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The Stability Performance of Indoor Environmental Quality (IEQ) Parameters: Emphasize the Strategies of Sustainable Comforts in the Learning Environment in a Tropical Climate

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ABSTRACT

Implementing sustainable construction practices in higher educational facilities in Malaysia would enhance the quality of learning activities. Students in higher education predominantly utilize learning areas. The objective of this study is to evaluate indices of indoor environmental quality (IEQ) that prioritise sustainability in educational environments. The major indicators comprised four significant key terms: Indoor Air Quality (IAQ), Thermal Comfort (TC), Visual Comfort (VC), and Acoustic Comfort (AC). The study utilized data from previous studies published between 2021 and 2023 to determine the present issue that emerged inside Malaysian higher educational facilities. This was achieved by a critical assessment of the parameters' findings via fieldwork measurement. This leads to a spectrum that falls within a satisfactory threshold to attain the desired degree of user comfort. The findings demonstrate that students' comfort level is enhanced by their preference for a stable level of IEQ parameters. According to this study, on average standards of IEQ parameters for a sustainable learning environment; temperature (27°C), humidity (40%), air flow (0.30 m/s), illuminate (400lux) and acoustic (40dB). The strategic framework has been recommended to enhance learning environments and act as a reference guideline for future evaluations of indoor environmental quality.

1. Introduction

Concept of green or sustainable buildings can improve individual health and suit the local climate, culture, tradition, and environment. Energy saving, recycling, and resource use are essential to reduce human and animal exposure to harmful compounds over a building's lifecycle. This research often uses "environmentally friendly" "green building," and "sustainable" interchangeably. Some sustainable architecture components, such as energy and water efficiency and carbon neutrality, help to reduce the environmental impact. Indoor Environmental Quality (IEQ) can improve or impede

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individual productivity, comfort, and enjoyment of their surroundings, helping sustainable buildings accomplish environmental and economic goals [1,2].

The significance of Indoor Environmental Quality (IEQ) cannot be overstated, given that a significant proportion of people spend between 80% and 90% of their time indoors. Building occupant health is measured by current adaptation of Indoor Environmental Quality (IEQ). Poor condition of indoor environment quality may decrease on the human performance [3]. IEQ affects occupant health, well-being, and learning [4]. According to Norazman *et al.,* [5], IEQ indicators include air quality, daylight, vistas, acoustics, and occupant control over lighting and thermal comfort. Occasionally, the presence of spaces may need to align with sustainable practices, thus requiring further investigation into the aesthetic features of educational environments regularly [6]. Learning spaces are educational environments where teaching and learning occur. Sound, lighting, and temperature affected respondents' attentiveness and anxiety levels. Examining how these factors affect learning settings is crucial, especially after the pandemic, when students may spend more time in classrooms or lecture halls [7].

Subsequently, the quality of the thermal environment plays a vital role in determining students' satisfaction and productivity in the lecture hall. Two approaches to thermal comfort are rational heat-balance and adaptive. The logical approach uses anticipated mean vote (PMV) and percentage of satisfied (PPD). In contrast, the adaptive method considered culture, climate, social dynamics, psychology, and behaviour. PMV is directly related to comfort temperature in university lecture halls, and PPD is quadratic with absolute temperature difference [8]. Noise impairs course comprehension and learning. Based on researcher by Mogas-Recalde *et al.,* [9], in spacious environments, the auditory environment can affect performance, but spatial acoustic design strategies to regulate sound are untested. Humidity, which denotes the amount of water vapour present in a specific location, is another important factor. Absolute humidity is water vapour density per volume. Humidity affects temperature. Nasir *et al.,* [10] stated that temperatures rise with humidity. Students' spatial sense can be improved by controlling classroom humidity. Additionally, Jin and Peng [11] mentioned that this can boost students' creativity and motivation to learn, increasing learning outcomes.

Furthermore, previous studies focused on the design of the interior and external surroundings of higher education buildings, with minimal attention paid to Indoor Air Quality (IAQ), Acoustic Comfort, Visual Comfort, and Thermal Comfort. This was done since these criteria are also important when assessing higher education facilities' internal and external settings [12]. After the 1986, WHO report found that a large percentage of newly built and remodeled buildings globally were receiving IAQ complaints, IAQ became a big concern in the early 1980s. IAQ was then linked to sick building syndrome (SBS), which was linked to building occupant exposure and time spent there. Building-related illnesses (BRI) induced by airborne pollutants in buildings were also linked to IAQ [2,12].

This study examines indoor environmental quality in Malaysian higher education learning environments. This study's findings don't apply to other structures. The purpose of this is to establish a structure for future technologies that can enhance learning environments and serve as a point of reference for future evaluations to broaden the assessment of indoor environmental quality.

2. Literature Review

2.1 Indoor Environment Quality (IEQ)

Indoor Environmental Quality (IEQ) refers to the overall operation of a building's indoor environment. Energy efficiency has been prioritised over IEQ in building design for a long time, with IEQ considered a cost-benefit when renovating or building new structures [13]. Privacy, accessibility, individual control over indoor air quality, furniture and furnishings, room organisation, cleanliness and maintenance, and spatial area affect IEQ [14]. Like Energy Performance Certificates (EPCs), IEQ should be easily and affordably accessible to building occupants and designers [13]. Thus, IEQ is crucial for any occupied building, including learning spaces.

Indoor Environmental Quality (IEQ) in schools is crucial since it affects student well-being and learning performance. Studies by Kapoor *et al.,* [15] show that low IEQ may affect student attentiveness and performance. Good IEQ in schools improves student health, learning, and productivity. Kapoor *et al.,* [15] argue that optimal IEQ circumstances promote concentration, efficiency, and student and lecturer health. Indoor Air Quality (IAQ), noise interruption, student capacity, indoor illumination, direct sunlight exposure, ventilation, room temperature, cleanliness, indoor humidity, and ergonomics all affect learning environment IEQ. Various aspects that affect student pleasure and well-being in the indoor space determine learning area comfort. IEQ is measured by Thermal Comfort (TC), Visual Comfort (VC), Indoor Air Quality (IAQ), and Acoustic Comfort (AC) [16]. However, not all instruments include all four IEQ components. This may be because the literature largely covers IAQ and thermal comfort, but not visual and audio [17]. The scarcity of resources in Malaysia makes it difficult to find VC and AC references.

Additionally, weather affects IEQ comfort. According to World Bank Climate Change Knowledge Portal [18], one of the causes why Malaysian interiors are uncomfortable. Malaysia has a tropical climate. Additionally, climate change can affect the inside environment by exchanging heat and mass with the outside [19]. Malaysia has a 25.4°C average annual temperature. Refer to Figure 1, minimum seasonal fluctuation is one degree Celsius for the average monthly temperature. The lowest temperature is 24.9°C in January and the highest is 25.9°C in May. April, May, and June are the hottest months.

On average, 3,085.5 millimetres of rainfall annually. From 200 mm in June and July to 350 mm in November and December, monthly precipitation is quite regular. The Southwest Monsoon runs from April to September, and the Northeast Monsoon from October to March. Malaysia has six hours of sunlight every day, with afternoon and evening gloomy circumstances being most likely.

This issue demonstrates how moisture, design, and other environmental factors affect a learning space's IEQ in addition to location, lecture hall setup, and climate change. However, low IEQ can harm students and the building's performance. It could negatively impact health, productivity, absenteeism, the environment, and learning and development. Maintaining proper IEQ is important for the occupant and student well-being, productivity, and societal and economic impacts. Good building design, construction, maintenance, and management can considerably improve IEQ and reduce these negative impacts. To ensure student health, comfort, and productivity, these spaces must respond to these changes through educated design and operating strategies.

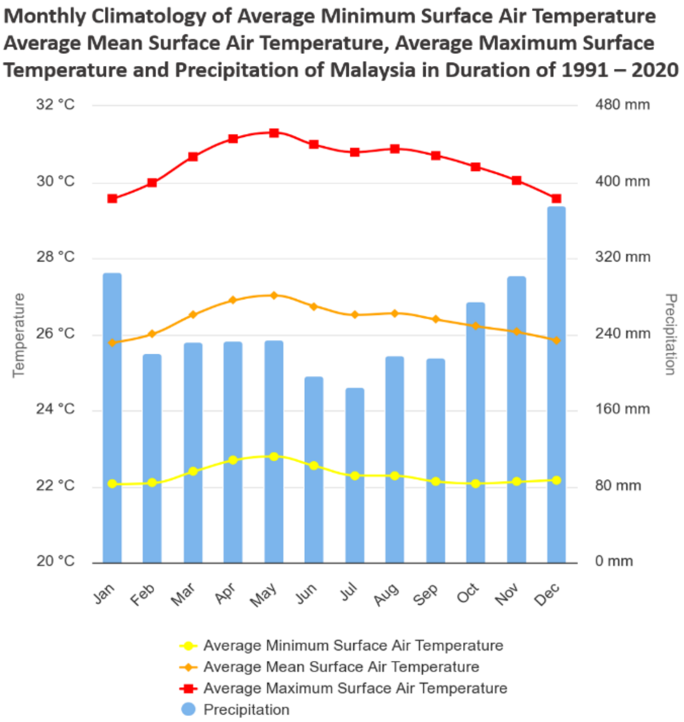

Fig. 1. Monthly climatology of the average minimum surface air temperature average mean surface air temperature, average maximum surface temperature and precipitation of Malaysia in the duration of 1991 – 2020 [18]

2.2 Thermal Comfort (TC)

Thermal Comfort (TC) refers to the mind state of being delighted with the temperature conditions in one's environment. Indoor productivity and contentment depend on an individual's well-being. ISO 7730 defines thermal comfort as a mental state of contentment with thermal circumstances. TC measures a user's satisfaction with an interior thermal environment. Thermal sensation is a building user's thermal environment impression. A building is successful if it meets 80% of its occupants' comfort needs, according to ASHRAE [20].

As stated by Tahsildoost and Zomorodian [12], TC had the greatest impact on IEQ quality satisfaction. TC alone cannot provide an ideal learning environment. Acoustic Comfort, Visual Comfort, and IAQ are important IEQ components. However, TC can be measured in many ways. According to Asadi *et al.,* [16], air temperature (°C), air velocity (m/s), mean radiant temperature (°C), and relative humidity (%) affect IEQ comfort. Indoor air temperature, velocity, and humidity must be measured directly. However, this study will merely measure ambient temperature and air humidity in each lecture hall.

2.3 Indoor Air Quality (IAQ)

Indoor Air Quality (IAQ) measures pollutant levels and thermal conditions in a building, which may negatively impact human health, comfort, and productivity [21]. Mujeebu [22] states that IAQ, which depends on airborne pollutants, determines indoor environment quality. Low IAQ is associated with Sick Building Syndrome (SBS) and occupant comfort and health. Asadi *et al.,* [16] stated that ASHRAE Standard 62.1 requires a ventilation rate that makes 80% of occupants comfortable.

Air quality is essential to a building's occupants. IAQ in learning environments affects lecture and student health, comfort, and performance. Maintaining air quality for occupants inside the learning space is also vital. Human activities, environmental conditions, building systems, and pollutant sources affect IAQ [23]. Asadi *et al.,* [16] stated that ventilation type, temperature and humidity levels, and chemical and biological contaminants affect IAQ and SBS symptoms. Low IAQ causes SBS, which harms students' health and productivity. Azlan *et al.,* [23] found a substantial correlation between SBS and IAQ symptoms. Thus, indoor air pollution has become a concern alongside energy efficiency and sustainability. Mujeebu [22] remarked that building energy efficiency and sustainability should emphasise occupant health, comfort, and productivity.

2.4 Acoustic Comfort (AC)

Acoustic comfort (AC) influences social welfare, efficiency, and perception in an area. Acoustic comfort is acoustic satisfaction [24]. Kapoor *et al.,* [15] defined AC as preventing people from outside noise and improving acoustics for conversation. Sound environment quality depends on several physical factors, including sound and space. AC increases learning space acoustics for communication and learning. To avoid disruptions and promote student comprehension, sound volume and persistence are regulated. Digital instruction is common in higher education. These strategies use auditory elements that alter listeners' perception and physiology. Improper acoustics can impair learning, performance, attention, listener fatigue, and communication.

In previous studies by Ramprasad and Subbaiyan [25], loud background noise negatively affected students' academic performance. Noise pollution can induce deafness with its loud sounds. This form of excessive loudness is sometimes called psychological noise. Mechanical sources and interior partitions and walls can cause indoor noise. Kapoor *et al.,* [15] have noted that students and teachers struggle to ignore background noise. Mujeebu [22] stated that the shape and size of a space, the production of sound inside or outside the space, the transmission of sound through the air, the impact of noise, and the acoustic properties (absorption, transmission, and reflection) of the surfaces inside the space can all affect its acoustic comfort.

Thus, American National Standards Institute (ANSI/ASA) [26] guideline indicated 35 dB background noise and 0.60-second reverberation for learning environments. Improved acoustics lessen discomfort. Comfortable learning environments reduce auditory fatigue and improve student attention. Educational environment design relies on it and affects learning.

3. Methodology

Numerous approaches are used in research methods for Indoor Environmental Quality (IEQ) studies to understand better and enhance the building conditions that impact occupants' comfort, productivity, and health [27]. The study used six lecture halls in the Malaysia Higher Educational Institute Building in the Northern Region of Peninsular Malaysia as case studies to develop a framework for future learning space enhancement tools and a reference for future reviews to broaden indoor environment quality analysis. Thus, this study's approach has three primary stages to achieve its goal

i. Systematic Review
ii. Field Measurement
iii. Comparative Study

However, every approach should be emphasised since they are interconnected to obtain the study's results and lead to the discussions. Prior research helps identify the subject topic and issue during systematic review. It also suggests research challenges and goals and specifies research parameters. The subsequent phase is field measurement, which entails a survey of the parameter's IEQ reading. The next step is to evaluate the parameter readings for the six lecture halls to comprehend the differences and similarities between the entities. Following is the study's methodology flow (Figure 2).

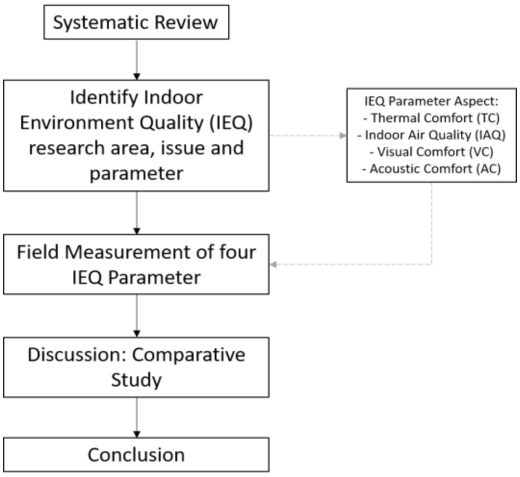

Fig. 2. Research flow of this study

3.1 Systematic Review

Systematic literature reviews aim to gather, evaluate, and synthesis existing research and publications regarding a topic. A systematic literature review strives to provide thorough information about subjects; therefore, this research employed these methods to gather, and analyze data to meet its goals. Systematic literature reviews on Indoor Environmental Quality (IEQ) research involve multiple organized steps to obtain and critically assess pertinent research. According to Mewomo *et al.,* [27], an Emerald Insight study emphasizes the importance of reviewing the latest research to identify if particular interior factors affect productivity and health. Therefore, this research will include two systematic review phases.

Assessment of research gaps within a year will be the first step. The second step will review learning space IEQ research. In the first step, data from 2021–2023 research was used to determine the current issue in Malaysian higher education buildings. This was achieved by thoroughly evaluating the parameters' results. This aimed to identify Malaysia's IEQ problem in educational facilities.

The approach involved analyzing a few books, journals, and conference proceedings from Science Direct, Taylor, Google Scholar, Web of Science, and others. IEQ impacts productivity and health directly and indirectly. Since most individuals spend most of their time indoors, IEQ elements that affect occupant comfort are crucial. Thermal comfort, indoor air quality, visual comfort, and acoustic comfort are defined in the literature and used as keywords in the evaluation.

These are described by glare, sound pressure, luminance distribution, and airflow. Table 1 summarizes Malaysia's constructing IEQ Parameter Weighting. As mentioned, this investigation would only analyze the educational institution. Indoor air quality is greatly affected by these heat conditions. IEQ evaluation emphasizes sustainable learning space practice regardless of heat, humidity, air flow rate, or sound pressure.

Table 1
IEQ parameter weighting in previous studies: thermal, air quality, visual and acoustic comfort

No.	Building Types	Reference	Thermal Comfort	Air Quality	Visual Comfort	Acoustic Comfort
1	Educational	Weng *et al.,* [28]	0.36	0.14	0.31	0.19
2	Office	Abdou *et al.,* [29]	0.38	0.19	0.43	0.11
3	Workplace	Asojo *et al.,* [30]	0.27	0.23	0.27	0.12
4	Office	Bourikas *et al.,* [31]	0.295	0.232	0.287	0.186
5	Educational	Mujan *et al.,* [32]	0.285	0.35	0.195	0.17
6	Office	Zhang *et al.,* [33]	0.243	0.21	0.131	0.146
7	Educational	Pittana *et al.,* [34]	0.27	0.08	0.14	0.19

3.2 Field Measurement

All six lecture halls were measured in the second part of the study. Field assessments of IEQ at educational institutions measure learning and health-related environmental factors. Surveying occupant well-being, productivity, and comfort in a building or collection of buildings is field IEQ measurement. Thermal Comfort, Indoor Air Quality, Visual Comfort, and Acoustic Comfort are these metrics. Objective experiments measured indoor environmental characteristics with varied equipment. Table 2 lists measurement tools.

Table 2
Basic information of instruments in IEQ measurements

IEQ Aspect	Parameter	Instrument	Unit	Range	Accuracy
Thermal Comfort	Temperature	Extech Thermo Hygro Anemometer (3-in-1)	°C	23°C – 28 °C	± 3%
	Humidity	Onset HOBO MX1102A Wireless Carbon Dioxide/Temperature/RH Data Logger	%	30% - 70%	± 2% from 20% to 80% RH
Indoor Air Quality	Air Flow Rate	Air Flow LCA 6000	m/s	0.15 m/s – 0.50 m/s	less than or equal to +/-1%
Acoustic Comfort	Sound pressure level	Extech Sound Pressure Level Meter (407732)	dB	30 dB – 40 dB	± 1.5 dB
Visual Comfort	Illuminance	Hanna Lux Meter	lux	300 lux – 500 lux	± 6% of the reading ± 2 digits

The six lecture halls' thermal comfort is measured by temperature and humidity. These field data collection methods record temperature and humidity in each of the six lecture halls for 11 hours on lecture days, from 8 a.m. to 7 p.m. The lecture hall's highest average radiant temperature, mean, median, standard deviation, and variance were obtained from hourly data.

Temperature was measured using the Extech Thermo Hygro Anemometer (3-in-1). Temperature is measured in Celsius. ASHRAE 2010 and DOSH Malaysia standards suggest 23–28°C and 23–26°C, respectively. The multipurpose Extech Thermo-Hygro-Anemometer combines thermometer, hygrometer, and anemometer functions. HVAC professionals, environmental health and safety specialists, and industrial facilities that monitor environmental conditions use this equipment. The instrument accurately measures air velocity from 80 to 5910 ft/min with ±3% precision. A built-in thermistor measures temperature from 32°F to 122°F.

The Onset HOBO MX1102A Wireless Carbon Dioxide/Temperature/RH Data Logger measures humidity. Humidity is expressed as a percentage. The DOSH Malaysia standards allow 40% to 70% relative humidity (RH), yet the ASHRAE 2010 standards allow 30% to 65%. The Onset HOBO MX1102A wireless data recorder measures CO2, temperature, and RH. It specifically targets interior air quality research, environmental monitoring, greenhouse management, and HVAC system inspections. The device's relative humidity measurement accuracy is typically ±2% from 20% to 80%. At 25°C (77°F), the maximum deviation, including hysteresis, is ±4.5%. This tool features 0.01% relative humidity resolution and a 1-minute reaction time to 90% humidity.

Airflow rate, measured in meters per second, is investigated for IAQ. Airflow is measured with the Air Flow LCA 6000. ASHRAE 2010 allows airflow from 0.15 m/s to 0.25 m/s, while DOSH Malaysia encourages 0.15 m/s to 0.50 m/s. The Air Flow LCA 6000 may be an anemometer or air flow meter. These devices measure airflow in a room or system, such as HVAC ductwork. The Air Flow LCA 6000, is a precise anemometer for air velocity between 0.25 m/s and 30 m/s. Its low measurement error of 1 digit and precision of +/-1% are outstanding.

The next IEQ aspect is acoustic comfort the assessment of sound pressure level (SPL) in a lecture hall, measured in decibels (dB). Sound pressure is measured with the Extech Sound Pressure Level Meter (407732).

The ANSI sound pressure range is 30 – 35 dB, while ENLC and Malaysia stipulate 30–40 dB. Following ANSI and IEC 651 Type 2 standards, the Extech Sound Pressure Level Meter 407732 precisely measures sound pressure levels in various environments. It's perfect for workplace noise assessments, fire alarms, speaker systems, and noise enforcement. Low (35 to 100 dB) and High (65 to 130 dB) sound levels can be measured by the tool. The 1.5 dB sound level precision fulfils Type 2 device standards. The device measures sound with a 0.5 (12.7mm) condenser microphone with fast and slow response times. Sound levels can be measured accurately using the 0.1 dB SPL Meter.

Final aspect of IEQ, is visual comfort, which is assessed by measuring the illuminance of the lecture hall. Illuminance, measured in lux, was measured using the Hanna Lux Meter. IESNA, UAE recommends 200-400 lux, while ENLC, Malaysia recommends 300-500 lux. This device can measure light from extremely low to tens of thousands of lux. Additionally, it can measure light from extremely low levels to tens of thousands of lux. Measurements at 25°C/77°F are accurate within ±6% of the reading, with ±2 digits.

3.3 Comparative Study

Conducting a comparative study constitutes the final stage of this research process. Comparative study research compares topics, fields, or occurrences. Comparative analysis is often used to find similarities and differences between examples or to reveal underlying patterns that may not be obvious in a single case. This research method analyses phenomena to find their similarities and differences [35]. Comparative Indoor Environment Quality (IEQ) analysis examines how different indoor environment factors affect health, satisfaction, and efficiency in different environments. IEQ includes interior air quality, thermal comfort, lighting, and acoustics. The author will assess and compare the IEQ reading performance of the six lecture halls in this phase.

To assist a full comparative investigation, the author has set comparison parameters. These parameters affect the interpretation of each IEQ component in each lecture hall, including building design, size, and capacity. Additionally, knowing the pros and cons of each lecture hall setting is beneficial. Comparative analysis indirectly encourages debates about creating a productive learning environment for students, taking into account the total IEQ score. This analysis helps establish sustainable learning space design and construction practices in higher education buildings to improve IEQ.

In conclusion, this phase provides a holistic understanding of each building's IEQ performance and the lessons that may be learned from the most successful environments. The Higher Education Institutions management team can make informed decisions to improve student comfort during learning by analysing diverse surroundings and their effects on IEQ. Thus, it improves student well-being, contentment, and efficiency, promoting good learning and community growth.

4. Results

The section on Indoor Environmental Quality (IEQ) in specific building contexts presents this study's findings. This assessment was done during field measurements in all six lecture halls for this study. Figure 3, Table 3 and Table 4 address lecture hall design, layout, size, and seating capacity. To help readers understand the lecture hall's arrangement, this data was given. Each parameter was analysed separately to determine the needed average maximum value. Every parameter reading will be evaluated based on its Indoor Environmental Quality (IEQ) aspect.

Lecture Hall A Lecture Hall B Lecture Hall C

Lecture Hall D Lecture Hall E Lecture Hall F

Fig. 3. The inside setting of six selected lecture hall

Table 3
The lecture hall capacity and dimensions

Lecture Hall	Capacity	Dimension		
		Length (m)	Width (m)	Length x Width (m^2)
A	300	19.8	22.0	435.6
B	150	11.3	10.1	121.3
C	250	220.0	12.0	264.0
D	200	25.5	11.5	293.3
E	220	15.0	12.0	180.0
F	400	28.2	18.8	530.2

Table 4
The building design and orientation of six selected lecture halls

Lecture Hall	Orientation (℃)				Building Design
	West of North	East of North	West of South	East of South	
A	305	25	201	118	Passive Design
B	295	45	220	125	Active Design
C	315	28	190	110	Passive Design
D	280	22	225	105	Passive Design
E	320	25	215	135	Passive Design
F	315	52	205	122	Active Design

4.1 Thermal Comfort

Temperature and humidity are critical components in determining the ambient conditions of a learning environment. Students and lecturers' thermal comfort is essential as it affects attention, productivity, and well-being. The air temperature and average radiant temperature of a lecture hall should be comfortable for the majority of occupants, which are students and lecturers. The Department of Health and Safety (DOSH) in Malaysia recommends a temperature range of 23℃ to 26℃ for best comfort. DOSH Malaysia recommends 40%–70% humidity. Abdulaali *et al.,* [14], Kapoor *et al.,* [15], and Azlan *et al.,* [23] found a correlation between environmental factors and learning efficacy, hence these ranges were chosen. Humidity regulates the body's cooling processes and temperature establishes thermal sensibility, affecting heat homeostasis and comfort.

Table 6 indicates the ambient temperature, whereas Table 6 shows the lecture hall humidity. According to Table 7, only lecture hall F fulfils the DOSH Standard temperature range with a temperature of 23.2℃. The lowest recorded temperature in hall D is 20.9 ℃, below the range that's allowed. The highest recorded temperature in hall A (27.6℃) exceeds the DOSH Malaysia recommended range. As shown in Table 7, ASHRAE 2010 and ISO 7730 consider the temperature range of 27℃ to 28℃ acceptable. Both standards suggest a permitted range of 23℃ to 28℃. Table 5 shows that only halls C and D have values below DOSH Malaysia and ASHRAE 2010 limits. The temperature was comfortable in halls A, B, E, and F.

Lecture halls A (60.5%), C (48.5%), D (47.6%), E (59.1%), and F (68.9%) had humidity levels within the DOSH Malaysia Standard, with the highest average value. Table 8 shows that ASHRAE 2010 and ISO 7730 encourage 30% to 65% humidity. This range merely involves halls A, C, D, and E. Meanwhile A and B halls have high temperatures and humidity, as seen in Table 5 and Table 6. In contrast, halls C and D have lower temperatures and humidity. However, only hall F displays temperature and humidity readings within the acceptable range set by DOSH Malaysia.

Table 5
The temperature reading of each lecture hall

Lecture Hall	Temperature (℃)												Mean	Median	Standard Deviation	Variance	Average Max Value
	8.00 AM	9.00 AM	10.00 AM	11.00 AM	12.00 PM	1.00 PM	2.00 PM	3.00 PM	4.00 PM	5.00 PM	6.00 PM	7.00 PM					
A	29.9	31.4	30.6	27.5	26.6	26.2	26.5	26.8	27.4	27.5	26.0	25.5	27.6	27.1	1.93	3.71	27.6
B	25.3	28.2	28.8	29.2	29.1	29.4	30.5	30.0	29.7	24.6	22.6	22.2	27.4	28.9	2.97	8.80	27.4
C	24.9	23.1	23.3	22.7	20.2	21.3	22.0	21.2	20.8	21.1	21.0	21.0	21.9	21.2	1.35	1.82	21.9
D	26.2	25.3	20.9	19.6	19.7	19.7	20.0	19.8	19.6	20.5	20.0	19.5	20.9	19.9	2.30	5.27	20.9
E	25.3	29.1	29.6	29.8	29.8	29.9	30.0	30.0	28.7	21.0	20.7	20.3	27.0	29.3	4.04	16.30	27.0
F	21.4	22	23.5	20.1	24.7	23	22.8	24.1	25	26.2	24.5	21.5	28.0	23.3	1.77	3.13	23.2

Table 6
The relative humidity reading of each lecture hall

Lecture Hall	Relative Humidity (%)												Mean	Median	Standard Deviation	Variance	Average Max Value
	8.00 AM	9.00 AM	10.00 AM	11.00 AM	12.00 PM	1.00 PM	2.00 PM	3.00 PM	4.00 PM	5.00 PM	6.00 PM	7.00 PM					
A	66.0	68.3	65.5	55.4	57.6	58.6	59.0	58.5	60.0	59.5	59.0	58.5	60.5	59.0	3.90	15.21	60.5
B	81.0	74.1	73.9	74.8	75.2	75.6	74.7	72.7	73.6	57.0	63.3	65.4	71.8	74.0	6.56	43.01	71.8
C	57.8	44.9	47.7	44.9	45.1	43.4	44.3	45.8	53.2	52.5	51.5	50.5	48.5	46.7	4.53	20.54	48.5
D	51.3	43.9	43.5	46.0	47.4	48.2	47.8	48.7	49.2	48.5	49.5	47.5	47.6	48.0	2.25	5.05	47.6
E	69.6	65.2	64.2	63.9	63.9	63.6	63.6	30.7	49.8	58.5	61.9	55.0	59.1	63.6	10.35	107.21	59.1
F	68.9	63.2	67.4	68.1	68.3	74.1	71.2	70.5	69.7	69.5	68.3	67.1	68.9	68.6	2.61	6.84	68.9

Table 7
The acceptable range of temperature and relative humidity

	Acceptable Range of Temperature	Acceptable Range of Relative Humidity
ASHRAE 2010 ISO 7730	23℃ to 28 ℃	30 % - 60 %
DOSH Malaysia	23℃ to 26 ℃	40 % - 70 %

Perspiration evaporation regulates body temperature during high-temperature lectures. When humidity is high, evaporation is less efficient, making it harder for the body to regulate temperature. However, evaporation from lower humidity can make hot weather more comfortable. Plus, it might cause dry skin and respiratory issues. Elevated humidity increases the feeling of coldness by allowing moist air to transfer heat, whereas low humidity can minimise chilliness but cause dryness and uneasiness.

Human breathing, perspiration, and plants may contribute humidity to in a lecture hall. These sources may not be enough to increase humidity, especially in a large auditorium with many people. According to Abdulaali *et al.,* [14], the hall temperature is affected by the outside temperature. The Malaysian Meteorological Department classifies its climate as equatorial or tropical maritime, with high temperatures and humidity year-round [36]. Compared to usual climates, Abdulaali *et al.,* [14] found that humid environments raise temperatures. Malaysia's climate is also defined by high humidity, severe temperatures, and abundant rainfall, according to the Malaysian Meteorological Department (MMD). A full day with bright skies is rare in Malaysia, especially in dry weather.

Temperature and humidity sensors are placed throughout classrooms to maintain these conditions. Measurements must be precise. Excess humidity can cause air moisture to adhere and mould to grow, while low humidity can cause respiratory irritation and discomfort. High temperatures can cause drowsiness and diminish concentration, while low temperatures can cause restlessness and hinder learning, according to Abdulaali *et al.,* [14], the indoor temperature and Sick Building Syndrome (SBS) influence depend on the inside temperature. High temperatures greatly increase SBS prevalence. Abdulaali *et al.,* [14] indicated that higher temperatures increase allergenic chemicals and lower resident satisfaction and productivity.

Maintaining a comfortable lecture hall temperature and relative humidity creates an excellent learning environment. Facility managers can adjust HVAC systems in real-time by monitoring temperature and humidity. This makes learning simpler and reduces energy by reducing system processes. Educational institutions can improve their learning environments by detecting and controlling these environmental factors. This meticulous care to detail shows a commitment to building a top-notch learning environment that puts student and lecturer welfare and academic success initially.

4.2 Indoor Air Quality (IAQ)

The airflow rate measures the volume of air that passes through a system in a given time. Larsen *et al.,* [13], state that IAQ assessment considers ventilation, building materials, and outdoor air quality. Ventilation is the main cause of IAQ [37]. Lecture hall HVAC systems depend on ventilation rates for comfort, air quality, and energy economy. According to ASHRAE Standard 62.1, 80% of occupants are comfortable with adequate ventilation. As stated in Table 8, ASHRAE 2010 and ISO 7730 authorise air flow rates between 0.15 m/s and 0.25 m/s. In contrast to the Malaysian Standard (Table 8), the range was 0.15 m/s to 0.50 m/s, potentially due to the climate. Figure 4 shows that lecture halls C, D, E, and F should have ventilation rates between 0.15 m/s and 0.40 m/s. At 0.40 m/s, lecture hall D has the maximum ventilation rate. Adding humidity and temperature balancing readings to the spot increases thermal comfort and IEQ. Figure 3 shows that the number of students (capacity) and hall dimensions influence air quality by determining ventilation circulation. Tahsildoost and Zomorodian [12], Kapoor *et al.,* [15], Petty [21], Mewomo *et al.,* [27], and Temprano *et al.,* [37] argue that secure and effective air ventilation systems improve IAQ, provide optimal settings for instructors and students, and reduce negative health and welfare implications. High airflow rates improve comfort by maintaining room temperature. In contrast, lecture halls A and B have airflow measurements below 0.15 m/s, with hall A having the lowest at 0.12 m/s. Thus, insufficient ventilation can cause stifling and discomfort, which can impair focus, productivity, and learning. Students may be distracted and uncomfortable if specific places get too warm or chilly. Kapoor *et al.,* [15] stated an impoverished indoor air quality reduces productivity and causes physiological imbalances such as weariness, headaches, lethargy, and mental depletion. According to Kapoor *et al.,* [15], low IAQ can cause SBS, which can lead to building-related illness (BRI) and affect one's health.

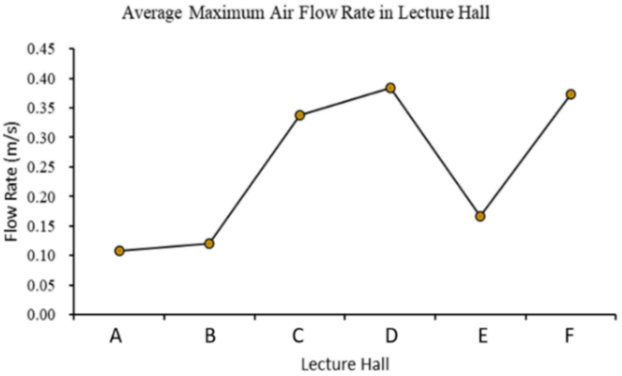

Fig. 4. The average maximum air flow rate in the lecture hall

Table 8
The acceptable range of airflow rate

	Acceptable Range of Air Flow Rate
ASHRAE 2010	0.15 to 0.25 m/s
ISO 7730	
DOSH Malaysia	0.15 to 0.50 m/s

Low IAQ may impact students and lecturers. Due to increased occupancy and inadequate ventilation, Temprano *et al.,* [37] found that learning spaces often have inadequate indoor air quality. Class absences and illnesses are common results of poor ventilation and IAQ. As Petty [21] notes, inadequate ventilation can also increase the rate of asthma and SBS among occupants. A low airflow rate in a learning setting may improve Acoustic Comfort by reducing fan and air handling unit energy consumption and HVAC noise.

This shows that low and high airflow rates necessitate equilibrium. HVAC systems are often designed to operate within a certain airflow rate range to improve energy efficiency and comfort. In contrast, precise air flow rate regulation optimises industrial operations for output quality and cost efficiency. The appropriate air flow rate for environmental and health reasons ensures enough oxygenation, clean air, and minimal turbulence and energy consumption. Effective airflow control and design increases lecturer and student health, comfort, and productivity in the classroom.

4.3 Visual Comfort

Light, including lamps and daylight, stimulates human vision. Learning needs appropriate lighting to be appealing and effective. Good lighting improves many human activities with low glare, enough brightness, and white light [38]. As stated in Table 9, UAE's Illuminating Engineering Society of North America (IESNA) recommends 200–400 lux. Malaysian ENLC specifies 300–500 lux of illumination. The Technical Committee on Lamps and Related Equipment of the Electrical and Electronic Standards Committee recommends 300-500 lux 9 classroom illuminance (SS531:2006). A building operator employs this standard to maintain proper illumination. Figure 5 exhibits 100-470 lux lecture hall illumination.

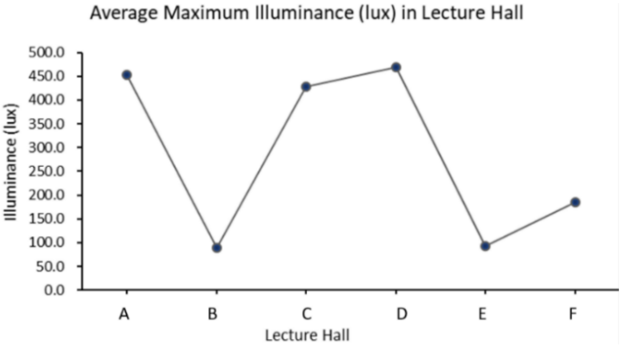

Fig. 5. The average maximum illuminance in the lecture hall

Table 9
The acceptable range of illuminance

	Acceptable Range of Illuminance
IESNA, UAE	200 – 400 lux
ENLC, Malaysia	300 – 500 lux

The highest reading is 470 lux in lecture hall D, followed by A at 450 and C at 430. Lecture hall F had 150 lux, which was not appropriate, whereas lecture halls B and E had 100 lux. According to field measurement data, all lecture halls need artificial lighting since they have no windows. These days, the majority of building occupants select artificial lighting since it plays a significant role in the IEQ evaluation [39]. According to Seman *et al.,* [39], learning space must have 300–500 lux artificial lighting. This illuminance value demonstrates light distribution and surface contact, as mention by Adnan *et al.,* [38], In addition to strategic sitting, computer screens and teaching surfaces can reduce window glare, enhancing student and teacher vision. Bright, reflective surfaces prevent dark spots. Hue, room function, lighting source, and lighting layout can distinguish the same space.

Learning spaces often have ineffective and unneeded lighting, according to Seman *et al.,* [39]. Inefficient fluorescent lighting causes headaches and eyesight disorders. Minor over lighting can cause eye stress, migraines, fatigue, eye discomfort, and repeated headaches, affecting occupant health and performance. Classroom illumination has been diminished as a result. For visual comfort in indoor learning settings, Adnan *et al.,* [38] recommended lighting that matches the area's hue, spaciousness, and arrangement. Lighting quality impacts interior surroundings, especially learning spaces. Ariffin *et al.,* [40] found that good lighting influences students' mood, behaviour, and learning. Academic building interior illumination enhances student concentration, learning efficiency, and productivity.

4.4 Acoustic Comfort (AC)

Acoustic comfort and learning are affected by SPL, which quantifies a learning space's loudness. Students with hearing or auditory difficulties in processing may have trouble hearing and interpreting high SPL speech. Speaking clearly and concentrating in class should not be affected by SPL. Sound pressure affects the learning environment and student efficiency. Students may have trouble processing information due to reverberation and sound pressure [41]. When noise exceeds decibel limitations, higher SPLs might lower learning efficiency. Noise hinders concentration and information processing, which are crucial for learning [42,43]. In Table 10, according to ANSI [26], sound pressure should not exceed 30–35 dB. ENLC Malaysia sets 30 – 40 dB. In Figure 6, only lecture hall E has SPL within ENLC's 39 dB range. Lecture hall C holds the highest reading at 52 dB, followed by hall F at 50 dB, D at 47 dB, A at 45dB, and B at 42 dB. Acoustics in lecture halls may be affected by high SPL. Mujeebu [22] believes learning room volume, interior surface, audio-visual equipment, reverberation, sound dispersion, and absorption can affect these high records [44].

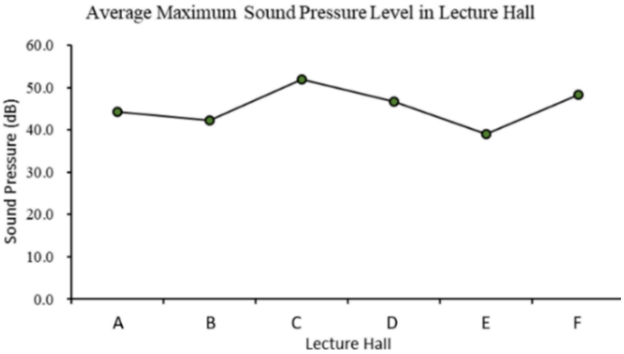

Fig. 6. The average maximum sound pressure level in the lecture hall

Table 10
The acceptable range of sound pressure

	Acceptable Range of Sound Pressure
ANSI	30 – 35 dB
ENLC Malaysia	30 – 40 dB

*America National Standard Criteria for Evaluating Room Noise (ANSI)
*Environmental Noise Limits and Control (ENLC) Malaysia

Lecture halls A and F are larger, thus sound waves have more room to travel before being absorbed, causing intense reverberation that can increase SPL and create echoes and altered hearing. Student conversations, HVAC, and movement generate noise in larger spaces, according to Dias *et al.,* [44], mood and IEQ may be affected by SPL. SPL in lecture rooms affects students' auditory perception and focus, SPL impacts focus, mood, and noise in learning contexts [45]. Dias *et al.,* [44] emphasized that SPL management is important for a healthy learning environment as it may affect both students and lecturers.

Small lecture halls like B and E have lower SPL. Students sit close to the speaker or lecturer in tiny halls. Small gaps make speakers louder, reducing SPL by eliminating background amplification. It also minimises hall noise and improves learning space acoustics. Acoustic comfort enhancements go beyond noise reduction to optimise learning and student experience. Acoustics are important to learning, hence learning room design and management should take it into account [46]. Acoustic comfort increases student and lecturer learning by matching acoustics to each learning space's function [47]. In conclusion, SPL impacts educational learning efficiency, focus, mood, and environmental perception. The best student learning and engagement demand excellent SPL management in learning spaces.

4.5 Enhancing Learning Environments in Higher Education Buildings through Sustainable Practices

Explaining Indoor Environmental Quality (IEQ) measurements in terms of thermal comfort, IAQ, visual comfort, and acoustic comfort requires understanding and articulating how these factors influence the indoor environment. Malaysia's unique climate, culture, and infrastructure must be considered when designing learning environments with better IEQ. In Malaysia's tropical climate, excessive heat and humidity make indoor comfort and health difficult. This recommendation led to sustainable IEQ practices in lecture halls by preserving or upgrading the indoor environment to reduce environmental impact and increase health, comfort, and productivity. These practices reduce environmental impact by promoting energy efficiency, resource conservation, and indoor health. Adapted framework for improving IEQ in Malaysian learning environments.

In addition to Table 11 shows the suggested strategies for enhancing learning environments in higher education buildings through sustainable practices, the following strategies can be used to improve IEQ in any learning space

i. Use HVAC systems that adjust to different room sizes, orientations, and occupancy levels. This may feature VAV and zonal temperature control.
ii. Utilise natural and artificial lighting solutions that can be modified based on time of day, season, and room occupancy. Consider sensor-equipped smart lighting.
iii. Use sound-absorbing materials, acoustic ceiling tiles, and carpets in bigger areas to reduce noise levels. The design should also address student capacity-related noise.
iv. Implement a Building Management System (BMS) or integrated control system to monitor and regulate environmental conditions.
v. Prioritise energy efficiency in heating, lighting, and humidification to minimise environmental effects and expenses.
vi. Monitor air quality, temperature, humidity, and light levels with sensors for optimal conditions.
vii. Seek sustainability certifications like LEED or BREEAM to confirm your sustainable practices.
viii. By addressing these factors together, a larger learning space can be made more comfortable and contribute to the institution's sustainability goals by promoting a healthier environment for all occupants and reducing the building's ecological footprint, making learning and teaching more enjoyable.

Table 11
The suggested strategies for enhancing learning environments in higher education buildings through sustainable practices

Indoor Environmental Quality (IEQ) parameter		Suggestion strategies to improve IEQ comfort in the learning space through sustainable practices
Temperature	High Temperature	Large-scale learning space: - Enhance insulation and use reflecting materials on roofs and exterior walls to lower heat gain. - Use indirect cooling methods to lower temperatures naturally, such as shading devices, green roofs, or more plants around the building. Small-scale learning space: - Install an effective air conditioning system to lower temperature. - Enhance wall and ceiling insulation to lower heat gain.

		- Block direct sunlight and reduce heat with blinds or drapes.
	Low Temperature	Large-scale learning space: - Insulate large windows and outside walls to avoid heat loss. - Flooring with carpet adds insulation, warming the space. Small-scale learning space: - Consider installing an effective heating system, such as central or portable heaters. - Use thermal insulation to retain warmth. - Layer window treatments to decrease heat loss.
	Average temperature	- Install an HVAC system to maintain a pleasant temperature of 23°C to 26°C. - Use programmable thermostats to conserve energy and adjust temperature. - Insulate and seal the space to prevent draughts and heat loss.
Relative Humidity	High Humidity	Large-scale learning space: - Use dehumidifiers to reduce air moisture levels. - Ensure appropriate ventilation for air circulation, reducing humidity levels naturally. - Ensure the air conditioning system fits the space, as it reduces humidity and cools air. - Use humidity-absorbing indoor plants to naturally manage humidity levels. Small-scale learning space: - Use dehumidifiers to reduce air moisture. - Ensure proper ventilation to allow damp air to exit and dry air to enter. Use mechanical ventilation systems or open windows if outdoor air is less humid. - Fix any causes of high humidity, such as leaks or condensation.
	Low Humidity	Large-scale learning space: - For higher humidity levels in bigger locations, a commercial-grade humidification system may be necessary. - Interior plants add humidity and beautify. Small-scale learning space: - Add moisture to the air with a humidifier to curb uncomfortable and harmful dryness. - Indoor plants aid in naturally increasing humidity levels.
	Average Humidity	- Consider using dehumidifiers for high humidity levels and humidifiers for low humidity levels.
Indoor Air Quality (IAQ)	High IAQ	Large-scale learning space: - Regularly ventilate the place with fresh air, either naturally or mechanically. - Maintaining HVAC is necessary for air quality. Small-scale learning space: - Maintain fresh air circulation with proper ventilation, such as an HVAC system with a thorough air filter. - To decrease dust and allergens, regularly clean and maintain the space. - Consider HEPA-filtered air purifiers for fine particle removal.
	Low IAQ	Large-scale learning space: - Boost fresh air flow with efficient ventilation systems (HVAC) to distribute fresh air evenly. - Consider installing air purifiers in locations with poor ventilation. - Regularly maintain and clean HVAC systems and air filters to enhance IAQ. Small-scale learning space: - Enhance ventilation to clean out indoor contaminants and introduce fresh outdoor air. - Keep HVAC systems maintained and filters updated regularly to maintain optimal air quality.
	Average IAQ	- To circulate fresh air, combine natural ventilation (windows) and mechanical systems (HVAC).

Visual Comfort (VC)	High Visual Comfort	Large-scale learning space: - Control excessive natural light with blinds, shades, or drapes. - Adjust the intensity or position of artificial lighting and use dimmable lights for high illuminance issues. Small-scale learning space: - Use dimmable artificial lighting. - Control natural light intensity using curtains or shades to avoid glare. - Place lights strategically to avoid shadows and guarantee even lighting.
	Low Visual Comfort	Large-scale learning space: - To compensate for limited natural light, increase artificial lighting. LEDs with good colour rendering and energy efficiency are recommended. - Set up adjustable lighting systems for various activities and times of day. - Implement light-coloured, reflective materials on walls and ceilings to increase existing lighting. Small-scale learning space: - Increase the amount of artificial lights. Energy-efficient LED lights are bright and clear. - Desk lamps or directed overhead lights can brighten dark environments. - Select bulbs with appropriate colour temperature for learning. Bright, neutral white light is suggested for schools at 4000K to 5000K.
	Average Visual Comfort	- Combine natural and artificial lights. LEDs offer adjustable brightness and are energy-efficient. For less glare and shadows, spread lights evenly.
Acoustic Comfort	High Acoustic Comfort	Large-scale learning space: - Controlling reverberation and echo is essential in large areas. Install sound-absorbing ceiling tiles, wall panels, or carpets. - To reduce exterior noise, install double-glazed windows and robust doors for better sound insulation. - Reduce internal noise by identifying sources like HVAC systems and implementing solutions like acoustic enclosures or vibration isolators. Small-scale learning space: - Ensure sound equipment is tuned for louder activity. - Use sound-absorbing materials like acoustic panels or foam to reduce echo and reverberation.
	Low Acoustic Comfort	Large-scale learning space: - Reduce ambient noise by using sound-absorbing materials such as acoustic panels, suspended ceiling tiles, and carpets to maintain a low SPL. - Use sound-absorbing soft furnishings like drapes and upholstered furniture. - When using PA systems or speakers for announcements, ensure correct calibration to maintain low SPL. - Implementing a "quiet culture" in the learning area can benefit students and staff by encouraging reduced noise levels. Small-scale learning space: - Use sound-absorbing items like rugs, drapes, and soft furnishings for quieter activities.
	Average Acoustic Comfort	- Echoes and dampness should be avoided. The correct blend of sound-absorbing and reflecting materials may accomplish this. - Maintain the average SPL by controlling HVAC or external noise.

5. Conclusion

Following extensive IEQ parameter study for all six lecture halls, the following conclusions were drawn. The average temperature was 27°C, which exceeds the DOSH Standard for thermal comfort in Malaysia's climate. However, the humidity level was continuously above 45%, indicating a slightly humid climate that balanced thermal comfort inside the hall, which can improve student comfort during lectures. For IAQ, the average airflow rate was 0.30 m/s above (DOSH Malaysia). It was observed to be at its peak for a small hall with a huge capacity. The ventilation system may be underperforming when the hall is full. The average 400 lux illumination was sufficient for visual tasks in a learning setting. Some spots at the hall's back might need more light. Finally, SPL was over 40 dB, which is insufficient for learning. High SPL implies poor lecture hall acoustics, maximising external noise and echoes.

In general, the lecture hall is comfortable even though the IEQ are somehow more or less. Sustainable practices improve IEQ in the building's learning spaces. Concerns centre on air quality and the ventilation system's functionality during full occupancy. Managing humidity will also improve comfort. Although the building has good air quality, thermal comfort, and lighting, it could improve with better control systems, natural ventilation, and daylight optimisation. Optimising adaptability and responsiveness improve occupant comfort and supports sustainability goals. Dehumidifiers and ventilation system upgrades are suggested. These enhancements can make the lecture hall more conducive to learning and teaching sessions.

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