UEM in the Web of Science (WoS). The findings showed that previous studies mostly focused on Urban Heat Island (UHI) effect and heat flux as the primary microclimatic factors affecting building operation. Only a few studies considered other factors such as humidity and wind velocity. The review also revealed that coupling strategies are among the most popular methods for assessing building-microclimate interaction, as they utilize the capabilities of both UBEM and UCM simulation tools.

The study conducted by Ascione et al. (2017) aimed to demonstrate the possibility of cost-optimal building retrofit towards nearly Zero Energy Buildings (nZEBs) by reducing energy consumption and environmental impact while considering cost-effectiveness of buildings. The study used an educational building in South Italy for base case scenario development. Energy Plus software was used to conduct BES due to its high accuracy and detailed building modelling capabilities. Additionally, MATLAB was used for optimization algorithms and data processing because of its programming capabilities. The study maximized energy efficiency by renovating the building envelope, optimizing HVAC systems, and integrating renewable energy sources [5]. The study found that the most profitable energy retrofit configurations included the installation of an air-source heat pump for space heating and a full-roof Photo Voltaic (PV) system.

Schwartz et al. (2024) evaluated how performance design can be implemented in educational buildings. This investigation focused on a case study of an educational building in London. The study used Thermal Analysis Software (TAS) Systems software to conduct advanced simulations of the building's HVAC plant and predicted energy usage, taking into account the requirements of the National Australian Built Environment Rating System (NABERS) to assess building fabric thermal performance. TAS software was used to perform the advance simulation of the selected case study building. The advanced simulation predicted energy usage for cooling (chillers), heating (boilers and other heat generators), circulation circuits (pumps), and ventilation (fans) [6]. The study also reviewed the RIBA Stage 4 package to ensure accurate representation and simulation of the Mechanical, Electrical and Plumbing (MEP) design. The study revealed that the presence of a combined heat and power (CHP) system did not have a significant impact on energy consumption. However, the benefit of having a CHP system is in reducing carbon emissions, which is necessary for the building to show a minimum 35% reduction in carbon emissions under Part L 2013. Furthermore, replacing boilers, CHP, and chillers with an Air Source Heat Pump resulted in a similar kWh/m2 as the original design, with increased cooling consumption due to the unit's size being based on demand. Abel (2021) investigated the impact of indoor environmental quality on occupants' thermal comfort and reviewed studies on indoor air quality in educational buildings and its influence on building ventilation strategies [7]. The study used a case study approach of the University of Reading and employed Integrated Environmental Solutions (IES) software to model both exist-

ing and refurbished buildings. The study found that for refurbishments, mechanical ventilation would be the best solution to achieve high indoor air quality, aligning with the university's energy targets if the energy use could be offset by renewable technology. Various low-carbon technologies such as PV, HP, and solar water heating were evaluated to determine the most suitable for incorporation within the proposed building. The inclusion of solar photovoltaics in the proposed model resulted in a 37% improvement in target emission rates for a University Campus building. The final model showed a 304% improvement in heating and a 195% improvement in cooling over benchmark figures. This study demonstrated the feasibility of delivering a building with high indoor environmental quality while meeting strict energy targets.

The purpose of the current study is to investigate the efficiency of an educational building to fulfil its purpose to improve energy efficiency. Therefore, the main objective of this research is to investigate the thermal performance of an educational building to assess overheating in the summer. This was tested by utilising a quantitative methodology involving an on-site environmental monitoring and conducting dynamic thermal simulations to explore potential interventions that could improve the thermal efficiency of the building.

2 METHODOLOGY

2.1 Research Design

The aim of this study is to determine the thermal comfort of a reference educational building. This is so that the information gained in this study may be used in further studies to develop benchmarking criteria for improving both thermal comfort and energy efficiency of educational buildings across the UK. This study was adopted a quantitative research methodology with concurrent data collection techniques applied to a case study building. This research project is undertaken in three phases: the first phase identifies the existing energy performance of the case study building and develop a reliable building simulation model for both the second and third phases. At the same time, the first phase sets out to assess the overheating risks and issues with indoor thermal comfort. The monitoring of indoor air temperature of the case study provides an in-depth investigation of the indoor environment conditions and validates the results from a simulation analysis of the occupied spaces, in that the monitored spaces reported relatively high indoor temperatures, which are not appropriate for occupants' thermal comfort. This detailed information is then used in the dynamic simulation modelling using the Integrated Environmental Solutions (IES) software suite to provide an in-depth understanding of the impact of material properties used in energy efficient building systems on building energy performance, as well as how this should be considered for appropriate retrofit delivery to combat exacerbated climate change. The statistical analysis was carried out to validate both on-site environmental monitoring and BES analysis.

2.2 Case Study: London South Bank University's Keyworth Centre

Keyworth Centre located on the London South Bank University's Southwark Campus has been selected as the case study as there have been several complaints received from the occupants regarding the lack of air movement and overheating of some of the lecture rooms in the summer, and the uncomfortably low temperatures of an open plan design studio on the 7th floor in the winter. Additionally, the ground floor reception, café and seating area had reported problems with of draught and uncomfortable temperatures in winter leading to the areas being underused. This building was built in 2010. It was constructed with steel frame and has metal cladding. The building comprises eight floors including an atrium. The building is generally occupied from Monday to Friday between the hours of 9am to 6pm. The building is busier from October to June during the university's term time, but is used throughout the year by staff, who use some of the offices and laboratories.



(a) (b)

Fig. 1 (a) Building envelope of Keyworth centre; **(b)** eight story large atrium space.

2.3 Environmental Monitoring

In order to assess the current energy performance of the base-case prototype building, an open plan lecture room was monitored by three data loggers from July-October 2024. The extensive monitoring campaign aimed to measure the impact of significant indoor air temperature fluctuations on the thermal performance of a building and the occupants' thermal comfort. Fig 2 (a) - (c) illustrate the location of the data loggers installed in the case study building. The physical parameters were measured at 10-min intervals in order to record the environmental conditions with absolute accuracy. The adaptive thermal comfort model assesses human thermal comfort by considering Va, Ta, RH, Tmrt, clothing insulation (*clo*), and metabolic rate (*met*). Adaptive thermal comfort model considers the combined effects of various factors on thermal comfort and is widely used to assess different environments. It is applied to predict thermal comfort not only in air-conditioned and naturally ventilated buildings but also in semi-enclosed and outdoor environments. Therefore, in this study, the indoor thermal comfort of the three factories was evaluated using the pythermal comfort code published by Tartarini and Schiavon [8] for the adaptive thermal comfort assessment.



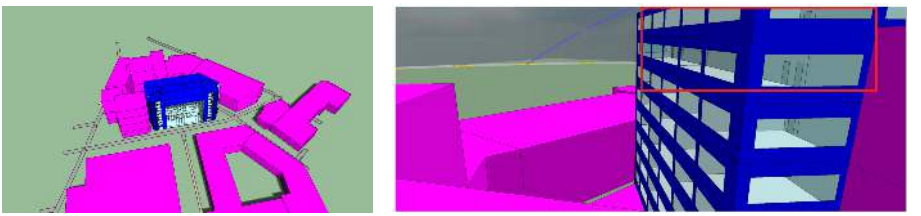
(a) (b) (c)

Fig. 2 (a) Installation of monitoring devices into a large open space; **(b)** data logger location in the design studio space; **(c)** data logger is mounted on the wall surface.

2.4 Building Energy Simulation

Dynamic thermal modelling using Integrated Environmental Solution Virtual Environment (IES) was employed for in-depth investigation of the building thermal performance and to facilitate data triangulation with the statistical analysis and indoor monitored data.

The building performance evaluation software package: Integrated Environmental Solutions-Virtual Environment (IES) using Apache-Sim in IES software suite for dynamic thermal simulation (DTS) was performed. Cooling load calculations using IES Apache-Constructions and Apache-Loads in IES software suite were undertaken. The input parameters required for modelling included the building geometry and properties of the construction materials, specifications of the building components, occupancy patterns, internal heat gain sources, and the outdoor air temperature. The building geometry was created using detailed construction drawings provided by the university facilities manager where each floor is modelled to include its specific thermal zones, as shown in Fig 3 (a) – (b) The outcome is twofold; first, a validation of the initial simulations of the base case against the indoor monitoring and occupants' thermal experience; and second, an investigation of appropriate retrofit interventions aiming to improve occupants' thermal comfort, reduce overheating risks and cooling energy loads.



(a) (b)

Fig. 3 (a) Analytical energy model of Keyworth centre and its neighborhood buildings; **(b)** representative floor level.

2.5 Statistics

We used the statistical software Statistical Package for the Social Sciences (SPSS) version 29.0 to conduct data pre-processing, resampling, and the cross-validation of research outputs in the Analysis and Results section. In this study, we conducted descriptive and frequencies analyses to fully understand the data. When it comes to conduct the inferential statistics, both parametric and non-parametric analyses were applied. Non-parametric analyses were considered when there is reason to worry about parametric assumptions, or when the measurements being considered demand them. To assess normality, skewness and kurtosis statistics are assessed. Skewness refers to the symmetry of the distribution and kurtosis refers to the peakedness. Univariate and multivariate outliers are also known as extreme values and can significantly bias any parametric test. We have checked our variables for univariate outliers. SPSS identifies these values as being three times the interquartile range beyond the 25th and 75th percentile values. In the present study, multivariate outliers were tested before the primary analyses were conducted where appropriate. Additionally, the study was applied to Pearson's correlations to explore the influencing factors of on-site environmental monitoring data.

3 ANALYSIS AND RESULTS

3.1 Overheating Risk Assessment

The aim of the overheating risk assessment is to evaluate the thermal environment within the occupied space and identify periods of elevated temperatures that may compromise occupant comfort and improve students' learning. This assessment is based on the provided temperature data ranged between July to October 2024, Fig 4 illustrates fluctuations in internal temperatures. The primary objectives are to analyse the temperature trends, determine the frequency and duration of overheating events, and assess the effectiveness of existing cooling strategies. Additionally, the assessment seeks to recommend appropriate mitigation measures to enhance thermal comfort and ensure compliance with relevant building performance standards.

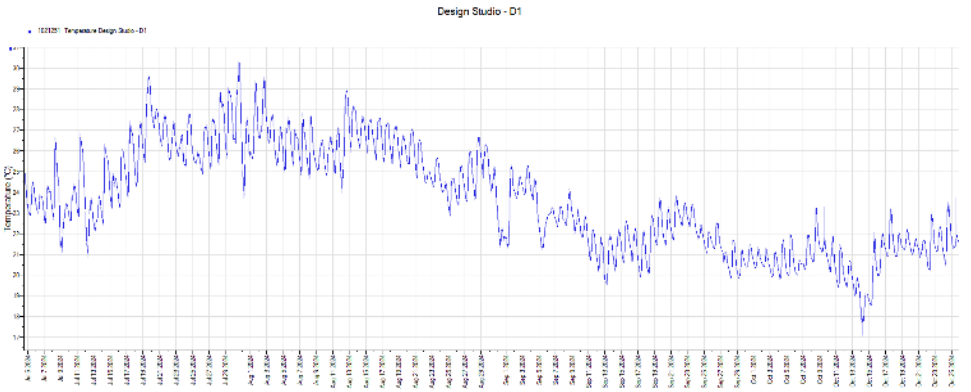


Fig. 4 Indoor air temperature fluctuations of the Keyworth Centre on the 7th floor between July-October 2024.

As shown in Figure 4, the temperature trend reveals distinct fluctuations, indicating both diurnal and seasonal variations. It can be seen that during the earlier months (July to mid-August), temperatures are generally higher, peaking around 30°C, which suggests a typical summer heat. This is likely influenced by external weather conditions combined with internal heat gains from equipment or occupancy. As the timeline progresses into late August and September, there is a noticeable downward trend in the temperature readings, which align with the transition from summer to autumn. The trend continues, with temperatures gradually stabilizing around 20-25°C by October. Despite this overall cooling trend, there are still daily fluctuations observed, reflecting the difference between day and night temperatures, potentially exacerbated by the thermal inertia of the building and HVAC system responses. The overheating risk assessment in such a scenario would focus on the frequency, duration, and magnitude of temperatures exceeding the comfort threshold (typically around 24-26°C). From the data, it is evident that the peak temperatures in July and August are a potential concern for overheating, especially during prolonged periods above 27°C. This can lead to discomfort for occupants and might strain cooling systems. An effective risk assessment would include monitoring the HVAC system's capacity to handle peak loads, ensuring adequate ventilation, and possibly implementing shading or insulation improvements to mitigate heat gains.

3.2 Adaptive Thermal Comfort

Adaptive thermal comfort assessment recognizes that people's perception of thermal comfort is influenced not only by physical parameters like air temperature, humidity, and air velocity but also by psychological and behavioral factors. Unlike static comfort models such as PMV/PPD, adaptive models account for outdoor climate conditions and occupants' ability to adapt, thus providing more realistic predictions of thermal comfort in diverse environments, as shown in Figure 5.

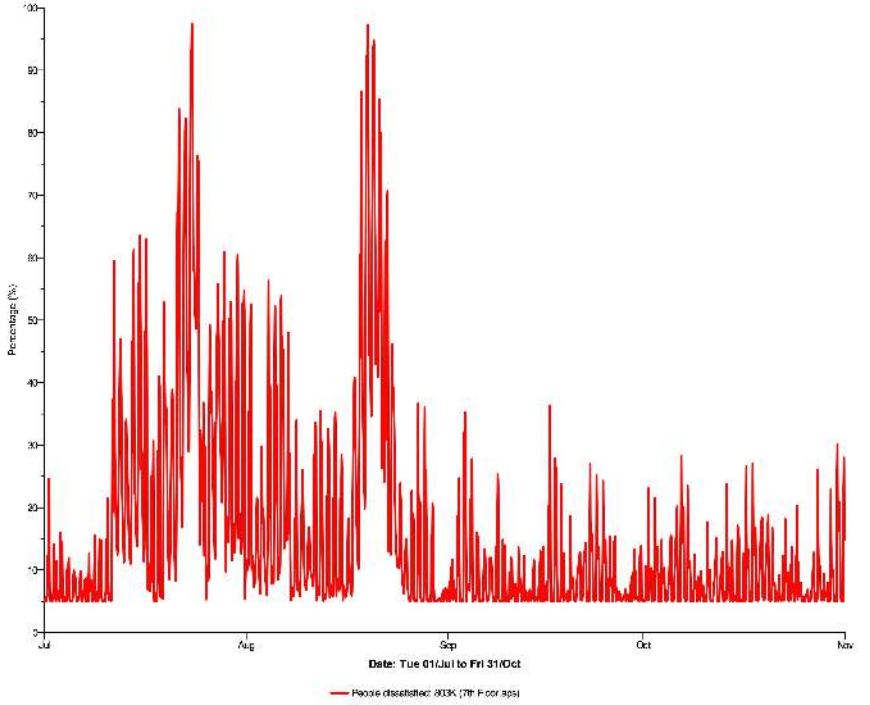
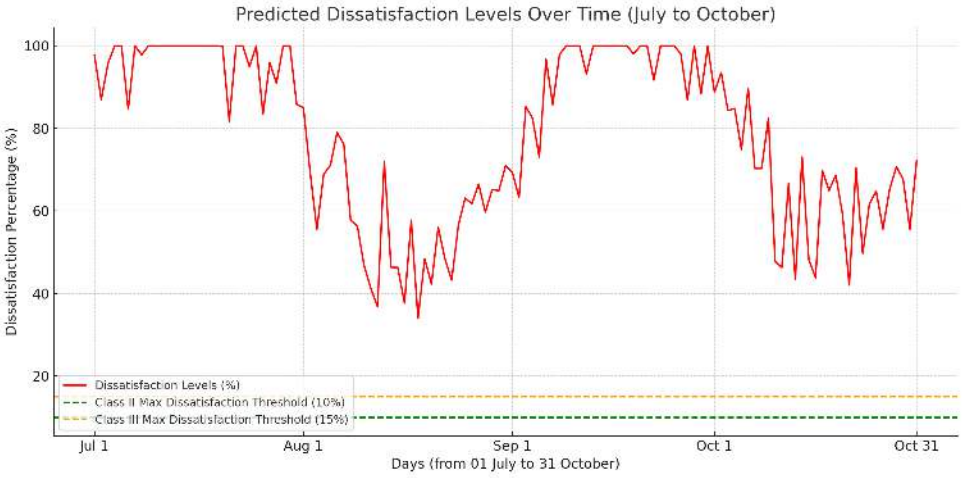


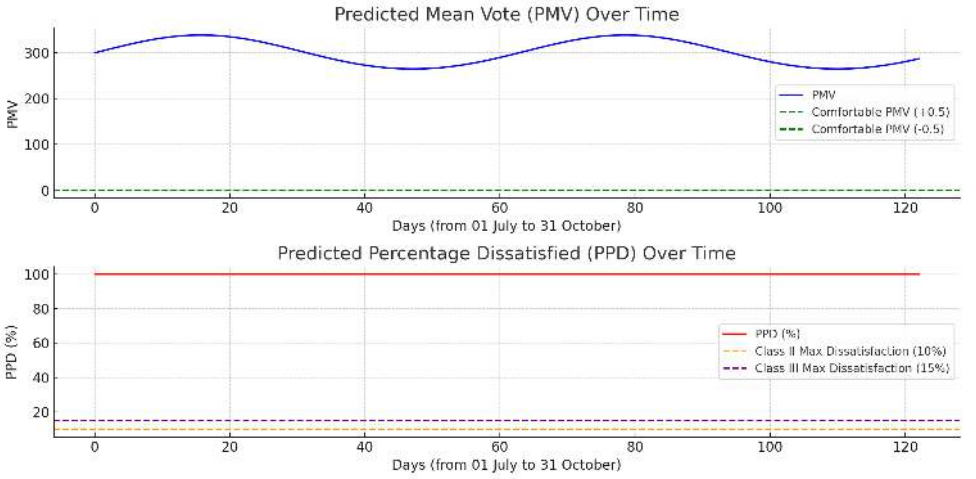
Fig. 5 Percentage people dissatisfied fluctuations.

Figure 5 presents fluctuations in predicted dissatisfaction levels over a period from July to October. It was found that dissatisfaction exceeds acceptable limits (10-15%) during the summer months, suggesting that indoor conditions are likely too warm. Likely causes include overheating during summer or poorly regulated indoor temperatures, pushing dissatisfaction rates well over 60-90%. Figure 5 indicates thermal discomfort that exceeds Class III limits, pointing to either inadequate ventilation or insufficient cooling. Frequent and intense peaks imply conditions where indoor temperatures could have been far above comfort thresholds (e.g., exceeding 26-28°C for extended periods) between July to early September. As outdoor temperatures decline (typical in London's temperate climate), dissatisfaction levels drop significantly. This is consistent with the building passively returning to comfortable thermal conditions without the need for active cooling between September to October. It was found that a PMV in the range of +2 to +3 during summer, indicating thermal conditions perceived as "warm to hot," correlating with dissatisfaction percentages above 90%.



(a)

Fig. 6 (a) Psychometric chart for the identification of neutral adaptive thermal comfort.



(b)

Fig. 6 (b) Psychometric chart for the identification of neutral adaptive thermal comfort.

Figure 6 (a) illustrates the simulated dissatisfaction pattern over time, consistent with EN-16798 criteria. According to the data, high dissatisfaction levels (above 90%) persist throughout July and August, suggesting severe discomfort due to thermal conditions. Sharp reductions in dissatisfaction are observed in early September, consistent with seasonal cooling, while dissatisfaction remains elevated relative to Class II (10%) and Class III (15%) thresholds. In Figure 6 (a) the green and orange lines indicate thresholds for

acceptable comfort categories. Most of the data points fall far above these lines, meaning that the thermal environment did not meet even the basic comfort criteria during peak summer. Figure 6 (b) breaks down the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) over time. The blue line shows PMV values, which remain well outside the comfort range of -0.5 to +0.5, indicating that indoor thermal conditions are far from optimal. PMV values suggest occupants likely felt consistently warm or hot due to elevated air and radiant temperatures during this period. The PPD (red line) confirms severe dissatisfaction, with values reaching nearly 100% throughout much of the observation period. Both Class II (10% max) and Class III (15% max) dissatisfaction thresholds are exceeded, especially during July and August, emphasizing the need for corrective measures.

3.3 Benchmarking

This section analyses frequency statistics based on the CIBSE 2017 overheating risk assessment criteria and critically assess the data using statistical theoretical frameworks.

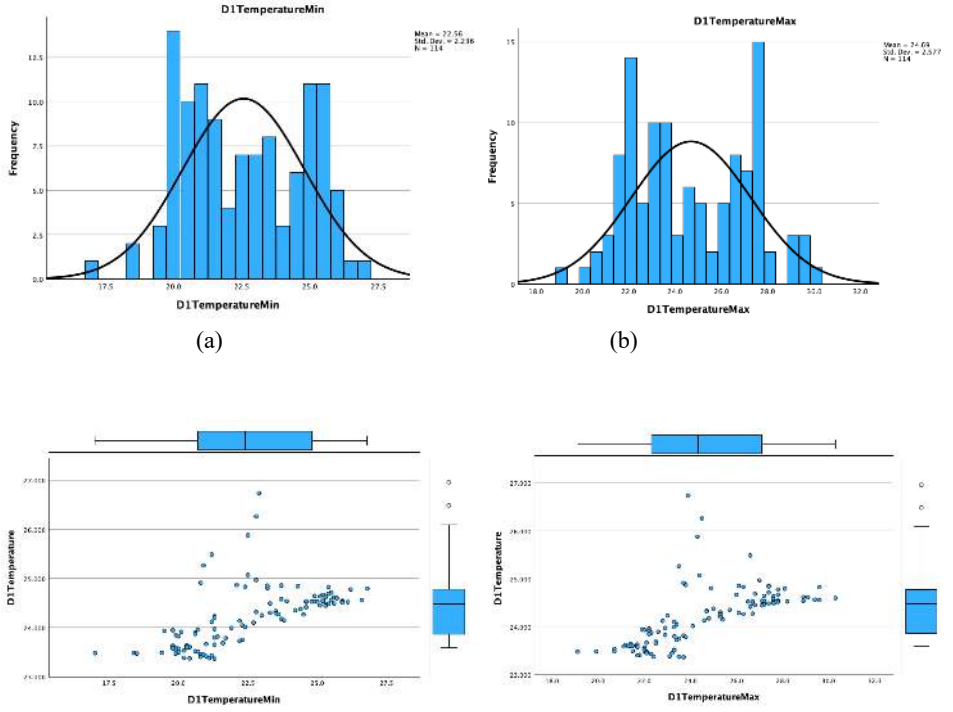


Fig. 7 (a) maximum recorded indoor air temperatures; **(b)**; minimum recorded air temperatures **(c)**; correlation analysis with maximum temperatures **(d);** correlation analysis with minimum temperatures.

The average minimum daily temperature depicted in Figure 7 (a) was calculated to be at 22.56°C. According to CIBSE's 2017 guidelines, overheating thresholds for living spaces are typically defined when indoor temperatures surpass at 28°C. The histogram represents the lowest daily temperatures, it is unlikely that these values alone exceed such thresholds. However, they could indicate insufficient cooling during nighttime. The standard deviation (SD) is at 2.236°C, which reflects a relatively tight clustering of temperatures around the mean, suggesting consistent nighttime cooling patterns. Nonetheless, temperatures approaching or exceeding threshold values could hint at potential nighttime overheating. The distribution of the data appears approximately normal, with a few outliers below 20°C and above 26°C. Most minimum temperatures fall between 20°C and 25°C, which exceeds the recommended thermal comfort range for sleeping (16°C to 20°C).

Figure 7 (b) illustrates daily maximum temperatures ranging from approximately 18°C to over 30°C. Several days exhibit maximum temperatures exceeding 28°C, signaling a potential risk of overheating. The mean maximum temperature is at 24.69°C, representing the central tendency of the recorded values. With a standard deviation of 2.577°C, the data shows moderate variability. Extreme high temperatures, exceeding 30°C, act as outliers and suggest poor environmental temperature regulation, possibly due to inadequate ventilation or cooling. The skewness of the data is slightly positive, reflecting the concentration of most temperatures below 30°C while still having a few unusually high values.

The spread of minimum temperatures is presented in Figure 7 (c), which highlights outliers below 17.5°C and above 27.5°C. Extreme values above 27°C may represent exceptionally high nighttime temperatures. The majority of the data points fall between 20°C and 25°C, indicating a relatively stable range of nightly temperatures. Additionally, the clustering of temperatures between 24°C and 26°C for average values further confirms this consistency. This distribution suggests a predictable pattern for minimum daily temperatures, although outliers indicate occasional deviations from typical conditions.

Figure 7 (d) focuses on the variability of maximum temperatures, emphasizing the range, interquartile range (IQR), and presence of outliers. A few extreme values, exceeding 30°C, highlight anomalously high-temperature days. Additionally, temperatures above 27°C suggest elevated overall daily temperatures, which are consistent with extreme maximum values. A positive trend is evident in the data, demonstrating a direct correlation between higher maximum temperatures and elevated daily temperature levels. These trends underline the potential for overheating, especially during periods of extreme heat.

Table 1. Kurtosis and Skewness analyses based on the environmental monitoring data.

		D1Temperature	D2Temperature	D1TemperatureMin	D1TemperatureMax	D2TemperatureMin	D2TemperatureMax	D3TemperatureMin	D3TemperatureMax
N	Valid	32614	32614	114	114	114	114	114	114
	Missing	0	0	32500	32500	32500	32500	32500	32500
Mean		23.63949	23.46957	22.561	24.685	22.454	24.453	21.713	24.123
Median		23.35900	23.18400	22.400	24.350	22.250	24.200	21.750	23.800
Std. Deviation		2.530538	2.608217	2.2365	2.5770	2.2874	2.6891	2.6303	2.7153
Skewness		.162	.193	.032	.152	.114	.186	-.122	.218
Std. Error of Skewness		.014	.014	.226	.226	.226	.226	.226	.226
Kurtosis		-1.007	-1.104	-1.081	-1.073	-1.248	-1.130	-1.007	-1.004
Std. Error of Kurtosis		.027	.027	.449	.449	.449	.449	.449	.449
Minimum		17.047	17.953	17.0	19.1	18.0	19.3	15.6	18.7
Maximum		30.342	30.472	26.8	30.3	26.9	30.5	26.6	30.2
Percentile	25th	21.46700	21.17400	20.675	22.300	20.475	21.975	19.475	21.675
	50th	23.35900	23.18400	22.400	24.350	22.250	24.200	21.750	23.800
	75th	25.82000	25.79800	24.800	27.125	24.700	27.000	24.225	26.500

The means of D1Temperature and D2Temperature are approximately 23.6°C and 23.47°C, respectively, suggesting a high level of consistency in the temperature trends between these two variables. However, D1 Temperature Min and D1 Temperature Max exhibit a broader range of values with mean temperatures of 22.56°C for the minimum and 24.69°C for the maximum. This reflects the anticipated variability between daily lows and highs. Both D1Temperature and D2Temperature have standard deviations of about 2.53°C, indicating a moderate degree of variation around their respective means.

The skewness values for most variables fall within a narrow range, from -0.122 to 0.218, suggesting that the distributions are nearly symmetric. However, D3 Temperature Min shows a slight negative skew (-0.122), indicating a mild inclination toward lower temperature values. The distribution's quartile analysis reveals that 25% of the data points are below 21.47°C, while 50% (the median) fall below 23.35°C, and 75% of the observations are under 25.82°C. The highest observed temperatures, such as 30.3°C for D1TemperatureMax**,** represent rare occurrences of extreme heat. These instances may hold significance for evaluating potential risks associated with overheating.

4 CONCLUSIONS

The study sought to undertake an in-depth investigation into the building thermal performance and occupants' thermal comfort of a representative educational building at the London South Bank University. The objective was to evaluate the occupants' thermal comfort on the 7th floor architecture design studio space following issues raised concerning poor thermal comfort levels. Quantitative research has been designed based on data collected from data loggers to monitor the office indoor environment, and dynamic thermal modelling and simulation undertaken by IES software suite.

The subsequent stage was to analyze the current thermal performance of 7th floor architecture design studio space and the potential retrofit solutions that can help improve occupants' thermal comfort. This was undertaken by building simulation modelling of the case study using real occupancy scenarios, internal heat gains and detailed construction materials to validate the results obtained from the survey and indoor monitoring concerning

overheating and thermal comfort. It was found that the temperature consistently fluctuates, with notable peaks during the summer months of July and August, indicating a potential risk of overheating during this period. The highest recorded temperatures approach 30°C, which could lead to discomfort for occupants and increased strain on cooling systems. As the season transitions into autumn, a gradual decline in temperature is observed, with values stabilizing around 20-25°C by October, reflecting improved thermal conditions. However, the next phase of the study is to explore other feasible and holistic proposals to further improve thermal comfort in educational buildings across the UK and determine the energy and cost savings of the optimum retrofit intervention.

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