Indoor Environmental Quality Study for Higher Education Buildings

Maigari, Mukhtar, Fu, Changfeng ORCID logoORCID: https://orcid.org/0000-0002-2019-5445, Deng, Jie ORCID logoORCID: https://orcid.org/0000-0001-6896-8622 and Bahadori-Jahromi, Ali ORCID logoORCID: https://orcid.org/0000-0003-0405-7146 (2023) Indoor Environmental Quality Study for Higher Education Buildings. In: Indoor Environmental Quality and Health. IntechOpen, London, UK.

http://dx.doi.org/10.5772/intechopen.113332

Indoor Environmental Quality Study for Higher Education Buildings

Mukhtar Bello Maigari, Changfeng Fu*, Jie Deng
The School of Computing & Engineering, The University of West London, St Mary's Road, Ealing, W5 5RF, London, UK

Abstract

Indoor environmental quality (IEQ) in school buildings have been concerned widely for many years, while research into the IEQ issues in Higher Education (HE) buildings have been overlooked to some extent. This chapter presents an experimental study of the IEQ issues in two typical HE buildings in London using the post occupancy evaluation (POE) methods. Various aspects of the IEQ have been considered in terms of human comfort in buildings, including indoor air quality, noise level, lighting, occupants' perception and so on. IEQ data have been collected using various IEQ meters and data loggers, as well as questionnaire surveys taken by the respondents. The results of the study reveal important findings. In terms of thermal comfort, several spaces were found to exceed the recommended temperature limit of 25°C. The data on indoor air quality indicated that rooms, particularly those with natural ventilation, such as the Architectural Studio, significantly exceeded the recommended CO_2 limit of 1500 ppm. Moreover, the survey feedback collected from the building occupants aligned with the IEQ data, particularly in the area of thermal comfort. The respondents' feedback provided valuable insights into their experiences and perceptions of the indoor environment, further reinforcing the findings obtained from the objective IEQ measurements. The work also discusses recommendations and possible actions to improve the IEQ in HE buildings.

1. Introduction

Indoor Environmental Quality (IEQ) is a critical aspect of the built environment that has a significant impact on the health, well-being, and productivity of building occupants. The quality of indoor air, thermal comfort, lighting, acoustics, and ergonomics are some of the factors that determine the IEQ of an infrastructure in the built environment (Kamaruzzaman et al., 2017). In higher education (HE) buildings, such as classrooms, libraries, laboratories and lecture halls, etc., the importance of IEQ cannot be overemphasized. Previous studies and research on the state of IEQ in educational institutions have predominantly centred around primary and secondary schools (Awang et al., 2015, Korsavi et al., 2020). The nature of higher educational buildings with complex spaces and structures consisting of various rooms such as laboratories, lecture theatres, PC rooms etc., has possibly added to the limited studies and research on the state of IEQ in HE buildings. As such, there has been heightened interest in understanding the IEQ state of HE buildings especially following the COVID-19 pandemic which has greatly increased awareness towards IEQ especially in public spaces such as educational institutions. This has led to the development of various strategies and tools for assessing and improving IEQ.

One of the most effective strategies for assessing IEQ in higher education buildings is the use of Post Occupancy Evaluation (POE) methods. POE involves the systematic evaluation of a building's performance after it has been occupied by its intended user (Leaman, 2003). POE methods provide a comprehensive assessment of the IEQ of a building by combining data from various sources, such as physical measurements, occupant feedback and building performance data. However, despite the potential benefits of using POE methods to assess IEQ in higher education buildings, there is still a lack of awareness and understanding of these methods among building managers and stakeholders. As such this article aims to address this apparent gap, coupled with the lack of IEQ awareness and understanding in higher education buildings through the following objectives:

- To gain comprehensive understanding on the current state of knowledge on IEQ and POE by reviewing relevant literature including peer reviewed journal articles, books and reports.
- To identify the existing IEQ situations in HE buildings and the current means for IEQ monitoring and control through case studies.
- To gain invaluable insights from students regarding their perception of IEQ with a questionnaire survey.
- To highlight issues with IEQ in HE Buildings based on the findings in the literature review, case study and student feedback as well as provide recommendations for how to mitigate such issues.

2. Background

2.1 Indoor Environmental Quality (IEQ)

The indoor environment constitutes the different kinds of indoor spaces available within built assets, such as residential buildings, offices, schools and hospitals. The state of the indoor environment has been a prominent research area and industry interest even before the COVID-19 pandemic. Improving the quality of life of building occupants, increasing work performance or simply in a bid to make a building more sustainable are few reasons why research into IEQ has gained lots of traction in the AEC industry (Kamaruzzaman et al., 2018). IEQ also refers to “the quality of a building’s environment in relation to the health and wellbeing of those who occupy space within it” (NIOSH, 2022). The IEQ is linked to indoor human comfort which is usually assessed from four aspects: thermal, respiratory, visual and acoustic comfort. Respiratory comfort is generally expressed as Indoor Air Quality (IAQ). These four factors all combine to affect the comfort, health, well-being and productivity of building occupants as depicted in Figure 1.

Figure 1 - IEQ embodiment (Medium, 2020)

Indoor Environmental Quality (IEQ) has a significant impact on the health, comfort, and productivity of building occupants, especially in educational buildings where students and staff spend a considerable amount of time. According to studies, poor IEQ can lead to discomfort, respiratory problems, allergies, and other health issues (Abdulaali et al., 2020). In higher education buildings, poor IEQ can also affect students' academic performance, attendance, and retention (Haverinen-Shaughness et al., 2007).

Assessing IEQ in higher education buildings is essential to ensure that the indoor environment is healthy, comfortable, and conducive to learning. The conventional method of evaluating IEQ in buildings involves using post-occupancy evaluation (POE) methods to collect data from building occupants after they have used the space for a while. POE involves gathering feedback from occupants through surveys, interviews, and other data collection methods to evaluate their experience of the indoor environment.

2.2 IEQ Factors

Thermal Comfort (TC)

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and International Organization for Standardization (ISO) defined thermal comfort as “that condition of mind that expresses satisfaction with thermal environment” for thermal comfort (ASHRAE, 2013; ISO, 2005). This definition is influenced by the significant contributions of Professor Povl Ole Fanger in the field of thermal comfort. His work, including his dissertation and book titled "Thermal Comfort," introduced a novel relationship between environmental physical parameters, human physiological parameters, and comfort perception (Lada Hensen Centnerova, 2018). This led to the development of the prediction mean vote (PMV) and prediction percentage dissatisfied (PPD), often known as the chamber model (Ali, 2018). According to the Health and Safety Executive body (HSE), thermal comfort is affected by a combination of environmental and personal factors which are represented in Figure 2.

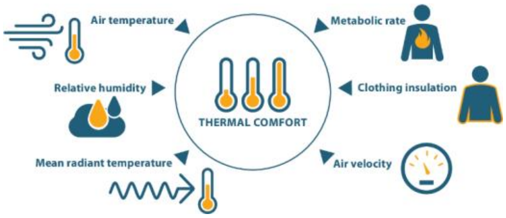


Figure 2 - Factors that affect thermal comfort (Dorizas, 2018)

Indoor Air Quality (IAQ)

The rapid progress in technology in recent times has ushered in the digital era, causing a significant shift in human behaviour towards spending more time indoors. Whether it's office workers, students in educational institutions, patients in hospitals, or individuals in their homes, studies have shown that approximately 90% of people's time is spent in indoor environments (Mannan & Al-Ghamdi, 2021). This reality underscores the importance of maintaining the quality of the indoor environment, particularly the indoor air quality (IAQ).

ASHRAE, in their indoor air quality guide (2016), defined IAQ as the "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction" (ASHRAE, 2016). Ensuring good IAQ is critical, and (Katiyar & Khare, 2008) outlined three key reasons for this:

- Indoor air serves as the interaction medium among weather conditions, people, and buildings.
- The physical, biological, and chemical characteristics of indoor air directly influence the health and well-being of building occupants.
- Given the straightforward nature of indoor air, IAQ can be clearly defined and managed to meet required standards.

Various studies have identified factors that influence IAQ, including temperature (oC), relative humidity (RH %), and pollutants (chemical, biological, and physical) (Sakhare & Ralegaonkar, 2014). Among these factors, pollutants play a significant role, with elements such as carbon dioxide (CO_2), nitrogen dioxide (NO_2), volatile organic compounds (VOCs), and viruses being of particular concern.

Acoustic comfort (AC)

Another important IEQ parameter is acoustic comfort (AC) which centres around "noise": an "unwanted sound" which when present in the built environment, affects concentrations, interferes with activities, prevents speech communication and if in high levels can impair hearing significantly. Thus, the capacity of a building to provide a suitable acoustic environment and protection against noise in line with the necessary acoustic requirements is the acoustic comfort of a building (Dorizas et al., 2018). Noise, being a form of pollution, evidently translates to the crucial impact acoustic comfort has in the health & well-being, productivity as well as communication of a building's occupants (Abdul-Mujeebu, 2019). The acoustic environment's comfort is typically influenced by various factors, including the acoustic properties (sound absorption, transmission and reflection) of the indoor space, the geometry and volume of the indoor area, the transmission of airborne noise, impact noise as well as noise from internal and external sources, such as background noise (Vardaxis et al., 2018)

Visual Comfort

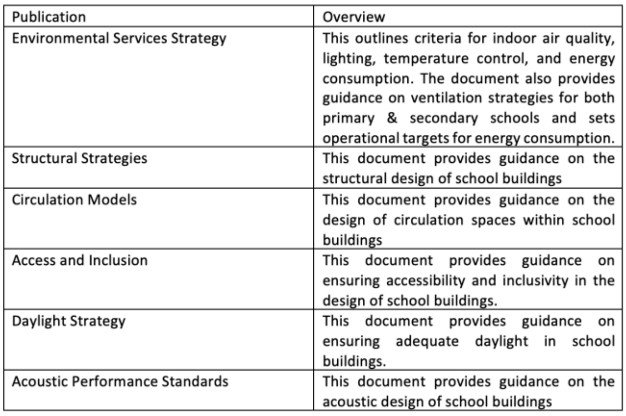
Visual comfort is an IEQ factor that involves lighting which could either daylighting or artificial lighting (Al-Khatatbeh & Ma'bdeh, 2017). It is an important element of the overall IEQ in education buildings with studies ascertaining it to be a major contributor in the creation of an optimum learning environment (Abdelatia et al., 2010). Walter Grondzik defined visual comfort as "the subjective visual wellbeing condition induced by the visual environment" and this definition clearly indicates a psychological element to the overall perception of visual comfort by individuals (Fakhari et al., 2021). It is achieved when the lighting quality and quantity, occupant perception and environmental quality of view are in a good balance (Kim & Kim, 2010). Lighting quality is a measure of the light's brightness and colour whereas lighting quantity involves the illumination levels and output (EN 12464-1, 2011).

2.3 IEQ Standards and Guidelines for HE Buildings

Indoor environmental qualities, like all aspects of sustainability, are mostly governed by certain standards. As established, IEQ is characterised by four environmental factors which are thermal comfort, indoor air quality, acoustic comfort and visual comfort. These four factors are different with different means of measurements and recording and thus, requirements for each IEQ factor is expected to be different leading to the emergence of different standards for most IEQ factors. In buildings generally, the evaluation and design of the indoor environment are governed by national and international standards. These standards provide guidelines in the specification of acceptable indoor environmental conditions for occupants (Suleiman et al., 2013). They are highlighted as follows:

1. Baseline Designs for Schools

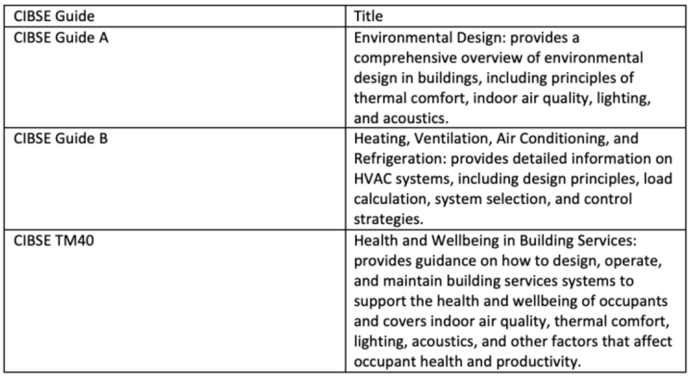
   These were developed by the Education Funding Agency (EFA) in response to a recommendation in the Review of Education Capital in April 2011. The review called for a suite of standardized drawings and specifications that could be applied across a wide range of educational facilities (EFA, 2014). The designs provide a light, bright, and airy learning environment for students and teachers. They were drawn up with the advice of environmental, architectural, and teaching experts to address problems such as dark corridors, poor ventilation, and inadequate classrooms, and to make the very best use of space (Department for Education, 2012). Table 1 provides an overview of the published guidelines on various aspects of design and construction:



Publication	Overview
Environmental Services Strategy	This outlines criteria for indoor air quality, lighting, temperature control, and energy consumption. The document also provides guidance on ventilation strategies for both primary & secondary schools and sets operational targets for energy consumption.
Structural Strategies	This document provides guidance on the structural design of school buildings
Circulation Models	This document provides guidance on the design of circulation spaces within school buildings
Access and Inclusion	This document provides guidance on ensuring accessibility and inclusivity in the design of school buildings.
Daylight Strategy	This document provides guidance on ensuring adequate daylight in school buildings.
Acoustic Performance Standards	This document provides guidance on the acoustic design of school buildings

Table 1 - - EFA Baseline design guidance document

2. Chartered Institution of Building Services Engineers (CIBSE)
   CIBSE stands for the Chartered Institution of Building Services Engineers. It is a professional body in the UK for building services engineers, encompassing a wide range of disciplines such as heating, ventilation, air conditioning, lighting, and plumbing. CIBSE was founded in 1976, and its main aim is to promote the science, art, and practice of building services engineering, as well as to promote the efficient use of energy in buildings. It achieves this through various means such as the publication of technical guidance and codes of practice, organizing seminars and conferences, and providing education and training for building services engineers.

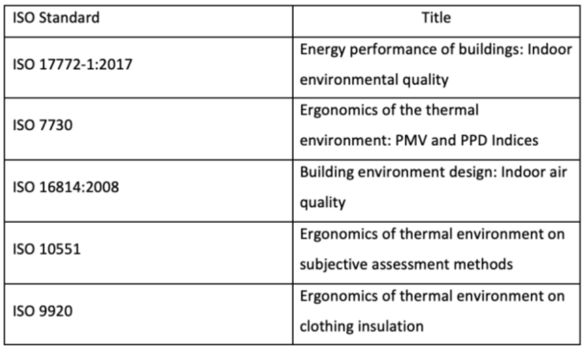


CIBSE Guide	Title
CIBSE Guide A	Environmental Design: provides a comprehensive overview of environmental design in buildings, including principles of thermal comfort, indoor air quality, lighting, and acoustics.
CIBSE Guide B	Heating, Ventilation, Air Conditioning, and Refrigeration: provides detailed information on HVAC systems, including design principles, load calculation, system selection, and control strategies.
CIBSE TM40	Health and Wellbeing in Building Services: provides guidance on how to design, operate, and maintain building services systems to support the health and wellbeing of occupants and covers indoor air quality, thermal comfort, lighting, acoustics, and other factors that affect occupant health and productivity.

Table 2 - CIBSE Guidance Documents

3. International Organisation for Standardisation (ISO)
   The ISO is an organisation consisting of 163 national standard bodies headquartered in Geneva (OECD/ISO, 2016 – dependant). Established in 1947, the ISO cover a range of areas in the field of engineering, business, health, technology, computing and

others (M. Ali, 2018). Its main goals are to provide global solutions to worldwide challenges and support innovation by developing “voluntary, consensus-based, market relevant international standards” (OECD/ISO, 2016 – dependent). Table 3 presents the relevant IEQ standards published by the ISO.

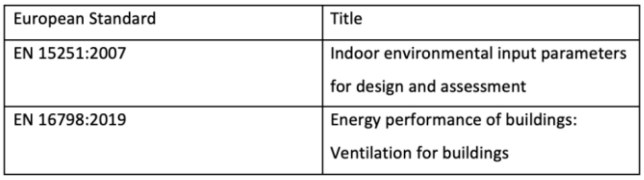


ISO Standard	Title
ISO 17772-1:2017	Energy performance of buildings: Indoor environmental quality
ISO 7730	Ergonomics of the thermal environment: PMV and PPD Indices
ISO 16814:2008	Building environment design: Indoor air quality
ISO 10551	Ergonomics of thermal environment on subjective assessment methods
ISO 9920	Ergonomics of thermal environment on clothing insulation

Table 3 - ISO Relevant IEQ Standards

4. European Standard (EN) – CEN

   The European standard (EN – European Norms) are sets of standards developed and adopted by the three European Standard Organisations: The European Committee for Standardisation (CEN), the European Committee for Electrotechnical Standardisation (CENELEC), and the European Telecommunications Standards Institute (ETSI) (Single-Market, 2020). It comprises more than 800 member organisations worldwide constituting research entities, private companies, academia and government organisations (CENCENELEC, 2021). Table 4 presents the relevant IEQ standards published by CEN.



European Standard	Title
EN 15251:2007	Indoor environmental input parameters for design and assessment
EN 16798:2019	Energy performance of buildings: Ventilation for buildings

Table 4 - European Standard (EN) relevant IEQ documents

5. The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)

   The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) is a global society established in 1894 geared towards the advancement of human well-being through sustainable technologies for the built environment (ASHRAE, 2020). By fostering innovation and disseminating knowledge, it plays a crucial role in shaping the practices and standards related to heating, ventilation, air conditioning, and refrigeration systems, contributing to the improvement of environmental sustainability and human comfort in buildings.

2.4 IEQ Indicator setpoints

The IEQ setpoints are a set of standards and guidelines that define the minimum and maximum acceptable levels of environmental parameters for optimal occupant comfort and well-being. They cover several key factors including thermal, visual, acoustic comfort, and indoor air quality (IAQ). For thermal comfort, the setpoints provide guidelines for temperature and humidity levels that ensure occupant comfort and productivity. For visual comfort, the setpoints provide guidelines for lighting levels and glare control to ensure occupant visual well-being and productivity.

Acoustic comfort setpoints provide guidelines for acceptable noise levels, sound transmission, and reverberation times to ensure occupant acoustic well-being and productivity. Finally, IAQ setpoints provide guidelines for acceptable levels of air pollutants, carbon dioxide, and relative humidity to ensure occupant respiratory health and well-being.

These setpoints are established by various organizations such as the Chartered Institution of Building Services Engineers (CIBSE), the Building Research Establishment (BRE), and the UK government, and are regularly reviewed and updated to reflect new research and standards. The adherence to IEQ setpoints can result in improved occupant comfort, productivity, and well-being, as well as reduced energy costs and environmental impact.

Standard	**Temperature (°C)**	**Relative Humidity (%RH)**	**Carbon Dioxide (ppm)**	**PM2.5 (µg/m³)**	**TVOC (µg/m³)**	**HCHO (µg/m³)**	**Illuminance (lux)**	**Background Noise (dB)**
CIBSE A	19 – 21	40 – 70%	≤ 1500	•	≤ 300	•	300; 500	35
BB 101	20-25	•	1500	25 (1 yr)	≤300 (8 hr)	•	•	•
BB 93	•	•	•	•	•	•		40 - 45
EN 12464-1:2021	•	•	•	•	•	•	500	•
UK Gov. (24-hr mean)	•	•	•	10	•	•	•	•
UK Gov. (Annual)	•	•	•	25	•	•	•	•
UK Gov. (30mins)	•	•	•	•	•	≤ 100	•	•

Table 5 – IEQ Setpoints from various published standards and guidelines

3. Research Methods

3.1 Post Occupancy Evaluation (POE) Methods

Post Occupancy Evaluation (POE) is a method for evaluating the performance of a building after occupancy. POE is an essential tool for assessing the indoor environmental quality (IEQ) in higher education buildings. It involves collecting and analysing data on the performance of a building's systems, such as HVAC, lighting, acoustics, and thermal comfort, to determine their effectiveness and efficiency. The purpose of a POE is to identify the strengths and weaknesses of a building's design and operation, and to identify opportunities for improvement (Hadjri & Crozier, 2008).

POE has been used for decades as a way to evaluate the effectiveness of building design and operation in terms of IEQ. According to a study by Fisk et al. (2004), POE has been used in a variety of settings, including office buildings, schools, and hospitals. In the context of higher education buildings, POE can be particularly useful in assessing the quality of the learning environment, which is a critical factor in the success of students.

Commented [GU1]: 3.1 POE methods
merge 3,1,and 3,2
talk about data monitoring and questionnaire surveying

For this study, the primary POE methods used are data monitoring and questionnaire surveying. Data monitoring involves the systematic collection and analysis of data related to building performance and IEQ indicators (Zimmerman & Martin, 2010). This data monitoring process may include the use of various measurement instruments and sensors to monitor IEQ indicators such as temperature, humidity, air quality, and lighting levels. Through data monitoring, researchers and building management teams can gain insights into the actual performance of the building and identify areas that require improvement. Questionnaire surveying involves the use of surveys which are conducted to gather feedback from building occupants regarding their satisfaction levels and experiences with the building environment (Zimmerman & Martin, 2010). The survey questions cover various aspects of building design, IEQ and other factors that may influence occupant satisfaction. The survey results provide valuable insights into occupants' perspectives and help identify areas where improvements can be made to enhance user satisfaction and comfort.

3.2 Case Study

For the actualisation of the research aim and objectives, it was necessary to collect relevant data from higher education institutions; primarily from the respective buildings associated with them. To achieve this, various factors such as the ease of collecting data, permissions required etc. were at the forefront of the selection process. After careful appraisal of the factors, two universities were identified and selected to serve as the study settings for this research with one being the main setting and the other being the complimentary setting. The study focused on assessing the state of IEQ in different types of rooms in the two universities (To satisfy ethical purposes, considerations and requirements, the Universities will be addressed in this article as University A and University B). The different types of rooms, their respective capacity as well as their ventilation type: (which is a key factor that studies have shown to affect IEQ) are represented in Table 6:

University	**Room**	**Capacity**	**Ventilation Type**
A	Classroom (A)	56	Natural
	PC Room (A)	24	Natural
	Lecture Theatre (A)	191	Mechanical
	Architectural Studio (A)	30	Natural
B	Classroom (B)	41	Natural
	Lecture Hall (B)	167	Mechanical

Table 6 – University Data

3.3 Data Collection Methods

As part of the POE process to assess the Indoor Environmental Quality (IEQ) in the selected rooms at aforementioned universities, a comprehensive data collection approach was employed. These data collection methods involved: physical measurements and questionnaire surveying with the collected data subjected to rigorous data analysis including the use of statistical methods, data visualization techniques and qualitative analysis.

3.3.1 Physical Measurements

Physical measurements involved undertaking a meticulous collection of data pertaining to key physical parameters that define the Indoor Environmental Quality (IEQ) of the space under study. These include: temperature (°C), relative humidity (RH %), CO_2 levels (ppm), airborne particulate matter (PM2.5 – $\mu g/m^3$), total volatile organic compounds (TVOC – $\mu g/m^3$), formaldehyde (HCHO – $\mu g/m^3$), illuminance (lux) and background noise (dB).

To achieve the recording process, the researcher employed the use of certain physical measurement procedures after rigorous review of the literature. Including in this is the use of instrumentation which involved the use of appropriate instruments and sensors specific to each IEQ indicator. Datalogging techniques were also employed to continuously log the relevant data over a defined period. Field measurements were conducted, including spot measurements at different times of the day, to capture variations in the IEQ indicators. Observation and documentation were integral to the data collection process, ensuring accurate and comprehensive records of the physical measurements.

By monitoring these IEQ indicators using suitable instruments and sensors, employing datalogging techniques, conducting field measurements, and documenting observations, a thorough assessment of the indoor environmental quality was achieved. This data serves as valuable information for evaluating the performance of the spaces and informing any necessary improvements or interventions.

3.3.2 Equipment Used

The following highlighted equipment were used for the purpose of collecting physical IEQ data. The equipment was placed in a situatable location on the classroom walls at 1.5m from the ground as that is best practice as seen in Figure 3d.

- Tinytag Datalogger (Figure 3a) - is a compact, battery-operated instrument designed to record data over a set duration. It can be set up to take readings at consistent intervals, which could range from minutes to hours, based on the monitoring needs. The device saves the gathered data in its internal memory or storage. In the context of this study, the environmental factors measured included temperature, relative humidity, and carbon dioxide (CO_2)
- Temtop M2000C(Figure 3b) - This is a compact and portable air quality monitor which is powered by a rechargeable battery allowing for continuous monitoring. The device allows for real-time monitoring, datalogging and measures several environmental and air quality parameters including temperature, relative humidity, PM2.5, PM10 and CO_2.
- Temptop LKC 1000S+ - This is a compact and portable air quality monitor which is powered by a rechargeable battery allowing for continuous monitoring. The device allows for real-time monitoring, datalogging and measures several environmental and

Commented [GU2]: more images of the equipment may be added here.

Commented [MBM3R2]:

air quality parameters including temperature, relative humidity, PM2.5, PM10, TVOC and HCHO.

- Precision Gold N09AQ 4-in-1 environment meter (Figure 3c) - This is a versatile, handheld device designed to measure and monitor various environmental parameters. It is equipped with a clear LCD display screen which provides an easy-to-read measurement. The device typically includes built-in sensors for measuring temperature, humidity, light intensity, and sound level.

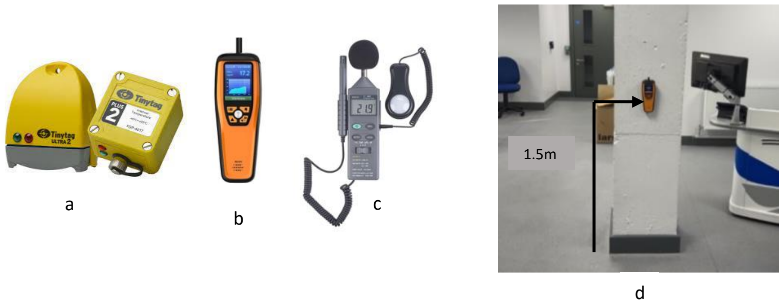


Figure 3 - Showing the equipment used and typical Temptop equipment placement in the classroom

3.3.2 Surveys & Questionnaires

Questionnaires are an effective and efficient method for gathering subjective feedback from occupants (students & staff) about their experiences and perceptions of indoor environmental quality. For this study certain considerations and potential areas of inquiries were identified which included: overall satisfaction, thermal comfort, air quality, lighting conditions and acoustic comfort.

4. Data collection outcomes

Commented [GU4]: this has not been done yet.

This section provides an overview of the data collection process and outcomes in this study. The data collection included two main types: quantitative data obtained through measurements and monitoring of various spaces in the two universities, and qualitative data gathered from questionnaire surveys. The objective of these data collection efforts was to assess the existing indoor environmental quality (IEQ) conditions in the higher education buildings. The measurements and surveys were conducted during the winter period, specifically between January and March 2023, in alignment with the seasonal conditions in the UK. By collecting these data, the study aimed to gain insights into the IEQ conditions and inform potential areas for improvement in the studied buildings.

4.1 IEQ Results gauged against published standards and guidelines

To highlight major findings from the IEQ data, it is important to gauge it against the published standards and guidelines such as the CIBSE and BB101. This process is conducted under the four IEQ factors under which the respective environment parameters such as temperature, CO_2, and so on.

4.1.1 Thermal and Humidity Data

Figure 4 illustrates the temperature data collected from various rooms at University A, along with the recommended temperature ranges (20°C - 25°C) provided by the BB101 guidelines. The graph clearly shows that, except for the Lecture Theatre, all other rooms exceeded the upper limit of 25°C, indicating a deviation from the recommended range. Of particular concern is the Architectural Studio, where temperatures consistently reached or exceeded 25°C for an extended period, with a peak of 29°C. The Lecture Theatre and the PC Room also experienced prolonged periods with temperatures around 25°C.

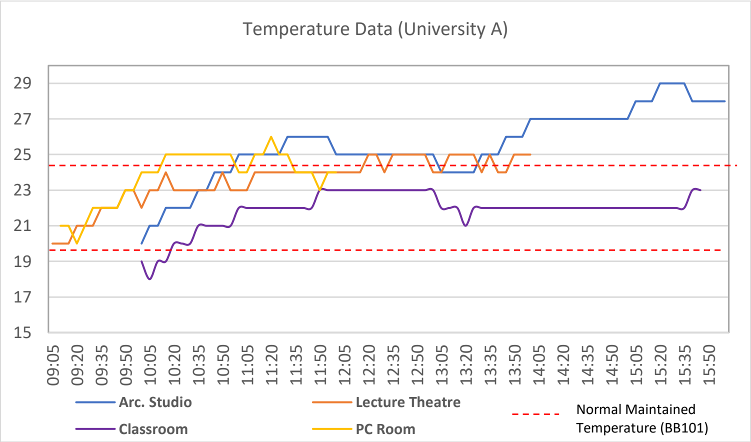


Figure 4 – Plotted Temperature Data for University A

Figure 5 illustrates the relative humidity data obtained from various rooms at University B. The graph also includes the recommended optimum levels of relative humidity as specified by the BB101 guidelines. It is evident from the graph that the two rooms exhibited contrasting data. The classroom largely maintained relative humidity within the recommended range of 40-70%, while the lecture hall recorded levels below the optimum range.

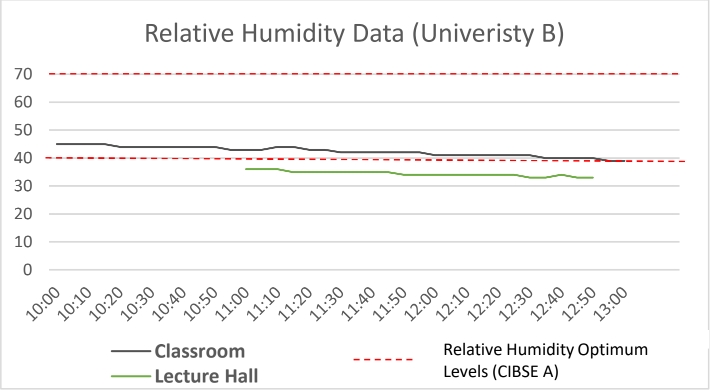


Figure 5 - Plotted Relative Humidity data for University B

4.1.2 Indoor Air Quality Data

CO_2

Figure 6 displays a sample CO_2 data retrieved from all the selected rooms from University A and B including the published CO_2 limit of 1500ppm. It can be observed from the graph that the Architectural Studio and the PC rooms especially recorded CO_2 levels reaching and exceeding the recommended limit.

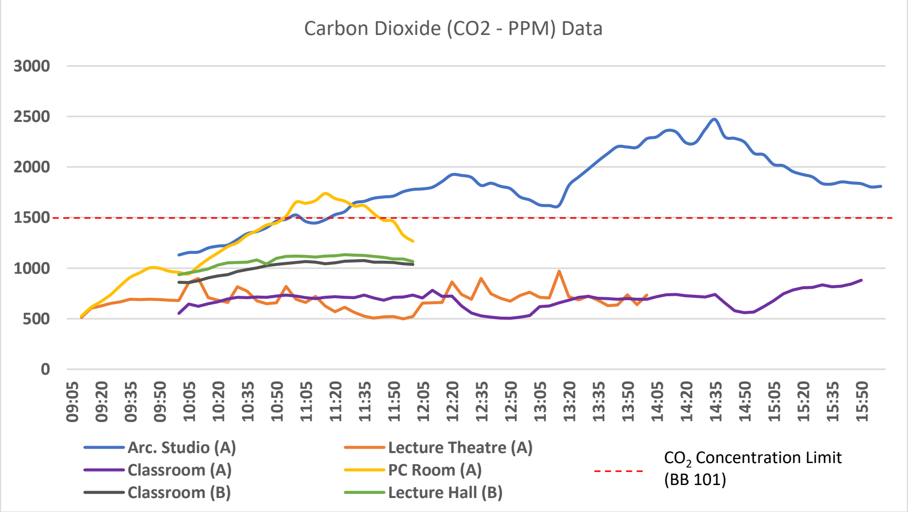


Figure 6 – Plotted CO_2 data for all rooms in University A & B

PM2.5

The typical PM2.5 data for all the rooms in both universities is presented in Figure 7. This included the 24-hour mean PM2.5 limit of 10 µg/m3 as published by the UK Government. It can be observed that the PC room, Architectural Studio and Classroom, all of which are in University A, exceeded the mean limit.

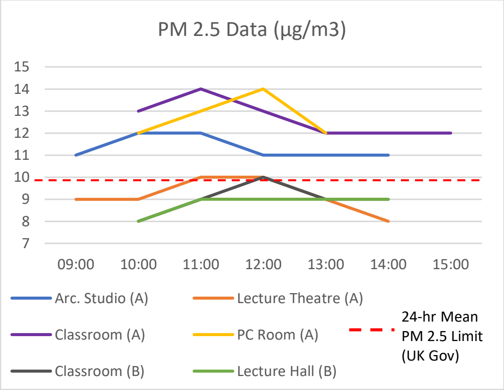


Figure 7 – Typical PM2.5 data for all rooms in both universities

TVOC

The typical TVOC data for all the rooms in both universities is presented and plotted in Figure 8. This included the 8-hour TVOC limit of 300 µg/m3 as published by the BB101. It can observed that all the rooms fell below the published limit.

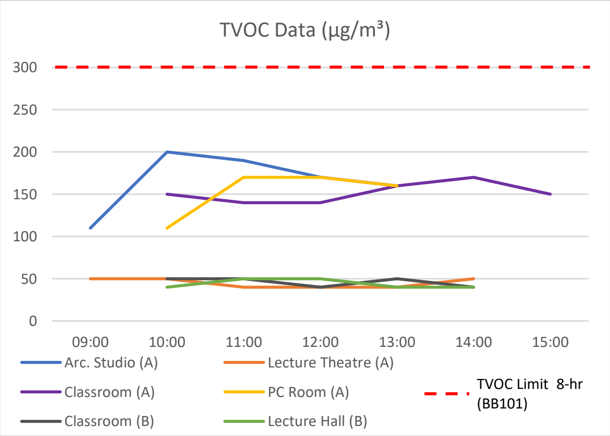


Figure 8 – Typical TVOC data for all rooms in both universities

HCHO

The typical HCHO data for all the rooms in both universities is presented and plotted in Figure 9. This included the 30-mins HCHO limit of 300 µg/m3 as published by the UK Government. It can that only the PC room recorded HCHO levels which exceeded the limit which even exceeded 30 minutes.

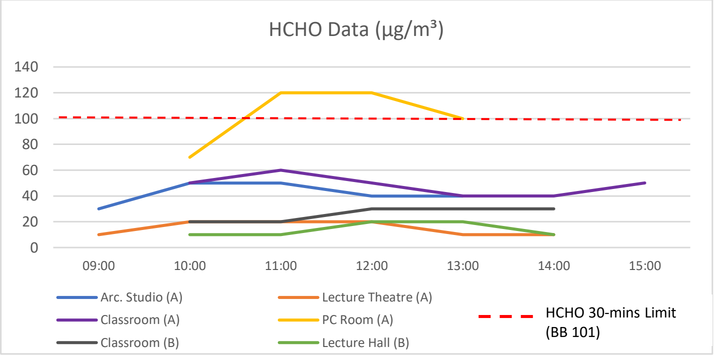


Figure 9 - Typical TVOC data for all rooms in both universities

4.1.3 Visual Comfort

The illuminance data collected from the classrooms showed a substantial compliance with the established guideline of 500 lux as shown in Figure 10. Most of the readings fell within this limit, indicating that the lighting conditions in the classrooms were generally appropriate for educational activities. However, there were instances where the illuminance levels exceeded the recommended limit especially in University A. Upon further investigation, it emerged that these instances were primarily due to the presence of natural light, particularly when the curtains were open. In contrast, the classroom in University B fell short of the illuminance standard substantially, likely due to the type of lighting fixtures and the presence of light-limiting blinds which limited the entry of natural light. While natural light can enhance the learning environment, it can evidently also lead to higher illuminance levels which can exceed a 1000 lux (Zong & Jakubiec, 2021). Therefore, it's important to manage the balance between natural and artificial light to maintain optimal lighting conditions in the classrooms.

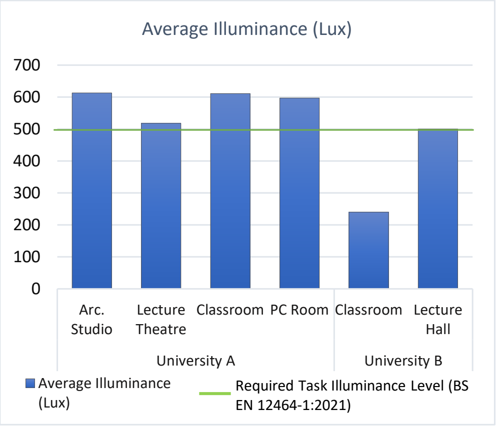


Figure 10 - Average Illuminance for all rooms

4.1.4 Acoustic Comfort

The noise data, as shown in Figure 11, collected for both unoccupied and occupied rooms showed a general adherence to the expected noise levels. In unoccupied rooms, the noise levels substantially fell within the 30 - 35 dB range. However, slight variations were observed in situations where external factors, such as open windows, allowed noise from passing traffic to infiltrate the rooms, thus reflecting in the data. In occupied rooms, the noise levels were typically around 45 dB. This limit was occasionally surpassed during data collection periods when a lecturer was speaking, contributing to an increase in the ambient noise level. It's important to note that these occasional exceedances of the noise limit could be attributed to specific activities within the room rather than a consistent issue with noise control.

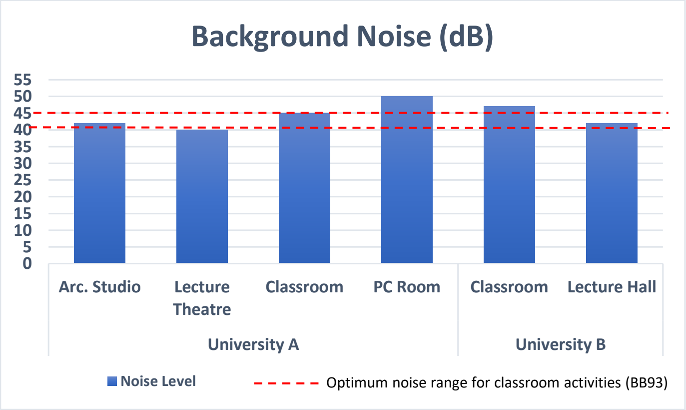


Figure 11 - Background noise levels for all rooms

4.2 Survey Feedback

The questionnaire survey was designed to gather occupants' satisfaction with the indoor environmental quality, focusing on four key aspects: temperature & humidity, air quality, lighting, and noise levels. A total of 41 feedback responses were collected from the spaces where data monitoring and measurements took place. The surveys were typically conducted at the conclusion of teaching sessions. The survey questions and feedback provided valuable insights into occupants' perceptions and opinions regarding the indoor environment, offering the following perceptions and hypotheses:

a. Temperature Perception

Among the questions asked are questions regarding the perception of temperature in classrooms by the students. The analysis, as represented in Figure 12, showed that majority of respondents described the room temperature as neutral, indicating overall comfort. However, a notable percentage felt it was either warm or cool, suggesting some variability in thermal conditions in the classrooms. Furthermore, emphasis was made for the heating season with most of the respondents having a moderate temperature perception, indicating effective heating system performance. However, a smaller percentage felt it was cool/cold, indicating a need for improvement during colder periods.

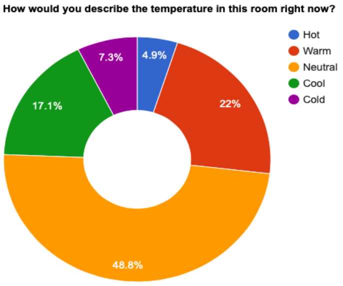


Figure 12 - Temperature Perception Feedback

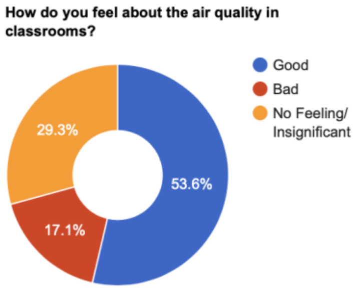


Figure 13 – Air Quality Perception Feedback

b. Air Quality Perception
Looking at air quality outlook in the classrooms was also important to the overall objectives of the research. Majority of respondents perceived the air quality as good, indicating that it met their expectations contributing to a comfortable learning environment. However, a significant number reported bad air quality, suggesting the presence of issues that should be addressed to ensure optimal indoor air quality. Additionally, a significant percentage of respondents indicated their willingness to take action if they were informed of poor air quality, such as opening or closing windows. This highlights the importance of providing students with information and control over their environment, empowering them to improve their immediate surroundings.

c. Light level Perception
Among the IEQ indicators is light which was also considered for this research. On this, most respondents perceived the light level in the classrooms as okay as shown in Figure 14, indicating that it was generally satisfactory for reading and visual tasks. However, a small percentage of respondents found the light level either too bright or dim, suggesting the need for adjustments or enhancements in lighting design.

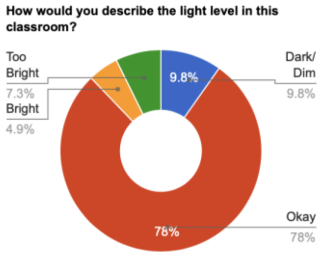


Figure 14 - Light Perception Feedback

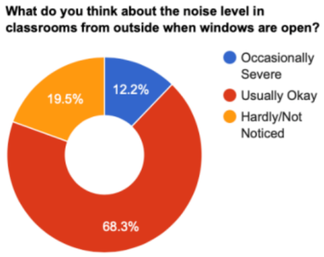


Figure 15 - Noise Perception Feedback

d. Noise Level Perception

Another important IEQ indicator is the noise level which was also considered in the survey process. Noise levels from outside were generally deemed acceptable as shown in Figure 15, but occasional severe noise was reported, which could disrupt concentration. Notably, a significant percentage acknowledged that noise in the classroom does affect their concentration, emphasizing the importance of noise control measures to provide for a conducive learning environment.

e. Miscellaneous

Finally, students recognized the overall impact of IEQ on concentration, with temperature ranking as the most influential factor, followed by air quality, noise, and lighting. These findings provide valuable guidance for improving IEQ in higher education buildings, aiming to create comfortable, healthy, and conducive learning environments that optimize students' well-being and academic performance. (as well as IEQ added knowledge such as weighting of IEQ factors)

5. Analysis and Discussion

5.1 Thermal & Humidity

The summarised temperature data presented in Table 7 reveals that a significant number of the rooms subjected to IEQ physical measurements (5 out of 6) exceeded the published upper limit of 25 ºC by the BB101. In University A, where the classrooms, PC room, and Architectural Studio are naturally ventilated, the maximum temperatures recorded during the winter months were relatively high. The classroom and PC room reached maximum temperatures of 28°C for 4 hours and 5 minutes, and 3 hours respectively, while the Architectural Studio recorded the highest maximum temperature of 29ºC for 3 hours and 10 minutes. In University B, the classroom recorded temperatures within the recommended range of 20-25 ºC, with a minimum and maximum temperature of 20-23ºC. This suggests that the heating systems or insulation in the classroom were able to maintain a suitable temperature level during the winter months. However, the lecture hall, despite being mechanically ventilated, exceeded the upper limit, reaching a maximum temperature of 26°C. It is worth noting that it is located in the basement level of the university which combined with the heating systems in place, might have contributed to the temperature rise.

These findings are particularly noteworthy considering that the data was recorded during the winter period, when the outdoor temperatures ranged between 0 – 10^{o}C. These results suggest that there may be challenges in maintaining optimal thermal comfort in the classrooms during colder months, potentially leading to discomfort for students and faculty. This observation suggests a potential issue with temperature control in the classrooms identified by the researcher, particularly during the colder months. One possible explanation for this discrepancy is the placement of temperature sensors predominantly in the corridors rather than within the classrooms themselves. As a result, the heating system may be working harder to maintain the desired temperature, leading to higher temperatures inside the classrooms. Additionally, this highlights the need for further investigation into the heating systems and insulation in these buildings to ensure a conducive learning environment, especially during extreme weather conditions.

University	**Room**	**Min – Max Temperature Recorded ^{o}C**	**Duration below 20^{o}C (hr/mins)**	**Duration Exceeded 25^{o}C (hr/mins)**
A	Classroom	19 – 26 ^{o}C	0 hrs 0 mins	4 hrs 5 mins
	PC Room	18 – 28 ^{o}C	0 hrs 20 mins	3 hrs 0 mins
	Lecture Theatre	17 – 26 ^{o}C	1 hr 0 mins	1 hr 45 mins
	Architectural Studio	20 – 29 ^{o}C	0 hrs 0 mins	3 hrs 10 mins
B	Classroom	20 – 23 ^{o}C	0 hrs 0 mins	0 hrs 0 mins
	Lecture Hall	21 – 26 ^{o}C	0 hrs 0 mins	0 hrs 15 mins

Table 7 – Temperature Data

For relative humidity, overall, the levels were found to be largely within the recommended standard range of 40-70% as indicated in Table 8. However, upon closer examination of the daily data, it became evident that the relative humidity levels tended to be on the lower side of the recommended range specifically in the 40% range. This suggests that the indoor environments in these rooms were relatively dry, approaching the lower end of the ideal humidity range.

In contrast, the lecture hall in University B displayed a lower relative humidity range, with a minimum and maximum of 33-36% respectively. This lower range might be attributed to the fact that the hall is mechanically ventilated which could impact humidity control of the space. But more importantly is the fact that it is located in the basement level of the university. Basements tend to have different environmental conditions compared to above-ground spaces, including potentially higher moisture levels. Considering the basement location and the potential challenges in humidity control, it is expected that the lecture hall in University B experienced lower relative humidity levels. If the recorded relative humidity falls outside the recommended range, it may be necessary to investigate further and implement measures to optimize humidity control, such as adjusting ventilation systems or introducing additional humidity management strategies, to ensure a comfortable and healthy indoor environment for occupants. Additionally, Figure 5 visually demonstrates that there were instances where the relative humidity did not meet the lower limit of the standard in certain classrooms. The researcher observed that the windows for rooms with natural ventilation were open on many occasions which could influence the relative humidity levels recoded. However, this issue still suggests a potential challenge in maintaining optimal humidity levels within the classrooms which highlights the need for further investigation into the causes of these deviations.

University	Room	Relative Humidity (%)	
		Minimum	Maximum
A	Classroom	41	46
	PC Room	42	49
	Lecture Theatre	42	49
	Architectural Studio	46	49
B	Classroom	39	45
	Lecture Hall	33	36

Table 8 – Relative Humidity Data showing the minimum and maximum recorded levels.

5.2 Indoor Air Quality

5.2.1 CO_2

The table provides an overview of the maximum CO_2 levels recorded in various rooms of two universities, along with the number of times the CO_2 concentration exceeded 1500 ppm and the duration of such exceedances. Analysis the data from both universities, it was observed that the rooms that exceeded the limit occurred in university A specifically, the classroom, PC room and Architectural Studio. In University B, both the Classroom and Lecture Hall maintained CO_2 levels below the threshold, implying better ventilation and lower occupancy in these rooms from the observations.

University	Room	Maximum CO_2 Recorded (ppm)	Duration Exceeded 1500 ppm (hr/mins)
A	Classroom	1617	1 hr 45 mins
	PC Room	1738	1 hr 0 mins
	Lecture Theatre	970	0 hrs 0 mins
	Architectural Studio	2360	8 hrs 55 mins
B	Classroom	1072	0 hrs 0 mins
	Lecture Hall	1133	0 hrs 0 mins

Table 9 – CO_2 Data

Upon further investigation, it became evident that the occurrence of high CO_2 levels primarily affected classrooms that relied on natural ventilation. Specifically, the Architectural studio, with the plan as shown in Figure 9, recorded the highest CO_2 level of 2360 ppm. This room is naturally ventilated and has two small windows, but only one window can be opened for airflow. Additionally, it is worth noting that the usable open window has a relatively small area of 0.93m^2, which may not be sufficient for the room size of 85m^2. This finding can be attributed to several factors related to the studio's ventilation and occupancy conditions. Firstly, the limited use of one window hindered the proper airflow and exchange of fresh air, resulting in a build-up of CO_2. Inadequate ventilation promotes stagnant air and the accumulation of pollutants. Secondly, the studio was frequently overcrowded, with a large number of occupants present. As people exhale, they release CO_2, and in a crowded space, CO_2 concentration can rise rapidly. The combination of limited ventilation and high occupancy levels likely contributed to the observed elevated CO_2 levels. These findings underscore the importance of optimizing ventilation strategies and ensuring an adequate supply of fresh air in crowded spaces. By doing so, it is possible to maintain healthy indoor air quality and minimize CO_2 build-up in classrooms relying on natural ventilation.

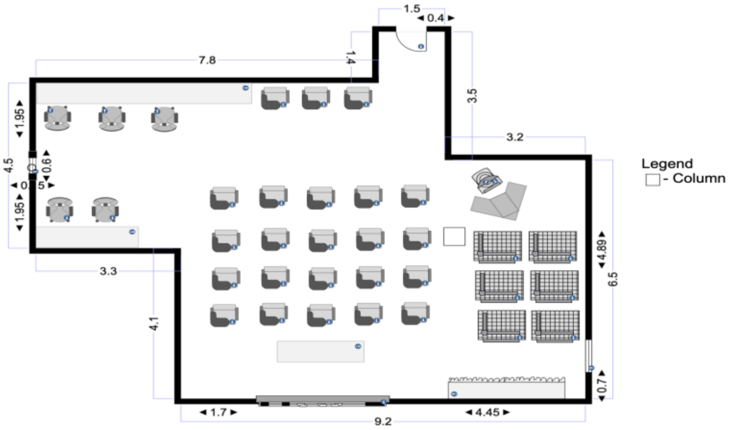


Figure 16 – Architectural Studio Plan

5.2.2 PM2.5, TVOC & HCHO

The PM2.5 data showed that in some classrooms, on certain days, the hourly PM 2.5 readings exceeded the daily limit of 10 ug/m3 (average) as represented in Figure 7. This primarily points to PM2.5 being a slight concern considering the case study settings are located in an urban area with high traffic which affects the quality of outdoor air. This in return affects the indoor PM2.5 readings with other possible factors being classroom conditions or student activities.

With regards to TVOC and HCHO, the analysis of these data sets revealed that the levels largely adhered to the established limit of 300 µg/m3 or 100ug/m3 respectively. This standard was exceeded only on one or two occasions, suggesting a high level of compliance with the recommended guidelines. The few instances where especially the HCHO levels surpassed the limit could potentially be attributed to increased student activity, which might have led to a temporary spike in emissions, or possibly equipment error. However, these instances were exceptions rather than the norm, indicating that the indoor environment was generally within the acceptable range for TVOC/HCHO levels.

5.3 Room IEQ Correlations

In the process of data analysis, correlations were carried out with the aim of examining various variables against each other in the bid to ascertain various findings align with those from prior research. The relationship between occupant density and temperature and CO_2 levels was examined. The results indicated a weak correlation between occupant density and

Commented [CF5]: Put this in analysis

Commented [GU6]: This part goes to analysis and discussion temperature, suggesting that the number of occupants in a room may not significantly impact the temperature. However, a strong positive linear correlation was observed between occupant density and CO_2 levels. This implies that as the number of occupants increases, the CO_2 levels in the room also rise, which is consistent with the findings from previous literature (Franco & Leccese, 2020).

		PC Room		Classroom		Lecture Theatre		Architectural Studio	
		Occ. density	Count	Occ. density	Count	Occ. density	Count	Occ. density	Count
CO_2 Concentration	Pearson correlation	0.7465	0.7632	0.7469	0.7375	0.5032	0.5081	0.7233	0.681
	Sig. (2 tailed)	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
		Correlation is significant at $p < .05$ and at $p < .10$ for both occupant count and density		**Correlation is significant at $p < .05$ and at $p < .10$ for both occupant count and density**		**Correlation is significant at $p < .05$ and at $p < .10$ for both occupant count and density**		**Correlation is significant at $p < .05$ and at $p < .10$ for both occupant count and density**	

Table 10 - CO_2 and Occupant density correlation data

5.4 Room Comparison: Mechanical and Natural Ventilation

To further scrutinise the IEQ data, it was pertinent to look at relationships and make comparisons with distinctive differences between classrooms such as looking at the data outlook with regards to mechanically and naturally ventilated classes. After undergoing various comparisons between the classrooms and the respective IEQ indicators, the researcher realised that the CO_2 data exhibited the most glaring differences when the two types of classrooms are compared. The analysis showed that CO_2 levels in mechanically ventilated rooms consistently remained below the recommended maximum limit of 1500 ppm, while naturally ventilated rooms occasionally exceeded this limit. This discrepancy can be attributed to the active control and circulation of air in mechanically ventilated rooms, as opposed to the passive air movement in naturally ventilated rooms, which can be less effective, especially in high occupancy spaces or rooms with limited airflow.

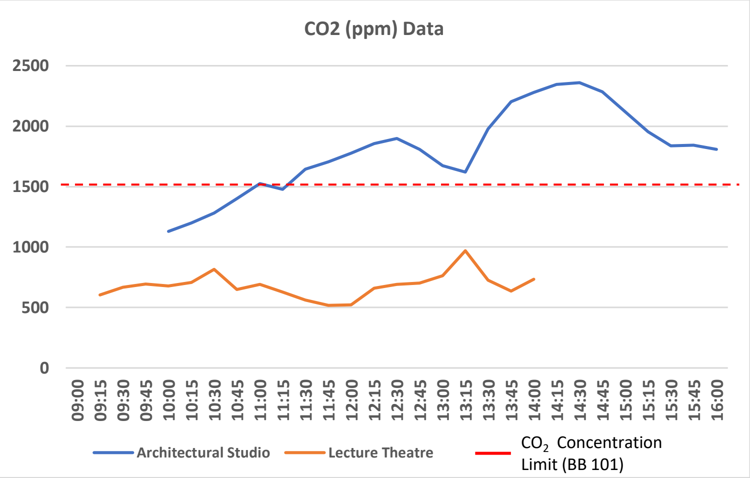


Figure 17 - CO2 outlook for a typical mechanically and naturally ventilated classroom

5.5 Combined IEQ & Survey Findings

Commented [CF7]: Go to analysis

The analysis of both the IEQ data and survey feedback presented various results and findings. Incidentally, analysing both the objective IEQ data and the subjective survey responses, meaningful connections and insights were highlighted as such:

1. **Temperature**: A notable percentage of respondents felt their classrooms were balanced, but a fair amount (4.9%) perceived the temperature to be hot. This aligns with the IEQ data, which indicates that the temperature in classrooms reached or exceeded the recommended maximum limit of 25°C. The discomfort expressed by students during these situations, leading to the removal of top layers such as coats and the opening of windows, further supports this alignment. Research has shown that the optimal temperature for a learning environment is between 18°C and 25°C, as temperatures outside this range can impact students' focus and learning abilities (Mendel & Heath, 2005).
2. **Air Quality**: While a sizeable percentage of respondents felt the air quality was okay, a notable percentage (17.1%) expressed it as bad. This strongly aligns with the IEQ data, particularly the CO_2 levels, which recorded high levels exceeding the maximum limit of 1500ppm, especially in naturally ventilated classrooms. The high CO_2 levels recorded in the IEQ data correspond to the dissatisfaction expressed by the respondents regarding air quality with elevated CO_2 levels being able to impact cognitive function and contribute to feelings of stuffiness and discomfort (Korsavi et al., 2020).
3. **Lighting**: The survey responses and IEQ data show some alignment in terms of lighting. While a majority of respondents felt the lighting was okay, a notable percentage found it to be bright or too bright. This aligns with the IEQ data indicating that the

illuminance in classrooms exceeded the recommended limit of 500 lux. The perception of bright lighting by some respondents is consistent with the measured illuminance levels.

4. **Overall IEQ**: The finding that most respondents agreed that the overall indoor environmental quality affected their concentration in the classroom is a strong indicator of student awareness regarding IEQ. This alignment also corresponds to the IEQ data, which identified different indicators, including temperature and CO_2 levels, exceeding their recommended limits. The impact of IEQ on students' well-being, comfort, and concentration underscores the importance of addressing and improving indoor environmental conditions (Shan et al, 2017).

5.6 Research Limitations & Challenges Faced

A few limitations or challenges were experienced by the researcher during the POE data collection process. Firstly, the research encountered technical gaps in equipment, which had a direct impact on the accuracy and precision of measurements. The quality and capabilities of the equipment used ultimately influenced the reliability of the data collected. Limited resources and funding also posed challenges in accessing specialized or advanced measurement tools, further compromising the evaluation process. This limitation particularly affected the assessment of specific building performance indicators, such as indoor air quality, which required expensive and less readily available equipment. Consequently, the depth and comprehensiveness of the evaluation were restricted. Moreover, the limited resources also had implications for the scope and scale of the evaluation, resulting in a narrower focus and reduced sample size. Additionally, establishing standardized metrics and benchmarks for physical measurements in higher education buildings proved to be a challenging task. The lack of uniformity in measurement protocols, criteria, published standards and guidelines hindered the ability to compare the performance of different buildings or assess their performance against established benchmarks. For example, after thorough scrutiny of the available published standards and guidelines, the researcher found that many of them focused on primary and secondary schools. This limitation made it difficult to draw meaningful conclusions and accurately evaluate the buildings' IEQ performance. The absence of a standardized framework limited the researcher’s ability to make comprehensive and reliable comparisons, thus slightly hampering the outcomes in the field of POE in higher education buildings.

6. Conclusions

The Post Occupancy Evaluation (POE) of higher education buildings provided invaluable insights into the Indoor Environmental Quality (IEQ) within these educational spaces. This study identified several critical IEQ issues associated with the factors that predominantly affect the state of IEQ.

Thermal discomfort emerged as a significant issue, with temperature and relative humidity often not meeting standard limits. This was particularly pronounced in rooms without heating/cooling control and spaces with either natural or mechanical ventilation. To address this, it is recommended that temperature control systems be installed and ensuring adequate ventilation in all rooms. Air quality represented another major concern, with elevated levels of CO_2, volatile organic compounds (TVOC), formaldehyde (HCHO), particulate matter (PM 2.5) exceeding established standard limits. Factors such as inadequate and insufficient ventilation as well as high traffic within the HE locations contributed to the problems. Recommendations include enhancing ventilation systems and possibly introducing air purifiers to mitigate these concerns. Noise pollution was identified as an issue, particularly in natural ventilated rooms and classrooms. To alleviate this, implementing soundproofing measures and reinforcing classroom behaviour guidelines may prove effective. Inadequate lighting was occasionally observed, negatively affecting visibility and potentially causing eye strain and reduced productivity. This could be addressed by re-evaluating and improving lighting placement and levels in classrooms. Ergonomic issues were also identified, with room layouts, furniture, and equipment sometimes failing to meet their intended purpose. It is recommended to comprehensively review and adjust these elements to ensure they are suitable for their intended use. Additionally, this study identified maintenance issues and a lack of access to green spaces as areas of concern. To address this, implementation of regular maintenance schedules to ensure that all building systems are functioning optimally is recommended. Furthermore, incorporating green spaces or elements of nature into building designs could enhance IEQ and the overall wellbeing of the students and staff alike.

These findings underscore the critical importance of IEQ in higher education buildings and the urgent need for effective strategies to enhance it. The feedback from building occupants reinforced the significance of these IEQ challenges, with a considerable percentage expressing discomfort with temperature and air quality, aligning with the recorded IEQ data. Most respondents acknowledged that IEQ significantly influenced their concentration in the classroom, indicating a heightened awareness of IEQ among students. Furthermore, this study and its findings highlight the value of POE methods in assessing IEQ and providing actionable insights for improving the indoor environment. Moving forward, it is recommended that future research continue to use POE methods to assess IEQ in higher education buildings. Doing so will not only help improve the design and operation of these buildings but also contribute to the growing body of knowledge on the relationship between IEQ and occupant satisfaction.

References

Abdelatia, B., Marenne, C. and Semidor, C. (2010) 'Daylighting strategy for sustainable schools: Case study of prototype classrooms in Libya', *Journal of Sustainable Development*, 3(3). doi:10.5539/jsd.v3n3p60.

Abdul Mujeebu, M. (2019) *Chapter Introductory Chapter: Indoor Environmental Quality* , *Intechopen*. Available at: https://cdn.intechopen.com/pdfs/65121.pdf (Accessed: 17 May 2023).

Abdulaali, H.S. *et al.* (2020) 'Impact of poor Indoor Environmental Quality (IEQ) to Inhabitants' Health, Wellbeing and Satisfaction', *International Journal of Advanced Science and Technology*, 29(3). doi:https://www.researchgate.net/publication/340278976_Impact_of_poor_Indoor_Environmental_Quality_IEQ_to_Inhabitants'_Health_Wellbeing_and_Satisfaction.

Al-Khatatbeh, B. and Ma'bdeh, S. (2017) Improving visual comfort and energy efficiency in existing classrooms using passive daylighting techniques. Energy Procedia, 136, p.102-108. Elsevier BV [Online]. Available at: doi:10.1016/j.egypro.2017.10.294.

Ali, S.M. (2018) *Measured and Perceived Conditions of Indoor Environmental Qualities (IEQ) of University Learning Environments in Semi-arid Tropics: a Field Study in Kano-Nigeria* . Thesis. University of Portsmouth.

ASHRAE (2013) *ANSI/ASHRAE Standard 55-2010*, *ASHRAE-RP*. Available at: http://www.ashraerp.com/files/ASHRAEStandard55-2013.pdf (Accessed: 16 May 2023).

ASHRAE (2016) *Ventilation for Acceptable Indoor Air Quality*, *Upgreengrade*. Available at: https://upgreengrade.ir/admin_panel/assets/images/books/25223276727.pdf (Accessed: 17 May 2023).

Awang, N. A., Mahyuddin, N. and Kamaruzzaman, S. N., (2015). Indoor environmental quality assessment and user's perception in Meru Secondary School (Smk Meru). Journal of Building Performance 6(1). Available at: https://spaj.ukm.my/jsb/index.php/jbp/article/view/160 (Accessed: 12 June 2023).

CENCENELEC (2021) About CENELEC. CEN-CENELEC. [Online]. Available at: https://www.cencenelec.eu/about-cenelec/ [Accessed: 18 August 2022].

Centnerová, L.H. (2018) *Rehva Journal 02/2018 - on the history of indoor environment and it's relation to health and wellbeing*, *REHVA*. Available at: https://www.rehva.eu/rehva-journal/chapter/on-the-history-of-indoor-environment-and-its-relation-to-health-and-wellbeing (Accessed: 16 May 2023).

Dorizas, P., De Groote, M. and Volt, J. (2018) The Inner Value of a Building Copenhagen: Buildings Performance Institute Europe (BPIE), p.8-33.

EFA (2014) *Baseline designs for schools: Guidance*, *GOV.UK*. Available at: https://www.gov.uk/government/publications/baseline-designs-for-schools-guidance/baseline-designs-for-schools-guidance (Accessed: 03 June 2023).

EN 12464-1 (2011) *Light and lighting - Lighting of work places - Part 1: Indoor work places* . European Standard, pp. 1–86.

Fisk, D. (2001) 'Sustainable development and post-occupancy evaluation', *Building Research and Information*, 29(6), pp. 466–468. doi:https://doi.org/10.1080/09613210110072665.

Haverinen-Shaughness, U. *et al.* (2007) ‘Clima - WellBeing Indoors’, in *Indoor environmental quality in schools in relation to academic performance of students: Observations of potential contributors to poor IEQ*. Helsinki: FINVAC, pp. 403–407.

Hwang, T. and Jeong Tai, K. (2010) ‘Effects of indoor lighting on occupants’ visual comfort and Eye Health in a green building’, *Indoor and Built Environment*, 20(1), pp. 75–90. doi:10.1177/1420326x10392017.

ISO (2010) *International ISO Standard 7730*, *Standards*. Available at: https://cdn.standards.iteh.ai/samples/39155/9632a0563ca742209edb45856ff69296/ISO-7730-2005.pdf (Accessed: 16 May 2023).

Kamaruzzaman, S. N., Egbu, C., Mahyuddin, N., Ahmad Zawawi, E. M., Chua, S. J. L., & Azmi, N. F. (2017). The impact of IEQ on occupants’ satisfaction in Malaysian buildings. Indoor and Built Environment, 27, 715-725. Available at: https://www.semanticscholar.org/paper/The-impact-of-IEQ-on-occupants%E2%80%99-satisfaction-in-Kamaruzzaman-Egbu/9fc8fce2e3d7e86c3b92c103aea78fdae0beffb0 (Accessed: 12 June 2023).

Karim , K. and Crozier, C. (2009) ‘Post-occupancy evaluation: Purpose, benefits and barriers’, *Facilities*, 27(1/2), pp. 21–33. doi:http://dx.doi.org/10.1108/02632770910923063.

Katiyar, V. and Khare, M. (2008) *Indoor air quality an emerging environmental challenge* , *Research Gate*. Available at: https://www.researchgate.net/profile/Vinita-Katiyar/publication/236605730_Indoor_Air_Quality-An_Emerging_Environmental_Challenge/links/00463518379af9fd71000000/Indoor-Air-Quality-An-Emerging-Environmental-Challenge.pdf (Accessed: 17 May 2023).

Khoraskani, R., Rezaallah, A. and Bolognesi, C. (2012) LEED and BREEAM; Comparison between policies, assessment criteria and calculation methods In: 2012, Porto: BSA.

Korsavi S, Montazami A, Mumovic D. Indoor air quality (IAQ) in naturally-ventilated primary schools in the UK: occupant-related factors. *Build Environ.* (2020) 180:106992. 10.1016/j.buildenv.2020.106992 (Accessed: 12 June 2023)

Leaman, A. (2003) *Post-occupancy Evaluation*, *Usable Buildings*. Available at: https://www.usablebuildings.co.uk/UsableBuildings/Unprotected/AdrianLeamanPost-OccupancyEvaluation.pdf (Accessed: 15 May 2023).

Mannan, M. and Al-Ghamdi, S.G. (2021) ‘Indoor Air Quality in Buildings: A Comprehensive Review on the Factors Influencing Air Pollution in Residential and Commercial Structure’, *International Journal of Environmental Research and Public Health*, 18(6). doi:https://doi.org/10.3390/ijerph18063276.

Medium (2020) *Indoor Environmental Quality Parameter*, *Medium*. Available at: https://medium.com/@ieqandwellbeing/indoor-environmental-quality-parameter-56aab5cffd8 (Accessed: 29 April 2023).

Mendell, M.J. and Heath, G.A. (2005) ‘Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature’, *Indoor Air*, 15(1), pp. 27–52. doi:10.1111/j.1600-0668.2004.00320.x.

NIOSH (2022) *Indoor Environmental Quality*, *The National Institute for Occupational Safety and Health (NIOSH)*. Available at: https://www.cdc.gov/niosh/topics/indoorenv/default.html#print (Accessed: 03 May 2023).

Ralegaonkar, R.V. and Sakhare, V.V. (2013) ‘Development of multi-parametric Functional Index Model for evaluating the indoor comfort in built environment’, *Indoor and Built Environment*, 23(4), pp. 615–621. doi:10.1177/1420326x13480515.

Shan, X., Melina, A.N. and Yang, E.-H. (2018) ‘Impact of indoor environmental quality on students’ wellbeing and performance in educational building through life cycle costing perspective’, *Journal of Cleaner Production*, 204, pp. 298–309. doi:10.1016/j.jclepro.2018.09.002.

Sulaiman, M., Yusoff, W., Pawi, S. and Kamarudin, W. (2013) Indoor Environmental Quality (IEQ) of Higher Education Institutions (HEIs): A User Perception Survey. Journal of Clean Energy Technologies, 1 (4), p.318-321. EJournal Publishing [Online]. Available at: doi:10.7763/jocet.2013.v1.72.

Tookaloo, A. and Smith, R. (2015) ‘Post Occupancy Evaluation in Higher Education’, *Procedia Engineering*, 118, pp. 515–521. doi:http://dx.doi.org/10.1016/j.proeng.2015.08.470.

Vardaxis, N., Bard, D. and Persson Waye, K. (2018) Review of acoustic comfort evaluation in dwellings—part I: Associations of acoustic field data to subjective responses from building surveys. Building Acoustics, 25 (2), p.151-170. SAGE Publications [Online]. Available at: doi:10.1177/1351010x18762687.

Zimmerman, A. (2010) ‘Post-occupancy evaluation: Benefits and barriers’, *Building Research and Information*, 29(2), pp. 168–174. doi:http://dx.doi.org/10.1080/09613210010016857.