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Indoor Air Quality Performance: Towards a Comprehensive Learning Environment in Malaysian Higher Education Buildings

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Abstract: Hot and humid weather impacts building occupants' daily time allocation, as well as their productivity and health. Indoor air quality (IAQ) is a crucial aspect of enhancing the comfort of a building and reflects its overall functionality. Consequently, most existing buildings in Malaysia, including higher education buildings, endeavoured to obtain a satisfactory level of IAQ. Hence, this paper aimed to examine the relationship between building experts' perceptions and IAQ measurements in the learning spaces of higher education buildings, using both qualitative and quantitative research approaches. The semi-structured interviews were conducted with 10 building experts and analysed using thematic analysis on NVivo 14 software. Fieldwork measurements were also conducted to evaluate the IAQ of four selected learning spaces in higher education buildings, specifically lecture halls, followed by a descriptive statistical analysis. The building experts highlighted maintenance as an essential aspect for improving and sustaining IAQ; but implementing it was complex due to inadequate incentive costs. The study found that some lecture halls had average measurements of IAQ, which did not comply with the standards set by Industry Code of Practice on Indoor Air Quality (ICOP) IAQ 2010 and MS1525:2019. Thus, this study contains beneficial initiatives, raises awareness among occupants and provides quotes for the maintenance and installation of IAQ monitors.

Keywords: Building comforts, Education building, Indoor air quality (IAQ), Learning space, Thematic analysis

INTRODUCTION

Generally, individuals spend between 60% and 90% of their time engaging in buildings for indoor activities (Merabet et al., 2021). The outdoor environment causes students in higher education buildings to devote numerous hours to lecture halls, tutorial classrooms and laboratories (Pedler, Willis and Nieuwoudt, 2022). This is especially true in Malaysia. Malaysia is a country with a hot and humid climate, which results in the average adult spending more time indoors (Lim et al., 2023).

However, indoor air quality (IAQ) may negatively influence occupants' safety, health and comfort (Bourikas et al., 2021). Ma et al. (2021) demonstrate that

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poor IAQ stemming from unavoidable circumstances, such as inadequate ventilation, causes loss of concentration and discomfort (Heracleous and Michael, 2019). Poor IAQ is also found to be a primary source of agitation, leading to severe illnesses such as respiratory health problems (González-Martín et al., 2021; Tran, Park and Lee, 2020), which in turn affect occupants' work performance and productivity (González-Martín et al., 2021). Among the efforts to increase comfort among occupants who must devote half of their daily schedule to a building's working space is through the heating, ventilation and air-conditioning (HVAC) system (Putra et al., 2022). However, a common problem of HVAC systems is associated with inefficient energy conversion, as well as poor maintenance and servicing, which leads to sick building syndrome (SBS) (Aziz et al., 2023; Murniati, 2020). Therefore, building performance aspects should be considered crucial, such as IAQ, thermal comfort, energy efficiency and water efficiency, to avoid SBS occurrence and ensure good academic performance among users, especially in a learning space (Jia et al., 2021).

Poor IAQ is often due to the inadequate fulfilment of criteria, which should be in accordance with IAQ guidelines, such as those established by American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and the Malaysian Code of Practice (Yau and Phuah, 2023). This results in the sensation of providing a satisfactory level of IAQ in the building, which should be a necessity for its occupants (Bourikas et al., 2021). Developing and sustaining good IAQ is essential to ensure the health and safety of the next generation. IAQ is said to be one of the crucial factors in achieving sustainable development when assessing existing buildings. However, Saini, Dutta and Marques (2020), during assessments and measurements to evaluate building performance, found poor IAQ (Saini, Dutta and Marques, 2020). Prior studies have also found that IAQ parameters have yet to become important key factors in learning spaces within higher education buildings (Azlan, Nata and Uzid 2022; Ismail et al., 2022; Naamandadin et al., 2020; Zuhari and Sheau-Ting, 2019), indicating poor parameters of higher education buildings according to standard requirements such as Industry Code of Practice on Indoor Air Quality 2010 (ICOP IAQ 2010) and Malaysian Standard (MS) 1525.

This paper gathered the understanding and perceptions of experts on IAQ in learning spaces in higher education buildings, specifically lecture halls. The study aimed to explore the factors of IAQ before conducting an assessment, a basic development of IAQ to distinguish the prerequisites for progress and maintenance.

INDOOR AIR QUALITY IN LEARNING SPACE

Learning Space within Higher Education Buildings

A higher education building refers to the physical structure that serves as a learning platform for students to pursue academic purposes, such as conducting physical activities, at higher education institutions. The building, which provides learning spaces such as lecture halls, laboratories, libraries, and tutorial classrooms with fully equipped resources and technologies, along with the necessary support, is designed to enhance comfort among students and encourage them to engage in learning activities (Kovalska et al., 2021). Therefore, learning spaces with adaptability and flexibility of functions for students to perform physical activities in higher education buildings are necessary (McFarland, Ross and Albright, 2021).

Enhancing building performance to achieve optimal building functions and ensuring the safety, health and comfort of building users is necessary. One of the building performance aspects includes the indoor environment, which should be taken as a significant factor when improving a learning space. This includes improving the IAQ in learning spaces. This study focused on lecture halls as the selected learning space due to the high occupancy levels of students spending time there daily, which could directly impact their safety, health and comfort (Bughio, Schuetze and Mahar, 2020).

Indoor Air Quality

IAQ is defined as the air quality that surrounds a building and is controlled for occupants' health and comfort (Kamal, Sazali and Sarnin, 2021; Tran, Park and Lee, 2020). IAQ in buildings can be affected by (1) outdoor airflow through the buildings (Zhang et al., 2022), (2) occupants' physical activities (Ganesh et al., 2021; Shum, Alipouri and Zhong, 2022) and (3) building materials (Mansouri et al., 2022; Tran, Park and Lee, 2020). Thus, a comfortable IAQ level can be achieved by following the indoor air parameters. The parameters affecting IAQ, including air temperature (TPR), relative humidity (RH) and air movement (AVR), must comply with the ICOP IAQ 2010 (Ismail et al., 2022) as stipulated by the Occupational Safety and Health Act (OSHA) 1994. Chemical and biological components are also included to measure IAQ.

IAQ level approaches the ideal weightage when the level is kept below the prescribed parameters to keep occupants' well-being and avoid serious illness and health problems (Asif and Zeeshan, 2023). Precedent studies demonstrate how occupants who were exposed to higher levels of air pollutants tend to show certain discomforts and symptoms, for example, allergy (Schikowski, 2021), asthma (Tiotiu et al., 2020), fatigue (Nezis et al., 2022; Sakellaris et al., 2021), nausea (Saini, Dutta and Marques, 2020) and loss of concentration during physical learning (Nezis et al., 2022; Saini, Dutta and Marques, 2020). Poor IAQ in a learning space occurred due to inadequate ventilation (Saini, Dutta and Marques, 2020) and the spread of microbiological pollutants. In fact, inadequate ventilation influenced the occupants' safety, health, comfort (De la Hoz-Torreset al., 2021), well-being (Abdulaali et al., 2020), as well as work productivity and performance (Fahim et al., 2021). This issue also brought common health effects involving respiratory health (e.g., shortness of breath, coughs, asthma) (Rabbani et al., 2022), fatigue (Nezis et al., 2022; Sakellaris et al., 2021), itchiness and eye irritation (Sakellaris et al., 2021). Concurrently, the spread of microbiological contaminants happened due to increased levels of moisture content and the reason is excessive moisture from water leakage or damage (Ahlawat, Wiedensohler and Mishra, 2020), which is also a probability of error during construction, poor maintenance and repairs, causing respiratory health problems. Furthermore, pollutants inside buildings can also be produced from building materials and furnishings (Mansouri et al., 2022; Tran, Park and Lee, 2020).

Additionally, the ventilation design allows air pollutants in the buildings (Tran, Park and Lee, 2020). To illustrate, poor ventilation produces high levels of carbon dioxide (CO_2) concentration regardless of the standards and regulations that have been established as guidance to all existing buildings in Malaysia. Old buildings commonly do not meet the standard compliance for some inescapable justification (Amoruso et al., 2021). The lack of maintenance of the ventilation system in the space, either natural or mechanical, causes the airflow in the building to be lower than the indoor pollutants (Lipinski et al., 2020), which mostly exceed the guidelines of the building standards. Nonetheless, the ventilation systems in most of the higher education buildings in Malaysia are often old and unable to meet the current building standards.

Indoor Air Quality Standards

IAQ standards improve a building's performance. Promoting IAQ standards can improve building performance by eliminating air pollutants, contaminants and substances (Tran, Park and Lee, 2020). These standards of compliance should be common to all constructed buildings, ensuring good IAQ and improving the building users' work performance. Hence, standards of compliance for IAQ were introduced. In Malaysia, common practices such as the ICOP IAQ 2010, introduced by the Department of Occupational Safety and Health (DOSH, 2010) and the Malaysian Standard under code MS1525:2019 (Department of Standards Malaysia, 2019), were developed to ensure that building performance could be sustained and to provide a working space for building users.

Indoor air pollutants can be harmful substances introduced through ventilation and HVAC systems. Indoor air pollutants could affect the building user's health, and they can also impact the building environment (Tran, Park and Lee, 2020). Nonetheless, when assessing IAQ, physical sampling of both indoor and outdoor air pollutants should be conducted. This helps measure the level of air quality in the learning space and determine compliance with standards. Additionally, it will identify the types of air pollutants present in the environment. Table 1 shows the factors in IAQ standards that measure IAQ levels in learning spaces and their acceptable range limit requirements.

Table 1. The acceptable range of IAQ parameters according to the DOSH

IAQ Factor	Unit	ICOP IAQ 2010	MS 1525:2019
TPR	°C	23 to 26	24 to 26
RH	%	40 to 60	50 to 70
AVR	Metre per second (m/s)	0.15 to 0.50	0.15 to 0.50
CO_2	ppm	C1,000	–

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

The current research was conducted to achieve a few research objectives, namely, to observe expert perception of IAQ in higher education buildings and to measure IAQ parameters in learning spaces. The research focused on lecture halls in one of the public universities in Peninsular Malaysia. Both respondents' experiences and current IAQ conditions were taken into consideration to achieve the aim of this research.

METHODOLOGY

Data Collection

The research was conducted by adopting the mixed methods approach, with semi-structured interviews and fieldwork measurement. The semi-structured interview method was conducted with experts. Meanwhile, IAQ indicators were measured in the four selected lecture halls within the higher education buildings. Figure 1 illustrates the research design for this study.

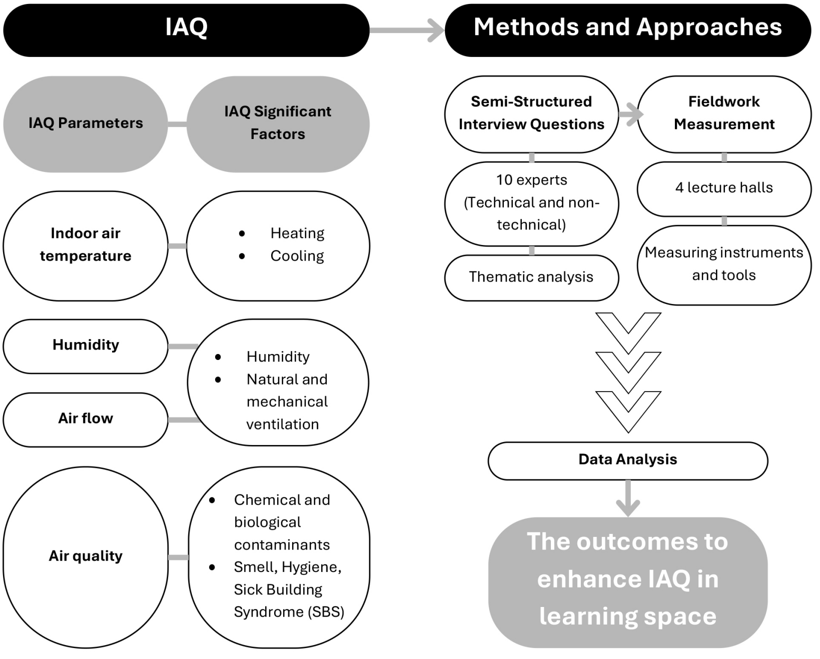

Figure 1. Research design

Semi-structured interview

This interview employed qualitative measurements that encouraged respondents to express various answers. The purpose of using the semi-structured interview in this study was to gather experts' perceptions from individual perspectives. The semi-structured questions were constructed with binary questions and subjective answers, involving one answer for each question in one section and a follow-up question with various answers. Specifically, the respondents were given predetermined and open-ended questions. Predetermined questions were standardised and thus were considered structured interviews (Mazhar, 2021). Meanwhile, open-ended questions were questions with no simple answers that were asked throughout the session.

Various perspectives were considered to develop the questions, aiming to consolidate specific information. They would be more accurate when incorporating multiple samples with diverse expertise and focusing on the primary subject of the study, which was IAQ. Rather than distributing questionnaires to a large population, interview sessions among experts could yield analytical, in-depth and dependent data. In addition, the dominant aspect was a fixed sample size and selected respondents that could represent the main subject of the study. According to Budaiwi, Mohammed and Harbi (2022), the general respondents should be between 25 years old and 30 years old, but a semi-structured interview session can have between 5 and 25 respondents.

This research began with literature readings to identify the factors of IAQ in the buildings, such as performance area, indicators, factors and previous studies that were related to IAQ findings, as shown in Table 2.

Table 2. Literature findings of IAQ factors

Factors of IAQ	Source
Humidity	Kamal, Sazali and Sarnin (2021)
Heating	Ganesh et al. (2021); Ma et al. (2021)
Cooling (HVAC)	Ganesh et al. (2021); Ma et al. (2021)
Air quality (chemical and biological contaminants)	González-Martín et al. (2021); Sakellaris et al. (2021); Tran, Park and Lee (2020)
Smell/Odour	Tsumura et al. (2023)
Building-related illnesses/Sick building syndrome	Ismail et al. (2022); Tsantaki et al. (2022)
Natural ventilation	De la Hoz-Torres et al. (2021); Heracleous and Michael (2019)
Mechanical ventilation	Ganesh et al. (2021); Zhang, Ai and Lin (2021)
Hygiene	Reshetnikov et al. (2021)

The oral interview was carried out in person and through online one-to-one sessions. Each respondent was given a brief description of the interview purpose, along with both structured and unstructured questions, before the session. Each interview lasted between 20 minutes and 60 minutes. This was to provide respondents with plenty of time to express their responses to a subjective exam that provided them with many points of view. The flow of the conducted semi-structured interview sessions is shown in Figure 2.

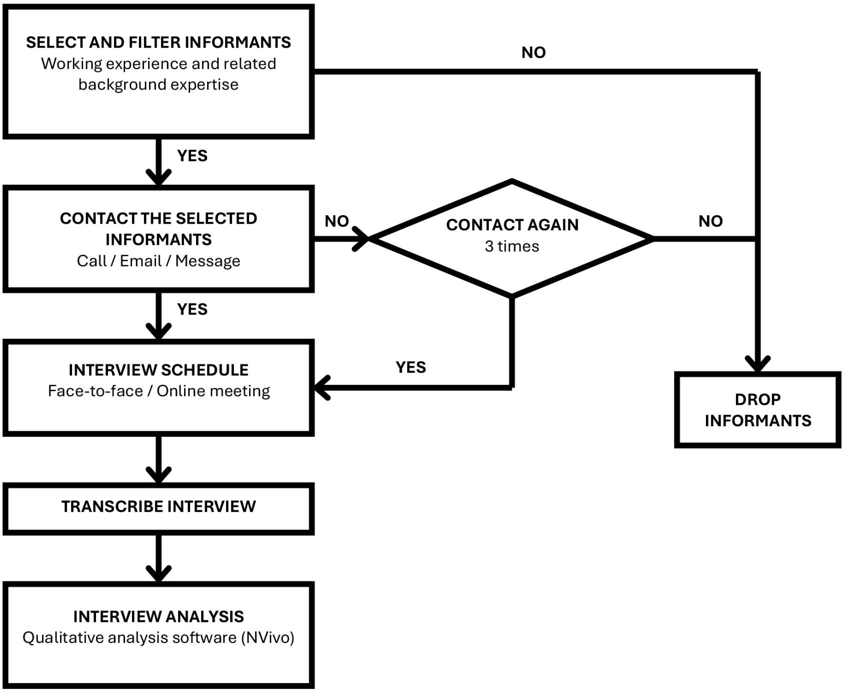

Figure 2. The flowchart of the semi-structured interview procedure

IAQ standards compliance in developing the evaluation assessment should be according to the ASHRAE Standard 62.1-2022 (Pang et al., 2023) and the Malaysia Standard MS1525:2019 (Esfandiari et al., 2021) as a benchmark to generate the outcome of the assessment into a framework of IAQ (Pang et al., 2023). The crucial part is choosing respondents with the expertise before assessing the IAQ by properly analysing the respondents' perceptions. Hence, it is significant to conduct a case study of existing higher education buildings to examine the relevance of the developed questions, including the cooperation of the respondents, the availability of resources and the preparation of the respondents. This procedure can help identify any unexpected issues that may arise when applying the method.

The interview questions consisted of three sections covering aspects of IAQ and purposely collected experts' knowledge about the significance of IAQ in higher education buildings. The cover letter addressed the aim of this research using explanatory terms and keywords related to IAQ indicators. The first section of the interview questions required the respondents to fill in their details to gather information about their area of expertise. The following section was objectively constructed based on IAQ factors to collect the factors in IAQ indicators that impacted the occupants' safety, health and comfort (as shown in Table 2). Following that, the responses were agreed upon or disagreed with in accordance with the structured-type questions on the IAQ factors. The final part of the interview shifted to unstructured types of questions, namely, a subjective statement that listed various answers. The questions included terms and keywords of IAQ factors and procedures that should be taken to measure IAQ. Specifically, two unstructured questions were asked during the session: (1) the experts' perception of IAQ in the learning space and (2) the implications of poor IAQ on occupants' comfort level.

Purposive sampling targets specific groups by providing relevant information to align with the research (Campbell et al., 2020). The purposive sampling method is selected according to certain characteristics and criteria. The study sample was chosen based on the respondents' identity according to their background of expertise, experience and educational background in the related subject. The selected respondents should be able to provide valuable input regarding IAQ. The respondents were from two categories of experts, namely, non-technical experts who worked in Malaysian public universities with experience in technical building, for example, those with engineering and building surveying expertise and the other category represented the public works department (PWD) with the same background of education and area of expertise. Each category was represented by five experts. All respondents answered three sections, including their demographic profile (as shown in Table 3).

Table 3. Respondents' background of expertise

Non-Technical Experts		Technical Experts	
Label	**Background of Expertise**	**Label**	**Background of Expertise**
R1	Green building	R6	Building performance
R2	Occupational safety and health	R7	Green building
R3	Building environment	R8	Mechanical and electrical engineering
R4	Heritage and conservation	R9	Building environment
R5	Green building	R10	Occupational safety and health

The study respondents were professionals specialised in various fields. A total of three respondents had experience and knowledge in green building practices, two in built environments, two in occupational safety and health and the remaining three in building performance, heritage and conservation, and mechanical and electrical engineering. All of them met the requirements to participate in the study interview session. The responses from the respondents were aggregated into the tabulated data according to their field of expertise.

Fieldwork measurement

Following the analysis of the semi-structured interview, quantitative research was conducted in four selected lecture halls from selected higher education buildings at one university. The halls were chosen to represent the learning space in higher education buildings. Figure 3 shows the four lectures, with two halls representing two different blocks.

Figure 3. The selected lecture halls

The IAQ measurement took between 6 hours and 10 hours, depending on the state of the air conditioning and the user's availability. TPR, RH, AVR and CO_2 were measured in the chosen lecture halls. The measurement was taken at one-hour intervals using instruments and tools, as shown in Table 4.

Table 4. The instruments and tools used to measure the main factors of IAQ

IAQ Main Factors	Analytical Equipment	Detection Range (Accuracy)	Origin Country/ City Acquired
TPR; RH	EXTECH Hygro 3-in-1 Pocket-Sized Thermometer Anemometer	0°C to 50°C (± 1.2°C); 10% to 95% (± 4%)	Taiwan
AVR	Air Flow 212972 LCA 6000	0.25 m/sec to 4.99 m/sec (± 0.1 m/sec); 5 m/sec to 30 m/sec, calibrated better than ± 2% of reading	Germany
CO_2	Onset HOBO Wireless Carbon Dioxide/ Temperature/RH Data Logger	0 ppm to 5,000 ppm (± 50 ppm or ± 5% of reading)	United States

Analysis Method

A thematic analysis gives an in-depth understanding of the respondents' experiences and perceptions in a specific study (Christou, 2022). The approach produces significant queries and codes by thoroughly examining the collected data (Alisop et al., 2022). The study utilised thematic analysis to analyse the data collected from semi-structured interviews to support the aim of this research. NVivo 14 was used to manage qualitative data analysis as a visual instrument to illustrate the relation between various responses. The data collection for fieldwork measurement was analysed using descriptive statistical analysis in IBM SPSS Statistics version 23 and then integrated into charts. The descriptive statistical analysis method summarises and describes the dataset involved in the measurement of central tendency (Siedlecki, 2020). This analysis also involved the measurement of variability to describe data dispersion. This analysis provides an overview of the pattern and relationship, identifying and summarising characteristics (Siedlecki, 2020). The analysed data for both semi-structured interviews and fieldwork measurements were compared to provide an outcome aligned with the aim of this study, for example, to enhance IAQ in learning spaces.

RESULTS AND DISCUSSION

Significant Factors of Indoor Air Quality Performance that Affected Learning Space

The IAQ factors were evaluated based on different backgrounds of expertise (as shown in Table 5). This was to specify important and perceived important factors of IAQ in learning spaces from multiple perspectives. Table 5 presents the agreed or disagreed IAQ factor that highly impacts occupants' safety, health and comfort.

Table 5. The overall results of IAQ factors

Experts/Factors	Non-Technical					Technical				
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Humidity	√	√	√	√	√	√	√	√	√	√
Heating	√	√	√	√	√	√	√	√	√	√
Cooling (HVAC)	√	√	√	√	√	√	√	√	√	√
Air quality (chemical and biological contaminants)	√	√	√	√	√	√	√	√	√	√
Smell/Odour	√	√	√	√	√	√	√	√	√	√
Building-related illnesses/Sick building syndrome	√	√	√	√	√	√	√	√	√	√
Natural ventilation	√	√	√	√	√	√	√	√	√	√
Mechanical ventilation	√	√	√	√	√	√	√	√	√	√
Hygiene	√	√	√	√	√	√	√	√	√	√

The study respondents conveyed that IAQ factors impacted the occupants' safety, health and comfort. All IAQ factors were considered by the experts to have impacted the occupants. Many respondents agreed on the importance of delivering satisfactory levels of IAQ throughout the buildings, including the facilities that were provided in the space to improve safety, health and comfort for people. Humidity was perceived as significant by all study respondents, with an average of 40% to 70%, because an exceeded limit can incur the growth of pathogenic or allergenic microorganisms in the space (Kamal, Sazali and Sarnin, 2021). The Department of Occupational Safety and Health has also highlighted indoor air contaminants (chemical and biological) as a factor that causes either short-term or long-term health problems. The respondents asserted that indoor air pollutants can be managed by regulating air-purifying humidity, preventing the discharge of microorganisms and eliminating accumulated CO_2 (González-Martín et al., 2021).

Sick building syndrome (SBS) was linked with the time spent in a building. SBS, due to exposure to chemical and biological agents, can cause respiratory health problems and eye irritation (Tsantaki et al., 2022). SBS appeared due to factors such as inadequate ventilation. Natural ventilation without proper filters to remove indoor-generated pollution would induce air pollution, while inadequate mechanical building ventilation correlated with the transmission of infectious disease. Thus, both natural and mechanical ventilation influenced IAQ and significantly affected the occupants' health (Zhang, Ai and Lin, 2021).

Heating and cooling were perceived to directly affect occupants' productivity, revealing that TPR should be maintained at 23°C to 26°C. Exceeding the limits can lead to growth and transmission of bacteria that cause discomfort to the occupants (Ganesh et al., 2021). Nonetheless, the respondents agreed that heating did not highly impact IAQ. Heating was not a critical factor and is not intolerable to the building's occupants based on their minimal reaction. On the contrary, based on knowledge and previous research, it has long-term impacts. Correspondingly, the overall result displayed all distributed factors as impactful, influencing aspects of IAQ as ascertained by both categories of experts and thus should be taken into account before initiating IAQ assessment.

Diverse Experts' Perceptions

The study respondents were asked two open-ended questions. Figures 4 and 5 summarise the variations and perceptions regarding IAQ factors in the respondents' answers.

The perception of IAQ improvements in the learning space

An in-depth analysis was conducted using NVivo 14 software. The software generated terms and keyword outcomes based on both groups of experts. Figure 4 shows that regular maintenance was a frequent and familiar word mentioned in most responses, indicating common mechanisms to ameliorate and sustain the IAQ. According to Dzulkifli et al. (2021) and Hauashdh et al. (2021), buildings in Malaysia face challenges in performing basic maintenance due to certain unavoidable factors, such as a lack of experts in the field and insufficient budget for maintenance.

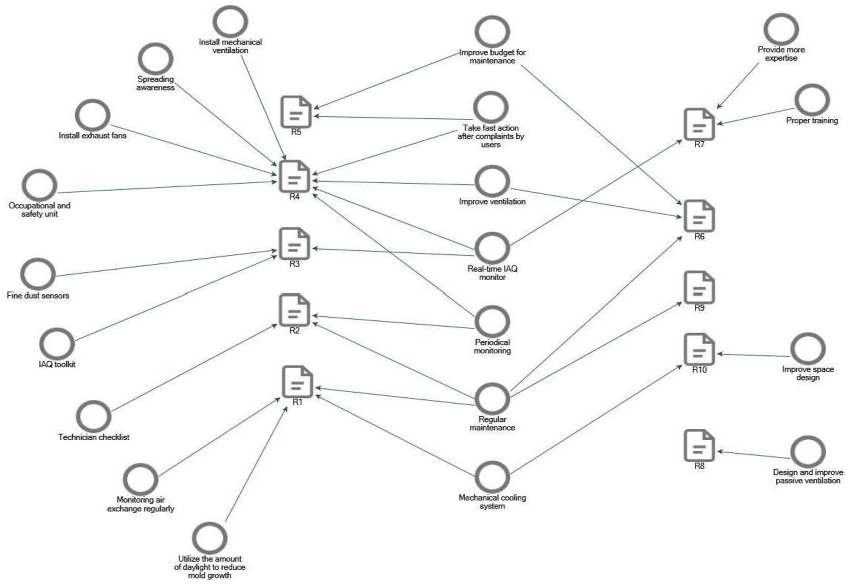

Figure 4. The experts' perceptions of IAQ improvement in learning spaces

Moreover, installing real-time IAQ monitoring was perceived as a practical appeal before the inauguration assessment based on R2, R3 and R6 responses. Improving budget maintenance and ventilation and periodic monitoring, as well as fast action, were mentioned as essential instruments to increase IAQ.

Poor indoor air quality performance impacts on learning spaces

Higher education buildings faced challenges in achieving comfortable IAQ. This could lead to negative implications. According to Figure 5, there was a similarity in responses. Lessened work productivity was found as the main implication of poor IAQ. R1 highlighted that poor IAQ reduced work productivity because much time was spent in the learning space. This was also agreed by R3. R3 believed that the longer time spent there was due to a lack of awareness of poor IAQ, which affected the building users' safety and health. Less comfort, loss of concentration and increased stress were also unavoidable issues because of poor IAQ.

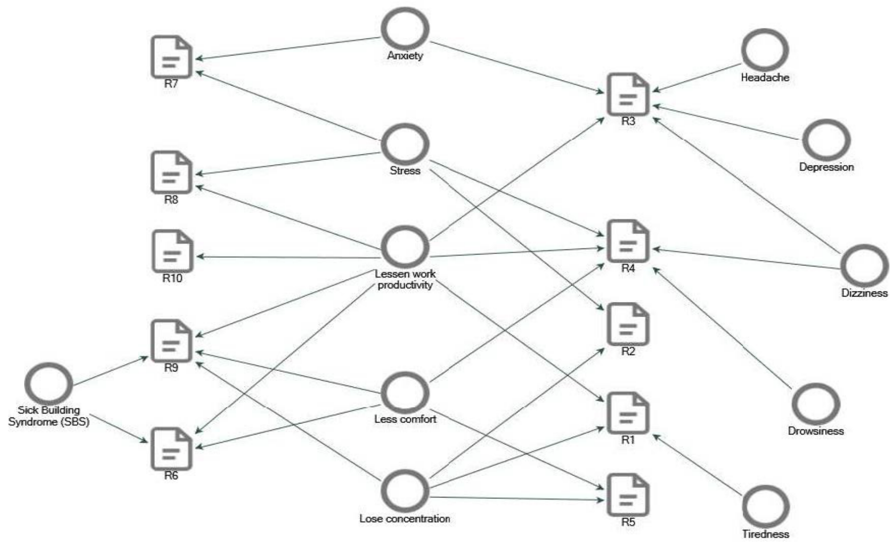

Figure 5. The negative impacts of poor IAQ performance on occupants' comfort level

Compliance with the Indoor Air Quality Main Factors

Based on the interview findings, the study identified the main factors affecting IAQ levels. The parameters were TPR, RH, AVR and CO_2. These main factors were crucial in determining building performance and the safety, health, and comfort of building users, according to experts. Thus, an analysis from the fieldwork measurement was conducted to identify the IAQ level of learning spaces in the selected higher education buildings. The overall measurement is indicated in Table 6.

Table 6. The mean ($\bar{x}$) and standard deviation (σ) of the lecture halls' measurements

IAQ Main Factors	TPR		RH		AVR		CO_2	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
Hall A	28.18	3.60	62.33	4.97	0.05	0.13	894.00	323.00
Hall B	19.96	0.61	68.71	3.36	0.39	0.25	1,018.00	190.00
Hall C	21.97	1.48	47.94	4.83	0.37	0.30	1,735.00	732.00
Hall D	21.15	2.62	47.31	2.51	0.49	0.15	779.00	51.00

Indoor air temperature

Figure 6 shows the measurement of TPR in Halls A, B, C and D. Hall A's average measurement was higher than the limited range of TPR based on both ICOP IAQ 2010 and MS1525:2019, which is in the range of 23°C to 26°C. Meanwhile, Halls B, C and D had lower average measurements than the range limit. The results revealed that the factor contributing to a lower temperature was the air conditioner, which automatically switched on according to a set schedule rather than being operated manually, ultimately helping to save costs and energy (Liu, Akçakaya, and McDermott, 2020). However, the temperature in the halls could not be adjusted to meet the comfort preferences of building users, which may negatively affect work productivity during classes (Wolkoff, Azuma and Carrer, 2021).

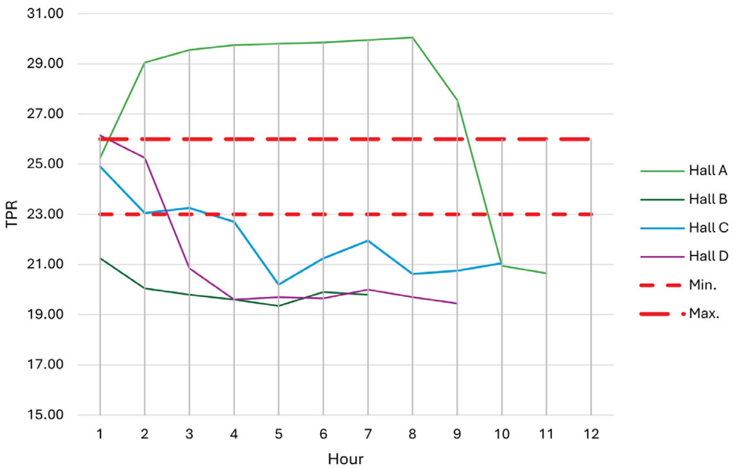

Figure 6. TPR measurement in lecture halls

Relative humidity

RH for Halls A, B, C and D was within the acceptable range of 40% to 70%. The range complied with ICOP IAQ 2010 and MS1525:2019, as shown in Figure 7. Unlike the TPR in these halls, the RH in each hall indicated that they were in good condition. This confirmed user comfort, concentration, safety, health, as well as the environment (Wolkoff, Azuma and Carrer, 2021).

Air velocity rate

According to Figure 8, the average measurements of Halls B, C and D were within the acceptable range. However, the airflow in Hall A was lower than the acceptable limit set by ICOP IAQ 2010 and MS1525:2019. The amount of airflow was affected by the type of ventilation system provided in the lecture halls (Zhang et al, 2021). The amount of air flow rate was also impacted when the windows and doors were always closed.

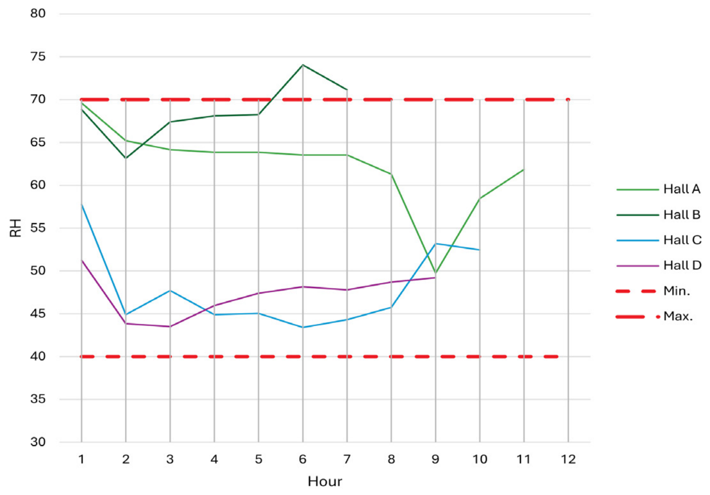

Figure 7. RH measurement in lecture halls

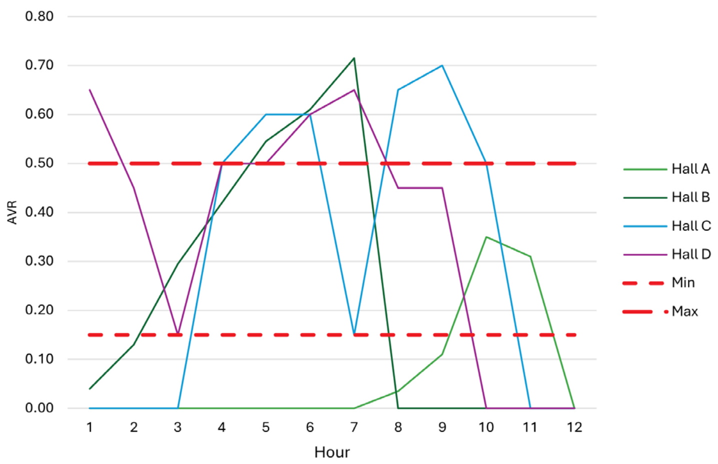

Figure 8. AVR measurement in lecture halls

Carbon dioxide

From Figure 9, Halls A and D showed a satisfactory CO_2 level at the acceptable limit of 1,000 ppm, in compliance with the ICOP IAQ 2010 standard. Hall B's CO_2 level was slightly higher towards the end, where the number of users in the lecture hall increased. However, the CO_2 level in Hall C was higher than the average measurement and the acceptable range of standard compliance due to the increased number of users in the lecture halls simultaneously. This could lead to respiratory health and air quality issues in the learning environment (Di Gilio et al., 2021).

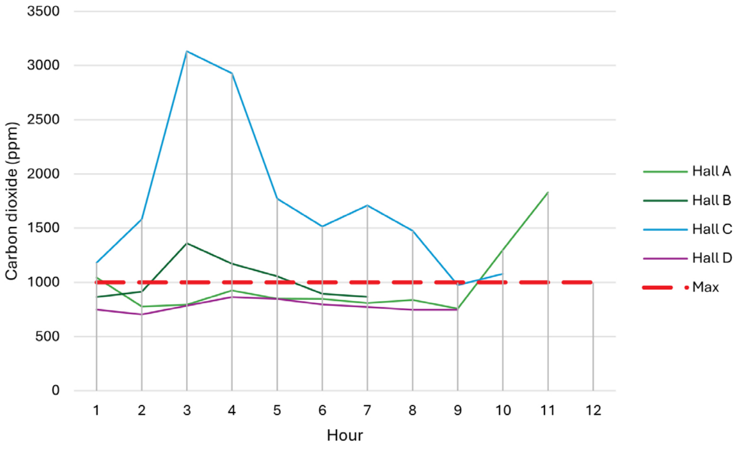

Figure 9. The level of CO_2 measurement in lecture halls

The Overall Indoor Air Quality Comprehensive Performance in a Learning Space

Based on the discussion from the interview sessions, both non-technical and technical respondents contributed various perceptions. However, keywords perceived as similar perspectives indicated common issues when improving IAQ in a learning space. These outcomes were anticipated as respondents were involved with daily tasks and activities as experts who were related to this study. Generally, respondents cited IAQ as an important factor that should be considered to ensure a safe, healthy and comfortable learning space. Based on the results, all factors were considered significant for IAQ. However, two respondents rated heating as the least critical factor. Nevertheless, all factors should be taken seriously, as confirmed by the five non-technical and three technical experts as the study respondents.

The perceptions of all respondents differed due to their background of expertise, building engagement, the time spent in the building and their main concerns about the building. Academic experts, as shown in Table 5, considered that all factors were responsible for sustaining IAQ in buildings.

Based on the IAQ fieldwork measurement results, the cause for poor IAQ was that some parameters in certain halls did not meet the standard compliance. For instance, TPR was not within the acceptable range in some halls, such as Hall A, due to a lack of maintenance. In contrast, Halls B and C exceeded the acceptable levels of CO_2. This situation raised concerns about decreased work productivity and ventilation efficiency in the learning environment (Ali, Ahmad and Yusup, 2020), as well as long-term health impacts on building users (Mentese et al., 2020). Hence, regular maintenance was suggested as a standard solution when conducting an assessment of IAQ to ensure that a clean environment can be produced (Moghadam et al., 2023). Two respondents (R6 and R7) believed maintenance work was essential to protect occupants from high exposure to harmful contaminants. The others directly recorded building reports and wrote occupants' feedback before initiating measurement. In addition, lessened work productivity was the implication indicated by seven respondents. Thus, piloting ways of attaining IAQ satisfaction levels in higher education buildings in Malaysia, specifically in learning spaces, is crucial (Saini, Dutta and Marques, 2020). In correlation to respondents' perceptions and IAQ measurement, the patterns are concluded in Table 7.

Table 7. The overall outcome enhances IAQ

Insights on IAQ	IAQ Measurement Results	Outcome to Enhance IAQ
1. Significant factors of IAQ influenced the safety, health and comfort of building users. 2. Encouraging regular maintenance to sustain the building and its facilities. 3. Installation real-time IAQ monitoring could raise awareness among users. 4. Improving building ventilation using high-efficiency ventilation instead of relying on conventional mechanical systems that consume more energy. 5. The lack of staff with IAQ expertise in the department involved was a factor that led to poor IAQ maintenance.	1. The temperatures in each hall did not meet the acceptable compliance range. 2. CO_2 levels exceeded the acceptable standard range, especially during classes when students were in the spaces. 3. The lecture halls operated automatically without manual controls, which failed to maintain a suitable temperature for users. 4. The halls relied on mechanical ventilation systems because the cost of materials and installation was cheaper.	1. The IAQ assessment should highlight significant IAQ factors as stated by the experts. 2. Allocate a budget specifically for maintenance, as experts have emphasised its crucial role in improving IAQ 3. IAQ real monitoring device should be installed in every hall. 4. Using high-efficiency air conditioning systems reduces energy consumption but incurs more cost. Hence, promoting a naturally ventilated system can also reduce energy consumption. 5. Hiring additional staff with relevant expertise to conduct IAQ assessments.

CONCLUSION

Air pollutants in a building may not be immediately visible, but they pose significant long-term health risks to occupants. Numerous air pollutants contribute to severe diseases that affect the human respiratory system (Tran, Park and Lee, 2020). Previous research has shown that IAQ is significant, even if occupants may not see the effects (Mentese et al., 2020). For example, poor IAQ in a building environment significantly impacts occupants' safety, health, comfort (De la Hoz-Torres et al., 2021), work performance and productivity (Fahim et al., 2021) and overall well-being (Abdulaali et al., 2020). Therefore, maintaining an acceptable range of IAQ factors in learning spaces is crucial, despite being challenging due to unavoidable reasons (Asif and Zeeshan, 2023).

Experts have given attention to and classified important aspects to attain the desired IAQ. Strategies and approaches to reduce air pollutants have been taken seriously by developing IAQ sensor technologies and continually monitoring pollutant concentrations. According to experts, it is important to follow the practice code that has been outlined in OSHA 1994 and MS1525:2019 before conducting an assessment. This ensures that all requirements and considerations are met before implementing the actual assessment. Significantly, the aim is to consider all IAQ factors to enhance IAQ in the future. Based on the findings, maintenance is highlighted as the main problem for most buildings in underdeveloped or developing countries because they seldom comply with the standardised IAQ standards.

The study also addressed some recommendations and improvements to enhance the IAQ of learning spaces within higher education buildings. First, the cost of maintenance should be considered in the budget. Although this may not be feasible, it can serve as an encouragement to maintain all the facilities and building spaces in the long run. Additionally, introducing sensory tools can help build users' detection of early signs of air pollutant exposure in the learning space and raise awareness among them about the importance of maintaining a good level of IAQ for their work performance. Another suggestion is to provide special training for staff in the departments involved in maintaining IAQ in higher education buildings. Improving natural ventilation enhances energy efficiency, reduces costs, and improves IAQ.

There is great anticipation for future research that aims to enhance IAQ in higher education buildings. The research should explore additional lecture halls, including those in the Borneo states of Malaysia, to expand the scope of IAQ studies and demonstrate the importance of good IAQ in learning environments. Furthermore, the initiative should involve taking more parameters into account and will require financial support for acquiring the appropriate tools necessary for measuring IAQ effectively in all higher education buildings.

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