Journal of Construction in Developing Countries, 30(Supp. 2), 57–88, 2025

Identifying the Recent Trends of Parameters for Indoor Environmental Quality: Towards the Sustainability of Physical Performance in Learning Space

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Published: 31 December 2025

To cite this article: Norsafiah Norazman, Siti Balqis Mohd Shukri, Siti Hamidah Husain, Naziah Muhamad Salleh, Adi Irfan Che Ani and Wan Norisma Wan Ismail (2025). Identifying the recent trends of parameters for indoor environmental quality: Towards the sustainability of physical performance in learning space. *Journal of Construction in Developing Countries*, 30(Supp. 2): 57–88. https://doi.org/10.21315/jcdc.2025.30.s2.4

To link to this article: https://doi.org/10.21315/jcdc.2025.30.s2.4

Abstract: Building performance in higher educational buildings plays a significant role in enhancing efficiency by improving the physical learning environment to meet intended functions and requirements, with a key focus on the sustainability performance of indoor environmental quality (IEQ). This study aims to measure and analyse one of the IEQ key factors within the learning spaces of higher educational buildings. A mixed-method approach involving interviews with experts from both non-technical and technical backgrounds related to the field was employed and data were analysed using NVivo14. Field measurements were conducted in lecture halls equipped with environmental monitoring tools to assess IEQ parameters such as indoor air temperature (TPR), relative humidity (RH) and air velocity rate (AVR). Questionnaires were also distributed to the lecture halls users to collect their views on current IEQ conditions. The findings were analysed against acceptable parameter ranges. Experts highlighted key considerations for evaluating building conditions that impact IEQ in learning spaces, emphasising that users may be unaware of the harmful effects of indoor air pollutants on physical health and work performance due to poor indoor environments. Field measurements revealed that current IEQ parameters in learning spaces do not comply with the acceptable limits specified by The Industry Code of Practice on Indoor Air Quality 2010 (ICOP IAQ 2010) and Malaysia Standard (MS1525:2019). This article delves into current trends and insights of learning environments, with a specific focus on investigating IEQ measurement within higher educational buildings to inspire initiatives and solutions aimed at enhancing overall building performance, ultimately leading to improvements in the sustainable learning space.

Keywords: Indoor environmental quality, Educational building, Building performance, Learning space, Sustainability

INTRODUCTION

Most people spend their time doing indoor activities (Saini, Dutta and Marques, 2020; Ganesh et al., 2021; Mannan and Al-Ghamdi, 2021), specifically students in higher education that spend their time within university buildings

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such as classrooms, libraries, laboratories and lecture halls. According to Miao, Gangolells and Tejedor (2024), university buildings have a high density of occupants at 0.9 person/m^3. Thus, the time spent indoors with high density users can cause high risk, especially towards health (Saini, Dutta and Marques, 2020) and affect one of the building performance areas, which is indoor environmental quality (IEQ) (Ganesh et al., 2021). The IEQ parameters consist of indoor air temperature (TPR), relative humidity (RH) and air velocity rate (AVR).

The IEQ has had growing concerns for decades as it impacts user's safety, health and well-being, mainly to improve work productivity, which is influenced by major factors of building users (Ganesh et al., 2021; Wolkoff, Azuma and Carrer, 2021). Nevertheless, users do not feel the same concern as to what overall environment has affected them as they assume the building environment has nothing to do with their daily activities (Day et al., 2020). Thus, IEQ should have a major improvement to ensure the comfort, satisfaction and work productivity of the users. To ensure the good quality of IEQ, modern buildings has implemented the concept of green building by complying the green building criteria and requirement as it has proven benefits and is favourable as well as providing a comfortable environment to the users doing their works indoor (Busono et al., 2021; Nurick and Thatcher, 2023). Hence, majority of users are satisfied and assumed to be more productive when previous studies have shown the workspace has become one of the factors that influenced their working behaviour.

Although previous studies have provided their findings with a similar environment, there are limitations to current IEQ in higher educational buildings. Therefore, the study aims to measure and analyse IEQ parameters in learning space within higher educational buildings. The study is conducted to identify the experts' perspective and to measure the current trend of IEQ factors in learning space within higher educational buildings, specifically in lecture halls.

LITERATURE REVIEW

Building Performance

A building needs to fulfil its intended functions which can influence building users and environment. This comprehensive evaluation is known as building performance that requires a wide range of requirements to make sure the intended purposes of the buildings operate efficiently and provide safety, health and comfort to the intended building users (Khalil, Husin and Nawawi, 2018).

A well-performing building can ensure health and well-being, provide comfort and improve productivity to the building users, as well as increasing building efficiency and contributing sustainability. Building performance consists of few areas such as energy efficiency, safety, operational effectiveness, as well as IEQ, which is the focus of this study.

Indoor Environmental Quality

Previous studies (Ganesh et al., 2021; Mannan and Al-Ghamdi, 2021; Saini, Dutta and Marques, 2020), stated that people spent more than 90% of their daily time in the buildings or indoor environments, specifically in Malaysia due to hot and humid weather (Izzati et al., 2023) that could impact their routine if exposed too much sunlight that led to health concerns. As their time is spent in closed space, the users are exposed more to the indoor environment which can affect one's working behaviour, both psychologically and emotionally (Schweiker et al., 2020). Hence, IEQ becomes the important building performance area to ensure the improvement to the surroundings and user's work productivity.

The IEQ is defined as the condition of the buildings specifically in environmental qualities that contributed to user's safety, health and comfort (Yang and Mak, 2020). The IEQ consists of a few key factors to determine the environmental level; thermal comfort, building ventilation, indoor air quality (IAQ), acoustic and visual ambiance (Yang and Mak, 2020; Jia et al., 2021). Previous studies showed that facilities, building and building users' health and work productivity are influenced by indoor environments, both positive and negative impacts (Ganesh et al., 2021). It is essential to preserve IEQ to ensure improvement of building user's work performance and well-being.

Key Factors of Indoor Environmental Quality

Better quality of indoor environment can increase building user's work productivity based on precedent studies. As stated by Saini, Dutta and Marques (2020), good building performance gives benefits to user's work productivity and improves the built environment but finds it difficult to measure. Thus, it brings attention to IEQ factors as consideration to improve building performance. There are several key factors that can influence building performance; thermal comfort, ventilation, IAQ, visual comfort and acoustic comfort (Jia et al., 2021).

This study measures and analyses one of the IEQ factors, which is thermal comfort. Therefore, these factors were collected from precedent studies and then evaluated by experts to identify the most significant IEQ factors when conducting the building performance. Then, the study develops a theoretical framework as shown in Figure 1.

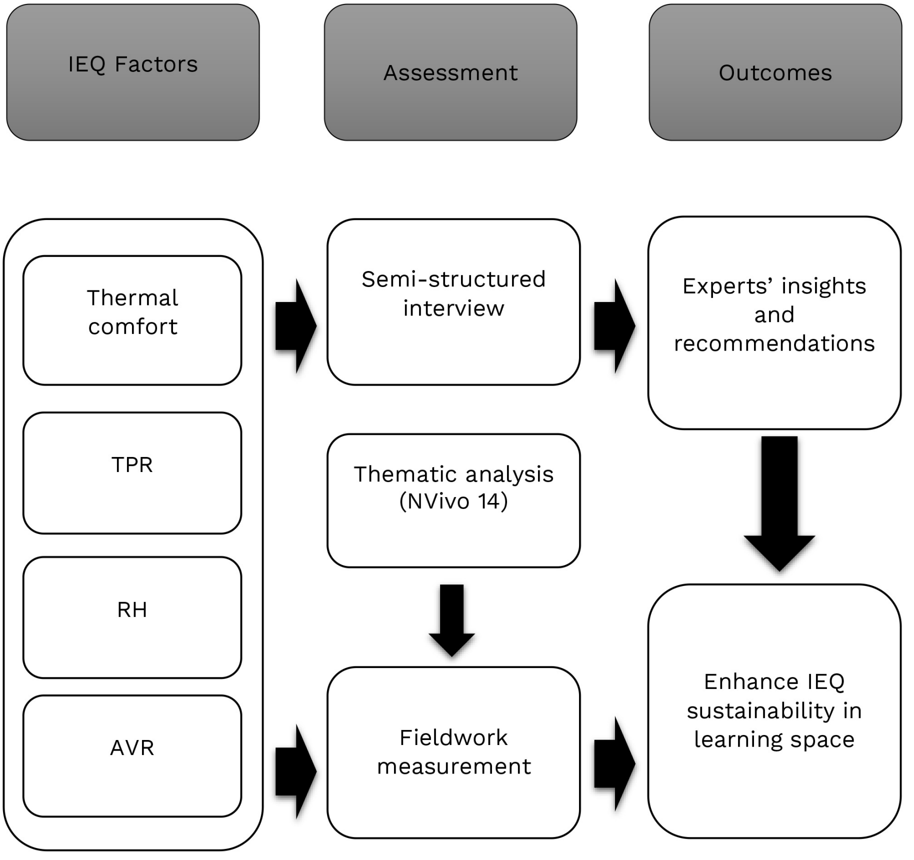

Figure 1. The framework of the study

Thermal Comfort in Learning Space

Thermal comfort is one of the IEQ key factors that became the focus of this study. Thermal comfort is defined as an expression of satisfaction to the environment, involving one person to feel conditions neither too hot nor too cold (Manasi et al., 2021). Thermal comfort has several physical parameters which are air temperature, humidity and air flow. These parameters can be determined as IEQ level from the environmental quality standard compliance such as the Industry Code of Practice on Indoor Air Quality 2010 (ICOP IAQ 2010), introduced by the Department of Occupational, Safety and Health (DOSH, 2010) and the Malaysia Standard (MS1525:2019) (Department of Standards Malaysia, 2019). Physical parameters in ICOP IAQ 2010 and MS1525:2019 can be referred to by all buildings to ensure these practices can be applied and improve good indoor environments. These practices help to improve and sustain the surrounding environment in the space as well as improve building user's health, well-being and work productivity.

Tools are used to measure the precaution steps of IEQ. The evaluation should be conducted according to ICOP IAQ 2010 and MS1525:2019. The range of each parameter is listed in Table 1.

Table 1. Parameters of thermal comfort

Parameter	Unit	Acceptable Range (ICOP IAQ 2010)	Acceptable Range (MS1525:2019)
TPR	Celsius (°C)	23–26	24–26
RH	Percentage (%)	40–60	50–70
AVR	Meter/second (m/sec)	0.15–0.50	0.15–0.50

Source: DOSH (2010) and Department of Standards Malaysia (2019)

The test of IEQ should be conducted with physical sampling and appraise the environment surroundings. Then, the collected data should achieve the aim of the study, which is needed to fulfil the standard compliances of ICOP IAQ 2010 and MS1525:2019. The IEQ measures the level of physical parameters in thermal comfort by measuring environment quality in the space using the appropriate tools.

The impact of IEQ on building users in the learning space explored through past studies indicates the key factors influenced safety, health and comfort, as shown in Table 2.

Table 2. Past studies of IEQ in learning space within higher educational buildings

Parameter	Research Findings/Gaps	Source
Air temperature	The TPR did not comply with the standard compliance and building users tended to lower the temperature to increase the comfort level.	Naamandadin et al. (2020); Talukdar et al. (2020); Guevara, Soriano and Mino-Rodriguez (2021); Izzati et al. (2023)
Humidity	The humidity in the space was always inconsistent which caused health symptoms such as dry skin, itchiness and mucus. The users still feel comfortable despite the increasing level of humidity.	Zuhari and Sheau Ting (2019); Talukdar et al. (2020)
Building ventilation	The space depends on mechanical ventilation system to produce colder environment.	Talukdar et al. (2020); Guevara, Soriano and Mino-Rodriguez (2021)

(*Continued on next page*)

Table 2. *Continued*

Parameter	Research Findings/Gaps	Source
Lack of awareness	Lack of awareness among users regarding the IEQ key factors that could affect their work productivity during physical activities. Hence, it is important to educate the building users on the significance of practicing minimal use to mitigate the environment influence in the long term.	Zuhari and Sheau Ting (2019); Izzati et al. (2023)
Health symptoms	Diseases such as allergies and headaches happened among the users because of the higher temperature in the space, especially during the evening.	Zuhari and Sheau Ting (2019)
Building maintenance	Suggestion to improve maintenance to ensure thermal comfort level is maintained according to the standard compliance.	Zuhari and Sheau Ting (2019); Naamandadin et al. (2020)

Higher Educational Buildings

Higher educational buildings are built purposely for academic pursuits by providing the learning environment to higher level of students performing physical activities. The learning spaces such as tutorial classrooms, lecture halls, laboratories and libraries should be designed and constructed with the consideration of improving their learning in a comfortable way by maintaining and sustaining indoor environments (Kovalska et al., 2021).

Hence, the building should function according to the adaptability and flexibility of the learning space when carrying out the physical activities (McFarland, Ross and Albright, 2021). The indoor environments of buildings are very essential to promote safety, health and comfort to the building users. The building's performance should be enhanced with a comfortable indoor environment, good ventilation and minimise the exposure to hazard to ensure the sustainability of the environment in the building (Kovalska et al., 2021).

The building also needs to be designed with sustainability and high energy-efficiency considerations (Li et al., 2021) such as heating, ventilation and air conditioning (HVAC) system and building materials because more energy consumption can negatively impact indoor environment. Providing accessibility for the users can be considered to improve building design (Reyes, Meneses and Melián, 2022). The IEQ measurement took place within higher educational buildings and the study specifically chose lecture halls among learning spaces available.

Sustainability of Learning Space

Sustainability implementation in learning space, specifically in higher educational buildings such as tutorial classrooms, laboratories, lecture halls and libraries, significantly influenced student's work performance and productivity. Hence, building environment and efficiency should be considered to enhance building performance. Designing a building environment with a sustainable approach is vital for sustainability and efficiency (Munaro, Tavares and Bragança, 2020). Therefore, learning space should be designed and retrofitted to attain good IEQ within higher educational buildings as the necessary requirements to ensure comfort among users.

The IEQ is building performance that should be focused on when it comes to building sustainability. These aspects include a few parameters such as temperature, humidity, illumination, orientation and assets that are necessities to sustain the learning space. For instance, learning space provides adequate natural ventilation to allow natural air flow from the outside of the building to reduce energy consumption instead of relying on conventional systems (Jia et al., 2021). The influence of IEQ parameters and the relation with sustainability were still not considered to be approached within most developing countries (Mannan and Al-Ghamdi, 2021) due to various reasons such as lack of maintenance incentives, less expertise, lack of awareness and the continuous usage of conventional systems. Thus, the study contributes findings leading to IEQ parameters and a sustainable approach that has been implemented in learning space within higher educational buildings.

METHODOLOGY

The study is conducted using a mixed-method approach. The first method is using semi-structured interviews of experts in IEQ factors and their perceptions to current IEQ in learning space within higher educational buildings (Nurick and Thatcher, 2023). Second method is fieldwork measurement where the data sample is collected (Chang et al., 2023). Both methods are related to the objectives of this study; to identify the experts' perspective and the factors to current IEQ and to measure the IEQ factors in learning space within higher educational buildings, specifically in lecture halls.

Semi-structured Interview

Semi-structured interviews were viewed as an optimum process for data collection to obtain the specific respondent's perspective that allow in-depth discussion with individual level of knowledge and experience (Nurick and Thatcher, 2023). In this study, seven skilled experts with technical expertise working in the public sector and seven knowledgeable experts with non-technical expertise working in academic background were chosen in this research.

The respondents also have some other specific criteria. First, their current working field aligns with the research objective. Three of the experts involved have a background of green building, which can view the building efficiency implementation in current buildings. Two experts from building performance background were also chosen to illustrate the criteria of building performance area related to the study. Two experts on the other hand have built environment expertise to describe the current learning space condition within higher educational buildings. One of the experts among all 14 experts has sustainable expertise to show the current sustainability level of higher educational buildings.

Two experts were chosen as they have occupational safety and health expertise which is considered vital to identify a few factors that lead to a user's comfort level. Also, one of the has architectural background, focusing on designing and retrofitting buildings. Mechanical and electrical experts were also chosen as they can recommend and review the mechanical and electrical system in the learning space.

For this approach, an invitation letter through email was distributed to selected experts to get their consent on their voluntarily participation in the interview. During the interview session, each respondent spent 20 minutes to 40 minutes of their time through video communication service via Google Meet and face-to-face interview in certain locations.

The interview questions have two sections and both experts were required to answer all the sections. First section had binary choice ("Yes" or "No") regarding the IEQ factors considered most important when impacting the building user's safety, health and comfort within higher educational buildings. The next section is an open-ended question where the respondents have been given two questions to answer based on their perceptions and level of knowledge to IEQ within higher educational buildings. Tables 3 and 4 summarise the respondents' backgrounds. Then, all the qualitative data were collected and analysed with a thematic analysis method using a qualitative data analysis computer software, NVivo 14 (Lumivero, Colorado, USA).

Table 3. The respondents' background and years of experience in the industry (non-technical experts)

Respondent	Expertise	Years of Experience in the Industry
R1	Green building	More than 16 years
R2	Building environment	More than 16 years
R3	Building performance	11 years to 15 years
R4	Occupational safety and health	11 years to 15 years
R5	Occupational safety and health	11 years to 15 years
R6	Green building	More than 16 years
R7	Architectural	More than 16 years

Table 4. The respondents' background and years of experience in the industry (technical experts)

Respondent	Expertise	Years of Experience in the Industry
R8	Occupational safety and health	11 years to 15 years
R9	Sustainable	Less than 5 years
R10	Building performance	6 years to 10 years
R11	Green building	11 years to 15 years
R12	Mechanical and electrical engineering	11 years to 15 years
R13	Mechanical and electrical engineering	6 years to 10 years
R14	Building environment	More than 16 years

Semi-structured interview was used as the approach to obtain the qualitative data in this research that aims to understand respondents' perceptions and their level of knowledge on IEQ and how this indicator affects building user's work productivity (Ruslin et al., 2022). Assessing performance in learning space within higher educational buildings can be subjective due to the varying roles and responsibilities of the respondents, as the optimum level of IEQ has limitations because the environment in the surrounding should depend on individual perceptions. These varying perceptions are influenced by some factors such as their work nature, their type of outfit and the material, their gender and their physical state.

The data collected from the respondents were analysed using the thematic analysis method based on the theoretical framework in Figure 1. It is a systematic organisation of the data obtained into groups that express the perception of a singular finding. It can form a separate group without overlapping the previous group, yet still remain part of the overall grouping that addresses the research aim.

Thematic analysis is noted as a non-linear research approach with only a singular answer but it is rather an iterative approach, which is a revising and repetitive method to review the data and derive the non-quantifiable results (Nurick and Thatcher, 2023). This method is considered effective for both deductive coding and inductive coding. The data collection results in thick description that involves more than one attribute such as:

1. Data interpretation within the framework,
2. Gathering perceptions and sentimentality,
3. Appointing purpose and determination,
4. Detailed and comprehensive account and
5. Understanding the scenario in detail.

The interviews were recorded and transcribed using NVivo 14 to identify the merged keywords from the data according to the output expectations:

1. Definition and understanding of IEQ,
2. Main challenges when conducting IEQ assessment and
3. IEQ suggestions and improvements.

Fieldwork Measurement

The findings from the interview session will be used to the next approach, which was collecting quantitative data. Fieldwork measurement was conducted at three selected higher educational buildings in Malaysia that represented regions of north, west and south of Peninsular Malaysia (as shown in Figure 2). The selected universities were chosen based on the age of the buildings, where all of them should be more than 50 years old. The investigations were conducted in March, October and November 2023.

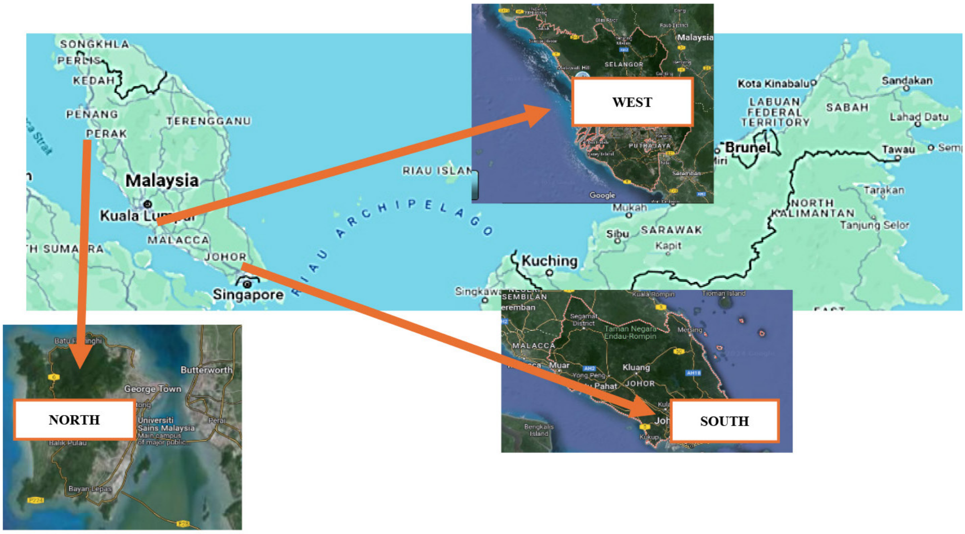

Figure 2. Fieldwork measurement locations of selected higher educational buildings

The measurement was conducted in a learning space, specifically lecture halls for each representative university. Lecture halls play a significant role in learning performance within higher educational buildings for students to experience the educational environment. In addition, lecture halls are the learning space with high frequency users within higher educational buildings and it could influence IEQ factors to the building users (Bughio, Schuetze and Mahar, 2020). The lecture halls become the focus to allow the measurement of IEQ parameters including air temperature, building ventilation and IAQ due to their impacts on user's safety, health and comfort.

As shown in Figures 3, six lecture halls were examined in University 1 (U1), representing north. Each of the three halls for University 2 (U2) (as shown in Figure 4), representing west, were from a different department. For University 3 (U3), representing south, the three halls were from three different blocks, as shown in Figure 6.

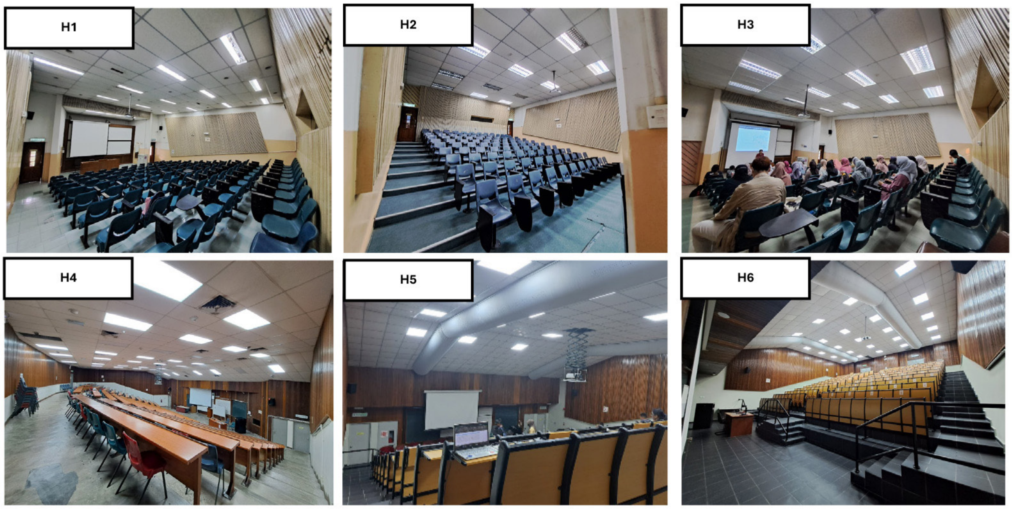

Figure 3. Indoor environment of the selected lecture halls in U1

Figure 4. Indoor environment of the selected lecture halls in U2

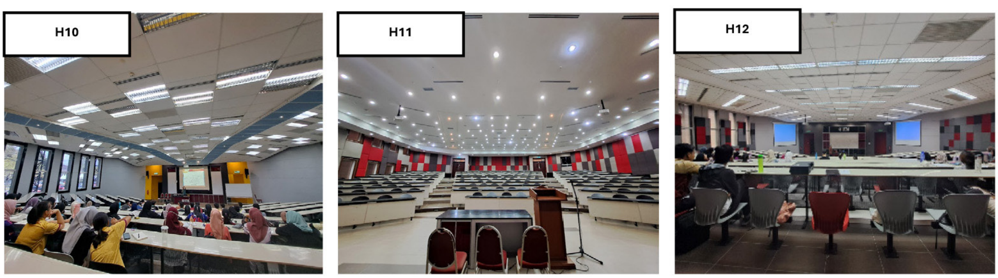

Figure 5. Indoor environment of the selected lecture halls in U3

All lecture halls within these university buildings that were measured for this research rely on mechanical ventilation installation to provide air movement in the space which is air-conditioners that control TPR to allow air flow in the surrounding environment. Some of the halls only start their air-conditioning system depending on the availability of class as shown in Table 5. However, the air-conditioning systems were functioning most of the time due to this research being conducted during the class session. The halls were always closed to not allow the air from inside flow out from the halls and to ensure the user's comfort and increase coolness in the space.

Table 5. The duration of the fieldwork measurement conducted and air-conditioning operation

University	Label	Fieldwork Duration (Hour)	Air Conditioner Operation (Hour)
U1	H1	12	3
	H2	10	4
	H3	7	7
	H4	6	3
	H5	10	10
	H6	9	7
U2	H7	10	10
	H8	8	8
	H9	9	9
U3	H10	6	6
	H11	9	4
	H12	9	9

The periods of the measurement were between 6 hours to 10 hours depending on the usage of air-conditioning and the availability of users in the lecture halls. The IEQ physical parameters, TPR, RH and AVR, were measured in the halls. During the measurement, the tools were placed at the centre of the halls at the height of human breathing level. An interval of 30 minutes was performed in the measurement using the tools (as shown in Figure 6) with the uncertainties and ranges as listed in Table 6.

(a) (b)

Figure 6. Tools to measure IEQ parameters: (a) EXTECH Hygro 3-in-1 pocket-sized thermometer anemometer (Extech Instruments, New Hampshire, USA) and (b) AirFlow 212972 LCA 6000 (Airflow Developments Ltd., Buckinghamshire, England)

Table 6. The details and the accuracy range of the tools

No.	IEQ Parameters	Analytical Equipment	Model No.	Detection Range (Accuracy)
1	Temperature (°C); Humidity (%)	EXTECH Hygro 3-in-1 pocket-sized thermometer anemometer	45160	TPR: 0°C to 50°C (±1.2°C); RH: 10% to 95% (±4%)
2	Air flow (m/sec)	AirFlow 212972 LCA 6000	LCA6000RVT	AVR: 0.25 m/sec to 4.99 m/sec (±0.10 m/sec); 5 m/sec to 30 m/sec calibrated better than ±2 m/sec of reading

Questionnaire Survey

Purposive sampling involves a group of selected participants that should align with the objective of the study, whereby they are most likely to yield related information according to their personal experiences. Purposive sampling was used in this study to gather the specific views of individuals who may hold different perspectives of the ideas and issues related to the questions (Campbell and Stanley, 2020).

Thus, this approach is used as a quantitative method by distributing the questionnaire to the targeted respondents (space users), including students, lecturers and staff who have used the space. The targeted respondents must use the hall at least an hour a day since 2022 until May 2023.

The questions in this survey were related to the interview and the collected data were analysed using Statistical Package for the Social Sciences (SPSS) version 23 (IBM Corp., Armonk, NY, US). The purpose of this survey was to understand the user's perspective and personal experience while using the selected lecture halls. The results will relate to the outcome of the interview with experts and the fieldwork measurement to determine IEQ factors in the lecture hall.

RESULTS AND DATA ANALYSIS

Semi-structured Interview Analysis

There were two sections of the interview questions regarding respondents' understanding of IEQ. First section focused on the IEQ indicators that have been taken from literature review of past studies to identify the significance of all the indicators when conducting the IEQ assessment. Second section is an open-ended question where the respondents have been given three questions to answer with varieties of perceptions. All the answers were transcribed and analysed using NVivo 14.

Indicators of Indoor Environmental Quality

First section interview required the respondent to only answer with two options, "Yes" or "No", whether the indicators give the impact to building user's safety, health and comfort. The answers are exported to SPSS to display and analyse the responses (as shown in Figure 7).

Table 7. Common indicators of IEQ

IEQ	Thermal comfort	Humidity
		Heating
		Cooling
	Ventilation	Natural
		Mechanical

Indoor environmental quality: Thermal comfort

Figure 7 shows that the respondents widely acknowledged "cooling" and "humidity" as the influential factors affecting the comfort, health and safety of building users. Cooling significantly contributes to increasing user comfort, which involves the maintenance of a comfortable temperature by using cooling systems such as air conditioners, especially to the space located in the place with hot and humid climates (Taib et al., 2022; Toosty et al., 2022). Humidity emphasises the essential of maintaining an optimal level of moisture content and this factor is deemed to be crucial in the surrounding indoor environment (Barak and Frana, 2020).

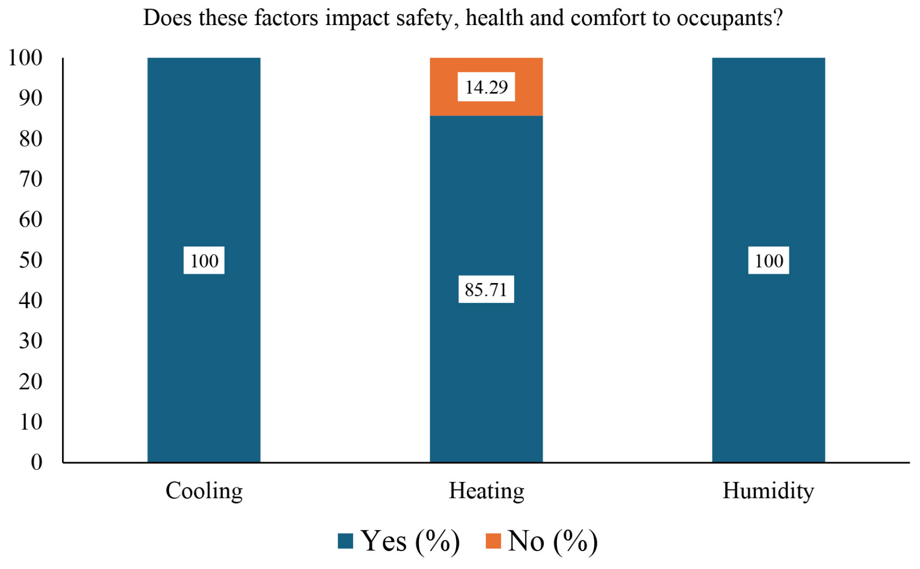

Figure 7. The responses of respondents on thermal comfort

"Heating" is also considered the influential factor that impacts building user's safety, health and comfort with 85.71% of the respondents agreeing. Their interpretation was based on a situation where cooling systems could not function and produce the hot atmosphere, which can reduce user's comfort (Taib et al., 2022). The respondents that considered the answer as "no" on the other hand gave different opinions; most Malaysians have adapted to the hot and humid weather conditions. They believed that it is unnecessary to install heating devices or implementing heating adaptations into the spaces to increase the temperature level. Thus, all the respondents agree that cooling and humidity are significant to increase building user's comfort and well, while heating is considered as less influential due to the hot and humid weather condition.

Indoor environmental quality: Building ventilation

Both "natural ventilation" and "mechanical ventilation" are important factors that impact building user's safety, health and comfort. Ventilation is considered important as it involves air circulation within the building to control the amount of air exchange and increase building user's comfort. Mechanical ventilation received more "Yes" as the answer compared to natural ventilation. Mechanical ventilation ensures proper air exchange which helps to distribute fresh air through the building (Adîncu, Popescu and Atanasiu, 2022) but it fully depends on the mechanical system (Osaro, Cookey-Gam and Iyerefa, 2022). Natural ventilation is also functioning as mechanical ventilation but not as impactful to building users as mechanical ventilation as stated by 21.43% of the respondents (as shown in Figure 8).

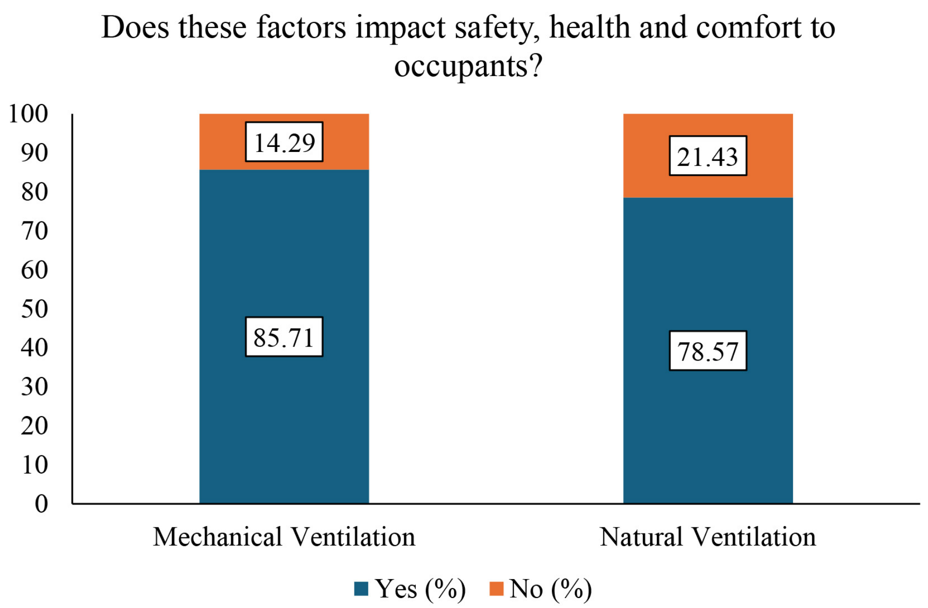

Figure 8. The responses of respondents on building ventilation

Indoor environmental quality in higher education building

The challenges of conducting the indoor environmental quality assessment

The challenges when conducting the IEQ assessment are inevitable experiences. The responses from the respondents demonstrated the challenges that happened before, during and after conducting the IEQ assessment (as shown in Figure 9).

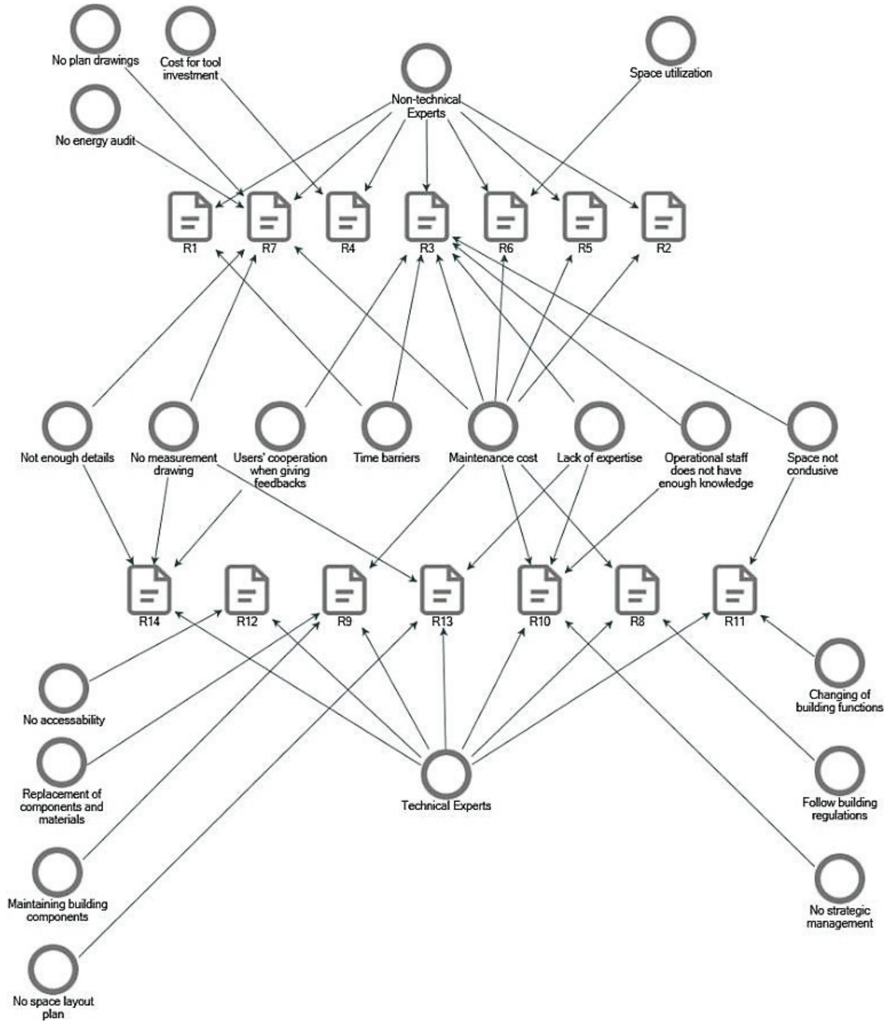

Figure 9. Challenges of IEQ assessment

The respondents (R2, R3, R5, R6, R7, R8, R9 and R10) mentioned "maintenance cost" as most challenging when conducting IEQ assessment. This challenge concerns striking a balance between the regular maintenance and repairs necessities and uphold to financial constraint at the same time (Besiktepe, Ozbek and Atadero, 2020). Building management in Malaysia have a difficulty with budget to sustain the building especially older buildings (Hauashdh et al., 2020), which lead to many defects that could risk the building user's safety, health and comfort (Faqih, Zayed and Soliman, 2020).

The challenge of "lack of expertise" was raised by R3, R10 and R13. Respondents R3 and R13 pointed out that they were having difficulty with a worker that has no background of related expertise in their department and due to shortage of experts, they need to handle other work. Furthermore, R10 stated that the staff in the management have no qualifications or basic knowledge related to the expertise. This challenge arose when Malaysia has the lack of local experts to sustain the buildings and facilities (Hauashdh et al., 2020).

Analysis of the suggestions and recommendations to improve indoor environmental quality

There are many suggestions and improvements given by the respondents to improve IEQ in the building. The ideas were developed to ensure the building users can feel comfort in the building.

Based on Figure 10, R2, R8, R9 and R12 suggested "regular maintenance" can improve IEQ in the building, which aligned with the suggestion of "preparing budget for maintenance" made by R8 and R9. This is because most of the buildings in Malaysia were having difficulty practicing and performing basic maintenance (Dzulkifli et al., 2021; Adeyemi, Rahman and Adeyemi, 2022). The reason is caused by less experts, limited maintenance budget and inefficient way to execute physical building performance (Hauashdh et al., 2021).

Next, "enhance energy efficiency" was suggested by R1, R7, R13 and R14. Respondents R1 and R7 suggested to emphasise the natural cooling systems in space. Respondent R1 explained that improving the cooling system can be done by revamping the building or space structure. The buildings in Malaysia have air-conditioning to lower the temperature inside, so this can be another alternative by constructing a structure that is suitable in hot and humid climates. Meanwhile, R7 shared the same viewpoint by highlighting that the usage of conventional air-conditioning systems was common in Malaysia due to cheap cost, but it is recommended to change into high efficiency usage of HVAC systems to save energy consumption (Bakthavatchalam et al., 2022).

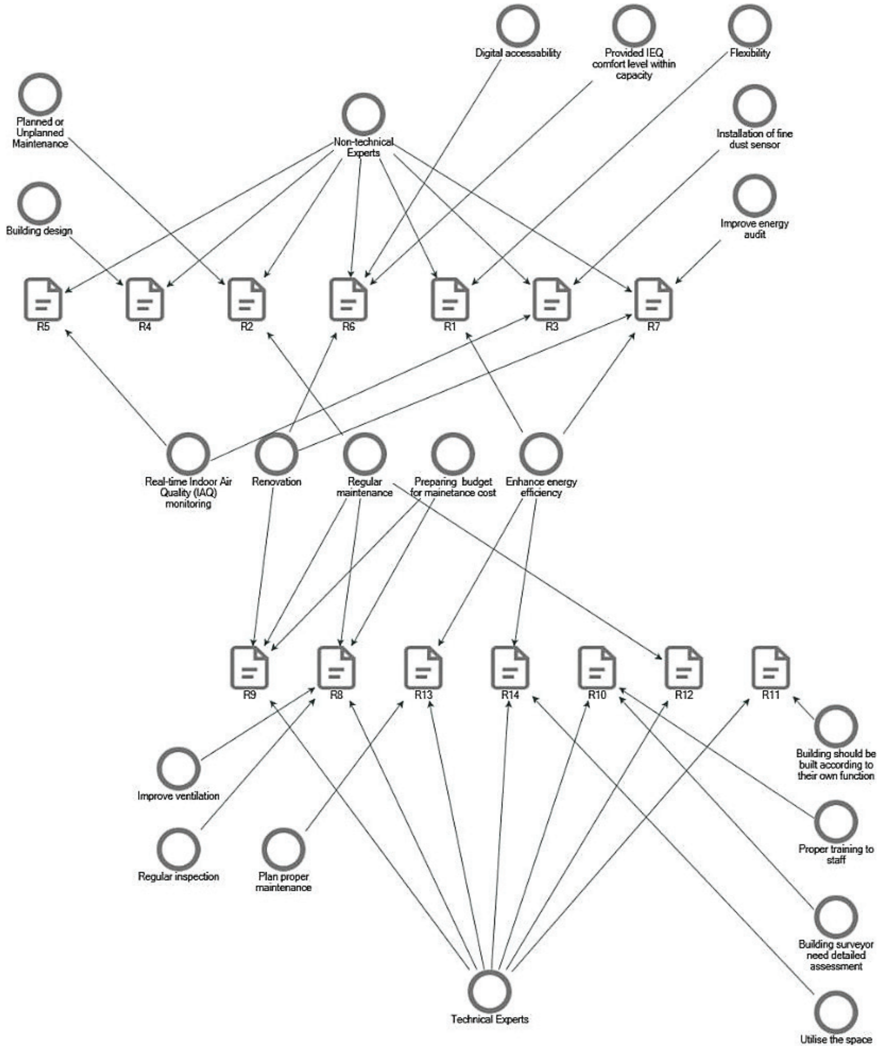

Figure 10. Suggestions and recommendations to appraise IEQ in learning space

Fieldwork Measurement Analysis

Thermal comfort is one of the significant factors of IEQ that gives an impact on user's safety, health and comfort. Figure 11 displays the measured TPR, Figure 12 displays RH and Figure 13 displays the AVR of 12 halls in total. The acceptable range of each IEQ parameter is shown as a red dashed line, based on ICOP IAQ 2010 and MS1525:2019. Based on these standard compliances, TPR should range between 23°C to 26°C, RH between 40% to 70% and AVR between 0.15 m/sec to 0.50 m/sec.

Indoor air temperature

The results show that TPR in halls H1, H2, H4 and H11 exceeded the acceptable range or parameters which is considered as outside of comfort level. Hall H9 showed the TPR within the average temperature of standard compliance. In a meantime, H3, H5, H6, H7, H8, H10 and H12 showed that the TPR is extremely low, which is below the average temperature. Based on these results, the research found that the main cause of low levels of TPR was that the air conditioners were automatically switched on at a specific time.

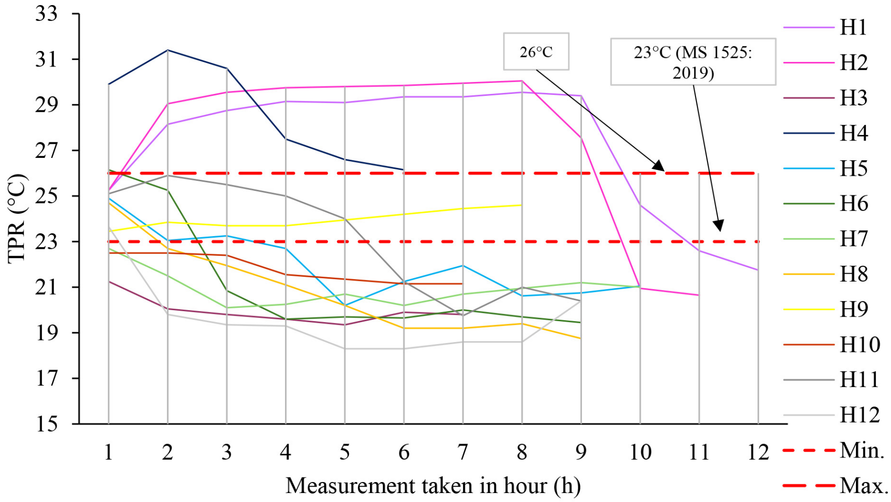

Figure 11. The TPR measurement in lecture halls

Relative humidity

Figure 12 shows the RH of H2, H3, H4, H5, H6, H8 and H12 within the acceptable range, unlike halls H1, H7, H9, H10 and H11 that displayed a level of RH that exceeded the average. It is noticeable that the difference between all the halls is due to the ventilation system used in the space where high indoor temperature tends to have high humidity in the surrounding, which is attributed to high moisture content.

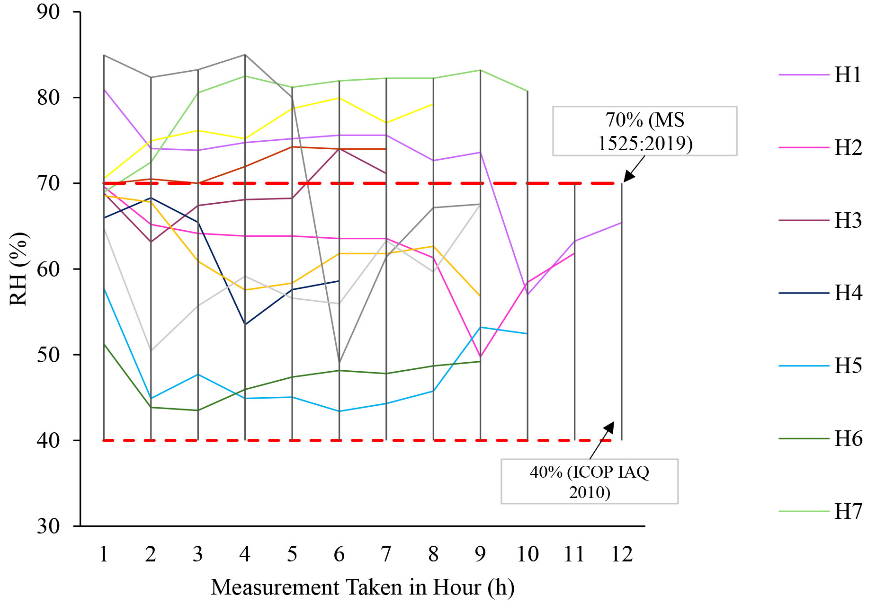

Figure 12. The RH measurement in lecture halls

Air velocity rate

Figure 13 displays the AVR levels with halls H3, H5, H6, H11 and H12 recording an average air movement. In contrast, the AVR levels in halls H1, H2, H4, H7, H8, H9 and H10 did not achieve the acceptable limit. Ventilation system presented in the halls impacted the air flow produced in the room which determined the condition of thermal comfort in the hall. The more the air flow, the lower the temperature since all the lecture halls depended on the air conditioner provided. In addition, some of the halls tend to close all the time, which also impacts the amount of air flow inside the halls.

Analysis of Questionnaire Survey on Indoor Environmental Quality Factors

The analysis of the survey is illustrated in Figures 14 and 15. Majority of the users found that the temperature in the lecture halls is neither too cold nor too hot. Unlike building users that choose "Agree" and "Strongly Agree", they feel the temperature in the halls was too low when they spend more than an hour. Majority of the users were sceptical whether they feel comfortable or not with low temperature but the other users that "Agree" and "Strongly Agree" feel that the lower temperature in the lecture halls gave them comfort.

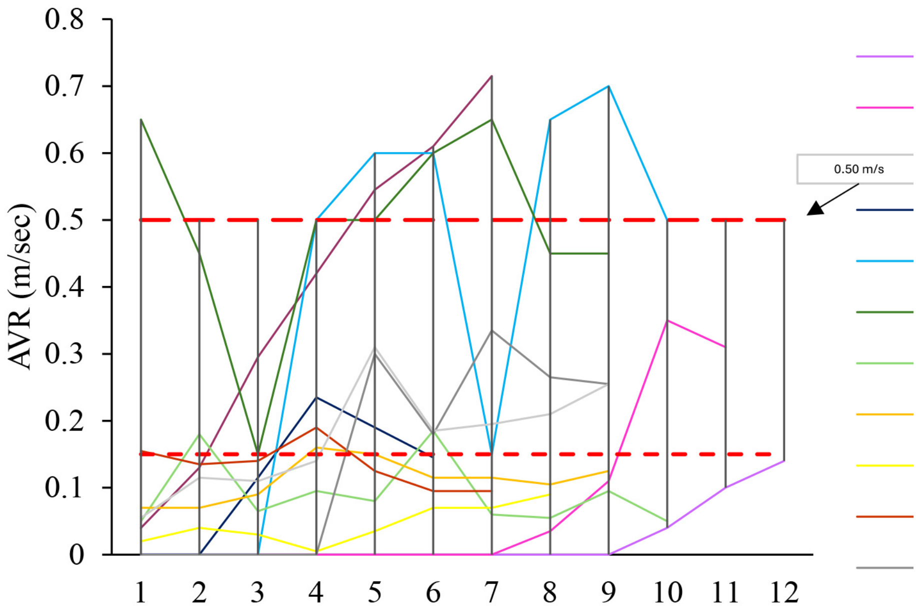

Figure 13. The AVR measurement in lecture halls

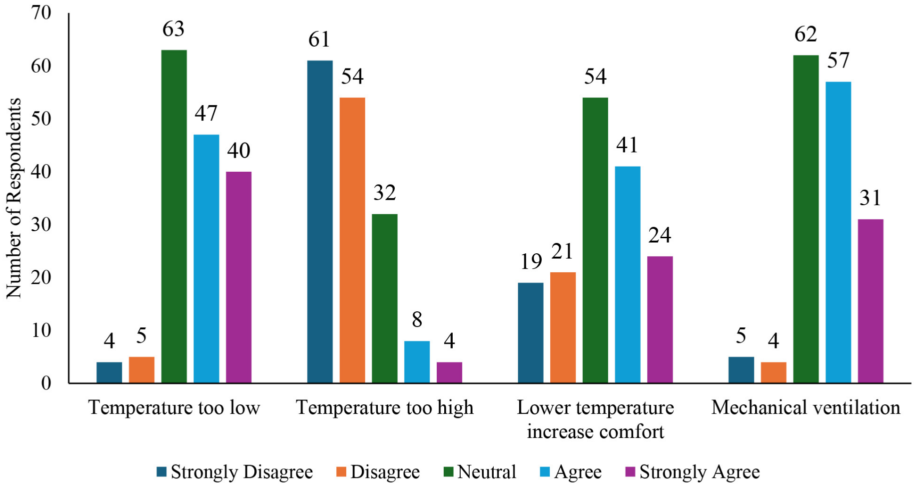

Figure 14. The results of the survey on IEQ factors: IEQ condition

The majority of users feel that the mechanical ventilation provides them comfort more than depending on natural ventilation. This is because the space is not designed for natural resources such as outside air flowing through the building. The extreme hot weather conditions especially in this hot and humid climate country encourage them to depend on mechanical ventilation systems to produce air flow. However, depending on mechanical ventilation too much can decrease the efficiency and consumes more energy, leading to more cost for electricity.

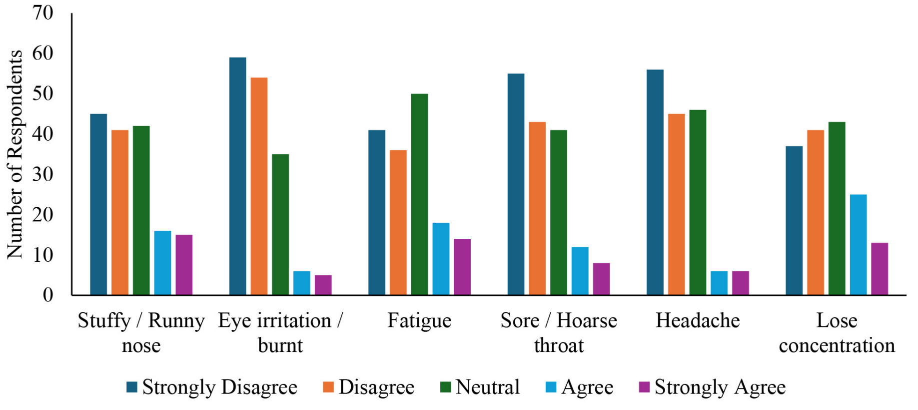

Figure 15. The results of the survey on IEQ factors: Health symptoms

Most of the users do not feel sore throat and headache when spending a lot of time in the hall. However, majority users still sceptical whether the current condition of IEQ in the lecture halls has affected their health, such as eye itching or irritation, fatigue and stuffy or runny nose. Most users also feel neutral whether the IEQ factors made them lose concentration. However, the results from the fieldwork measurement showed the opposite where the IEQ parameters were not within the acceptable range which could affect the users' health and productivity. This proven the point where some of the building users still lack awareness about the significance of IEQ in their daily lives since they spend a lot of time in the lecture halls for a whole week.

DISCUSSION

The Recent Trend of Indoor Environmental Quality Towards Sustainability

The framework based on Figure 1 illustrates the process of analysing the current IEQ and enhance IEQ towards sustainability. The findings from the interviews have been summarised with the support from past studies that have resulted in IEQ measurement. This approach appraised individual perspective and relied on self-evaluation, mainly based on subjectivity. The data collection is considered acceptable in this study as it also referred to precedent studies that use the same method. Fieldwork measurements were also conducted in selected learning spaces, specifically lecture halls within higher educational buildings to identify IEQ conditions by measuring parameters (TPR, RH and AVR) and the suggestions for improvement can be implemented based on the findings in Figure 10.

Current indoor environmental quality parameters in relation to sustainability: Thermal comfort

Based on the analysis, TPR and RH are essential to enhance the surroundings to boost the learning environment and support effective learning processes. On the other hand, building ventilation by both natural and mechanical systems can increase building user's comfort and reduce the risk of health problems such as respiratory diseases (Adîncu, Popescu and Atanasiu, 2022). The findings have shown that the indoor environment directly influenced building users. All these factors that were presented in Figures 7 and 8 were agreed by the majority of the respondents that they impact building user's comfort.

The results discovered that the TPR levels did not fall within the acceptable range, pointing to issues observed during the measurements. The mitigation measures to improve can be made based on the recommendations of the respondents but it is proven to be not well-implemented in the learning spaces. This issue can be overcome with a regularly monitoring control system by the designated personnel to ensure the necessary operational time and frequency in the lecture halls. Another way is based on an expert's suggestion but it incurs more costs which is revamping design to encourage more natural ventilation into the learning space instead of relying on mechanical systems that need more cost for maintenance.

Current indoor environmental quality parameters in relation to sustainability: Indoor environmental quality concerns in learning space

Maintenance cost is one of the most highlighted points in facing challenges when conducting IEQ assessment mainly because of the scarcity of maintenance budgets (Besiktepe, Ozbek and Atadero, 2020). Other challenges that have been highlighted is lack of expertise which led to shortage of experts in Malaysia in general, thus, it became very difficult to conduct IEQ assessment. Hence, the challenges to implement a good indoor environment become the major concern to improve the learning environment leading to poor work productivity among building users.

The ideas that were contributed by the respondents open the viewpoint to improve indoor environment within higher educational buildings with various suggestions and recommendations based on their expertise (as shown in Table 8). The majority highlighted maintenance as the necessity of ensuring good learning environments and enhancing building user's work performance. Another way to enhance the indoor environment is enhancing energy efficiency since buildings, specifically older buildings of higher education were using conventional systems, such as air conditioning to increase user's comfort but it became difficult to sustain and led to user's feeling uncomfortable and slowly deteriorated their health, both mentally and physically. Therefore, conducting IEQ measurement helps to identify the problem in the learning space and implement these suggestions.

Table 8. Comparison of findings between past studies and the current study

Parameter	Research Findings/Gaps	Current Findings
Air temperature	The TPR did not comply with the standard compliance and building users tended to lower the temperature to increase the comfort level.	Majority of halls provide lower temperatures which do not comply with standard compliance. Building users prefer low temperatures due to hot weather.
Humidity	The humidity in the space was always inconsistent which caused health symptoms such as dry skin, itchiness and mucus. The users still feel comfortable despite the increasing level of humidity.	Majority of halls showing the level of humidity within the range. Some halls still have an inconsistent level of humidity.
Building ventilation	The space depends on mechanical ventilation system to produce colder environment.	The space still depends on mechanical ventilation instead of utilising natural ventilation system due to extreme hot weather.

(*Continued on next page*)

Table 8 *Continued*

Parameter	Research Findings/Gaps	Current Findings
Lack of awareness	Lack of awareness among users regarding the IEQ key factors that could affect their work productivity during physical activities. Hence, it is important to educate the building users on the significance of practicing minimal use to mitigate the environment influence in the long term.	The experts believed that awareness should be influenced among the users by installing monitoring or sensory tools in the lecture halls. In addition, building users still found it very comfortable to have lower temperatures that can affect their work productivity.
Health symptoms	Diseases such as allergies and headaches happened among the users because of the higher temperature in the space especially during the evening.	The health symptoms can occur every time users spend more than an hour in the lecture halls.
Building maintenance	Suggestion to improve maintenance to ensure thermal comfort level in maintaining according to the standard compliance.	There is a lack of maintenance due to cost that is not prioritising regular maintenance.

Current indoor environmental quality parameters in relation to sustainability: Overcome challenges to enhance indoor environmental quality

There are some suggestions to overcome the challenges when conducting IEQ assessments which is allocation to maintenance cost. Also, the respondents suggested enhancing energy efficiency by changing cheap conventional air-conditioning systems to high efficiency air-conditioning systems (Bakthavatchalam et al., 2022). Revamping building design also helps to secure structure (Passoni et al., 2021).

The findings within higher educational buildings in Malaysia are linked to Malaysia's climate conditions. The weather influenced the indoor environment of learning space, thus, all buildings should consider the building design as mentioned in the analysis and Figure 10. Another finding is linked to green building implementation which is more prevalent in Malaysia compared to conventional buildings as a common implementation especially to older buildings due to cost effectiveness. Also, the halls can be installed with a real-monitoring device with display screens to inform the indoor condition to the building users.

CONCLUSION

This study gives an opportunity to future research that potentially further the knowledge widely in higher educational buildings in Malaysia. Lecture halls were selected for this research to provide insights that contribute to enhancing student learning in higher education. The respondents were chosen based on their position in the department, their previous research and their experience in the industry.

The research came out with the findings of current trend that still circulating in lecture halls within higher educational buildings and is summarised as follows:

1. Most buildings in developed countries depend on mechanical ventilation, for example, the usage of conventional air conditioning, to produce air flow that circulated in the lecture halls. The usage of mechanical ventilation was widely used due to the cheap cost of the appliance and installation.
2. Problems arose when the financial incentives were cut off to reduce cost which led to irregular maintenance provided in learning space.
3. Shortage of expertise in significant roles and if there were staff in the department, most of them do not have a proper training or having related background of expertise, leading to difficulty to maintain the learning space.
4. Building users, specifically students, were not aware of the importance of IEQ factors that could influence their productivity during class, lose concentration, affect health and reduce their comfort.

The research then concluded with suggestions by experts to improve IEQ in learning space within higher educational buildings. The suggestions to improve IEQ are:

1. Improving ventilation by implementing building design with natural ventilation system to improve air circulation in the lecture halls.
2. The cost of maintenance should be taken as a consideration in the budget to maintain all the learning spaces and facilities provided in the long term although it incurred more cost for installation.
3. Providing training to the staff and increasing the number of experts related to background expertise in the department to ensure the maintenance and sustainability in the building so the building performance could be preserved.

4. Early alarm or sign of air pollutants by installing sensory tools such as real time IAQ monitor in the learning space to increase awareness among the building users.

Based on this study, future research can explore different sectors, such as transportation, agriculture, technology and retail. Hence, further studies with bigger context should be taken as a consideration especially beyond IEQ. In addition, this study was limited within selected higher educational buildings and mainly focused on hot and humid climate conditions. This research is also conducted to indicate thermal comfort conditions but not other IEQ indicators such as IAQ, acoustic comfort and visual comfort. Moreover, the suggestions to mitigate were based on observation of IEQ parameters without considering other measurements such as chemical and biological concentrations.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Ministry of Higher Education Malaysia for funding this research through the Short-Term Grant Scheme by Universiti Sains Malaysia with project code: 304/PPBGN/6315529.

ETHICAL STATEMENT

This study was conducted in accordance with the ethical standards of Universiti Sains Malaysia. Ethical approval for the research protocol was obtained from the Jawatankuasa Etika Penyelidikan Manusia Universiti Sains Malaysia (JEPeM-USM) under protocol code USM/JEPeM/21100688. Participation was voluntary, and informed consent was obtained from all respondents prior to data collection. All collected information was kept confidential and used solely for research purposes.

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