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Mixed-Method Assessment of Indoor Environmental Quality in an Educational Multipurpose Hall: A Case Study of Dewan Jubli Perak, Politeknik Ungku Omar

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ABSTRACT

Indoor Environmental Quality (IEQ) is important for occupant comfort, health and concentration in educational buildings, especially in multipurpose halls used for examinations and formal activities. However, these spaces are often assessed based on complaints rather than systematic measurement. This study evaluated the IEQ performance of Dewan Jubli Perak, Politeknik Ungku Omar, using a selected-parameter mixed-method approach. Seven parameters were assessed: air temperature, relative humidity, air velocity, carbon dioxide (CO_2), particulate matter (PM_{10} and $PM_{2.5}$) and illuminance. Continuous measurements were conducted from 7 to 10 May 2026 at a representative occupied zone, while illuminance was measured using a 10 × 10 grid consisting of 100 points. Occupant perception was obtained through a 15-item questionnaire involving 40 hall users. The measured data were benchmarked against ICOP-IAQ 2010, ASHRAE Standard 55-2020, MS 1525 and the New Malaysia Ambient Air Quality Standard. The results showed that air temperature ranged from 22.51 to 26.12 °C and was generally close to the recommended range, while air velocity remained acceptable between 0.172 and 0.200 m/s. PM_{10} ranged from 3.76 to 13.52 µg/m³, and $PM_{2.5}$ was recorded at 15.65 µg/m³, indicating acceptable particulate levels. CO_2 was mostly below the 1000 ppm ceiling, although short exceedances above 1100 ppm occurred during peak occupancy. The main deficiencies were relative humidity and illuminance. Relative humidity reached 73.67%, exceeding the 70% upper limit, while average illuminance was only 77 lux, approximately 61.5% below the 200 lux minimum requirement. Questionnaire responses supported the measured findings, particularly regarding lighting discomfort, breathing difficulty during full occupancy and drowsiness during prolonged use. Overall, the hall showed acceptable performance for several air-quality indicators but did not fully comply with the selected IEQ benchmarks. Priority improvements should include LED lighting upgrades, better humidity control, occupancy-based ventilation monitoring and periodic IEQ reassessment using multiple sampling points and longer monitoring periods.

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1. Introduction

Indoor Environmental Quality (IEQ) refers to the combined indoor conditions that influence occupant comfort, health, concentration and satisfaction. These conditions include indoor air quality, thermal environment, relative humidity, air movement and lighting. In educational facilities, IEQ is particularly important because students, staff and other building users often remain indoors for extended periods during teaching, examinations, meetings and formal institutional activities. Previous studies have shown that classroom air quality and ventilation are closely related to attention and learning performance, where lower Carbon Dioxide (CO_2) concentration and sufficient fresh-air supply contribute to better task performance [1], [2]. In addition, broader assessments of higher-education buildings have reported that air quality, thermal conditions, acoustics and lighting collectively influence learning quality, occupant wellbeing and short-term academic achievement [3], [5], [7].

Among educational spaces, multipurpose halls present a unique IEQ challenge. Unlike ordinary classrooms, these halls are designed for flexible use and may accommodate different activities such as examinations, ceremonies, assemblies and institutional events. As a result, occupant density, internal heat load, ventilation demand and lighting requirements may vary significantly depending on the function of the space. During examinations, occupants may remain seated for several hours with limited movement, making thermal comfort, air freshness and adequate illuminance especially important for maintaining concentration and reducing discomfort. Reviews of classroom IEQ indicators consistently identify air temperature, relative humidity, CO_2, particulate matter and illuminance as key measurable parameters for assessing indoor conditions [4], [6]. These parameters therefore provide a suitable basis for a selected-parameter IEQ screening assessment.

Poor indoor conditions may contribute to discomfort and complaints such as headache, fatigue, eye irritation, drowsiness and reduced concentration. These symptoms are commonly associated with poor indoor air quality or Sick Building Syndrome; however, they cannot be accurately attributed to a single cause through observation or user complaints alone. Objective measurement is required to distinguish whether the main source of discomfort is related to humidity, air movement, particulate concentration, ventilation performance or lighting quality. In Malaysia, the Industry Code of Practice on Indoor Air Quality (ICOP-IAQ) 2010 issued by the Department of Occupational Safety and Health (DOSH) provides acceptable limits for indoor physical parameters and contaminants, including the use of CO_2 as an indicator of ventilation performance [13]. ASHRAE Standard 55-2020 further supports the assessment of thermal environmental conditions for human occupancy [14], while MS 1525 provides recommended illuminance requirements for non-residential and assembly spaces [15].

Dewan Jubli Perak at Politeknik Ungku Omar is a multipurpose hall that is used extensively for examinations, ceremonies and formal activities. Despite its frequent use and high occupancy during major events, its actual indoor environmental condition has not been systematically assessed using objective measurement. Without measured evidence, building management may find it difficult to identify which IEQ parameters are deficient, and which corrective actions should be prioritised. General complaints from users are useful as preliminary indicators, but they cannot clearly determine whether discomfort is caused by poor ventilation, high humidity, inadequate air movement, particulate matter or insufficient lighting. Therefore, the main problem addressed in this study is the lack of measured evidence on whether Dewan Jubli Perak provides a suitable indoor environment for long-duration occupancy and which specific IEQ parameters require improvement.

Accordingly, this study aims to: (i) assess the indoor environmental quality of Dewan Jubli Perak using seven selected parameters, namely air temperature, relative humidity, air velocity, CO_2, PM_{10},

$PM_{2.5}$ and illuminance, by combining instrument measurements with occupant feedback; and (ii) identify the problematic IEQ parameters and propose practical improvement measures for building management. This study is deliberately framed as a selected-parameter IEQ screening assessment rather than a comprehensive IEQ audit. Its contribution lies in providing a practical, low-cost and transferable assessment approach for educational multipurpose halls in tropical climates, where high humidity, variable occupancy and ageing lighting systems are common but often under-reported issues [9], [17]..

2. Methodology

This study adopted a mixed-method design by integrating quantitative instrument measurement with qualitative occupant feedback. The purpose of this approach was to obtain both measured IEQ performance and user-based perception of comfort inside Dewan Jubli Perak. Instrument readings alone may not fully represent occupant experience because discomfort can be influenced by localised variations in humidity, air movement, temperature or lighting. Therefore, questionnaire feedback was used to support and interpret the measured data.

The assessment was conducted in four main stages: walkthrough inspection, quantitative measurement, questionnaire survey and data analysis. The measured parameters were benchmarked against relevant standards and guidelines, namely the Industry Code of Practice on Indoor Air Quality 2010 (ICOP-IAQ 2010), ASHRAE Standard 55-2020, MS 1525 and the New Malaysia Ambient Air Quality Standard (NMAAQS) [13]–[16]. Since the assessment involved selected measurable parameters and a limited number of monitoring points, this study is treated as an IEQ screening assessment rather than a full compliance audit.

2.1 Study Area

The study was conducted at Dewan Jubli Perak, Politeknik Ungku Omar, which is a multipurpose hall with an approximate floor area of 900 m². The hall is about 30 m × 30 m with an estimated height of 8 m and is commonly used for examinations, ceremonies, assemblies and institutional events. The space is mechanically air-conditioned and can accommodate variable occupancy depending on the activity, with an estimated maximum occupancy of approximately 400 users during major events.

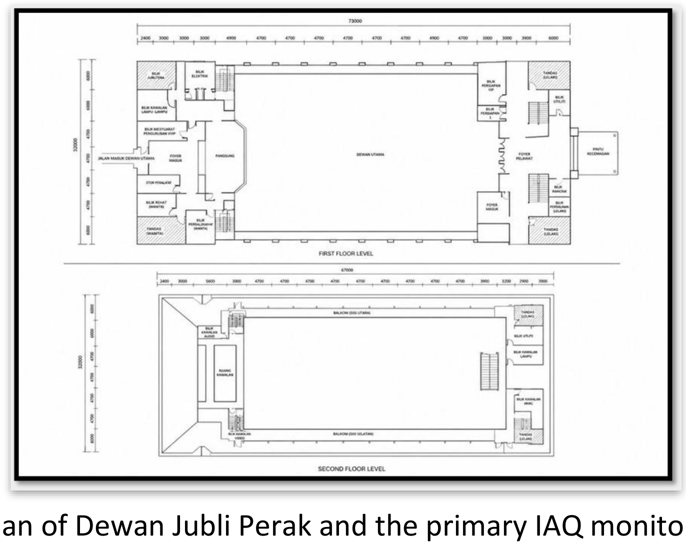

Fig. 1 Floor plan of Dewan Jubli Perak and the primary IAQ monitoring point

The large floor area, high ceiling, variable occupant density and tropical outdoor conditions make the hall a challenging space for maintaining stable indoor environmental conditions. During long-duration examinations or formal events, the hall may experience increased internal heat, moisture generation and ventilation demand. These conditions may affect occupant comfort, especially when users remain seated for long periods. The hall layout and the primary indoor air quality monitoring point are shown in Fig. 1.

2.2 Selected Parameters and Benchmarking

Seven IEQ parameters were selected for this study: air temperature, relative humidity, air velocity, carbon dioxide (CO_2), particulate matter with aerodynamic diameters of 10 µm and 2.5 µm or less (PM_{10} and $PM_{2.5}$), and illuminance. These parameters were selected because they are directly related to thermal comfort, ventilation performance, indoor air cleanliness and visual comfort. They are also measurable using available portable instruments within the study period.

Other IEQ parameters, such as acoustics, volatile organic compounds, formaldehyde, ozone, carbon monoxide, biological contaminants and mean radiant temperature, were excluded due to instrument availability and project scope. Therefore, the results should be interpreted as a selected-parameter IEQ screening assessment and not as a comprehensive IEQ audit. Each selected parameter was compared with an appropriate benchmark, as summarised in Table 1.

Table 1 Selected IEQ parameters, units and benchmark references

Parameter	Unit	Benchmark / limit	Reference
Air temperature	°C	23–26	ICOP-IAQ 2010
Relative humidity	%	40–70	ICOP-IAQ 2010
Air velocity	m/s	0.15–0.50	ICOP-IAQ 2010 / ASHRAE 55
Carbon dioxide (CO_2)	ppm	1000 ceiling	ICOP-IAQ 2010
PM_{10}	µg/m³	100, 24-h	NMAAQS 2020
$PM_{2.5}$	µg/m³	35, 24-h	NMAAQS 2020
Illuminance	lux	200 minimum	MS 1525

2.3 Instrumentation and Sampling

Air temperature, relative humidity, CO_2, PM_{10} and $PM_{2.5}$ were measured using a direct-reading IAQ monitoring device. Air velocity was measured using an anemometer, while illuminance was measured using a digital lux meter. The instruments used in this study are listed in Table 2. For final submission, the instrument model, measurement range, accuracy, resolution and calibration status should be added if available to improve the technical reliability of the methodology.

For IAQ and thermal parameters, a primary monitoring point was selected within the main occupied zone of the hall. The monitoring point was positioned away from direct supply diffusers, walls, corners and other obstructions to reduce localised measurement bias. Measurements were taken at approximately seated occupant breathing height to represent the condition experienced by hall users during examinations or seated events. Continuous IAQ measurements were collected under normal operating conditions from 7 to 10 May 2026.

Since Dewan Jubli Perak has a large floor area, the use of one primary IAQ monitoring point is a limitation. ICOP-IAQ 2010 indicates that larger spaces may require multiple sampling points to fully represent spatial variation. Therefore, the IAQ results in this study are interpreted as screening-level findings rather than full-hall compliance evidence.

Illuminance was measured using a more detailed spatial approach because lighting levels can vary significantly depending on luminaire position and distance from light sources. The hall floor area was divided into a 10 × 10 grid, with each grid cell measuring approximately 3 m × 3 m. This produced 100 illuminance measurement points across the hall. Measurements were taken at working-plane height, and the minimum, maximum, average and distribution of illuminance were determined. The illuminance measurement grid is shown in Fig. 2.

Table 2 Instrumentation used for quantitative measurement

Instrument	Parameter(s) measured	Unit
IAQ monitoring device	Air temperature	°C
IAQ monitoring device	Relative humidity	%
IAQ monitoring device	CO_2	ppm
IAQ monitoring device	PM_{10}	µg/m³
IAQ monitoring device	$PM_{2.5}$	µg/m³
Anemometer	Air velocity	m/s
Digital lux meter	Illuminance	lux

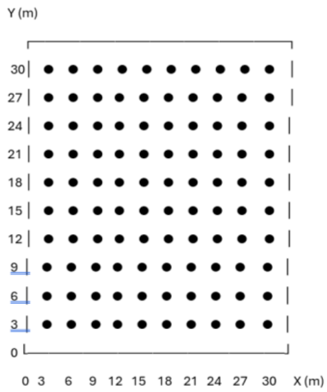

Fig. 2 Illuminance measurement grid (10 × 10 arrangement, 100 points)

2.4 Questionnaire Survey

Occupant perception was collected using a 15-item questionnaire that covered air quality, temperature, humidity, air movement, lighting and overall comfort. A total of 40 respondents who had experience using the hall participated in the survey. This number represented approximately 10% of the estimated 400 users who may occupy the hall during major activities.

The questionnaire responses were analysed using frequency and percentage analysis. The purpose of the questionnaire was not to replace instrument measurement but to provide supporting evidence on how occupants perceived the indoor environment. The measured data and survey responses were then compared to identify whether user feedback agreed with the instrument findings.

In this study, a parameter was considered a high-priority issue when it exceeded the relevant benchmark and was also supported by occupant complaints. When a parameter complied with the benchmark but still received complaints, the result was discussed as a possible localised or perception-based comfort issue.

2.5 Data Analysis

The quantitative data were analysed using descriptive statistics, including minimum, maximum and mean values for each measured parameter. Where applicable, temporal trends were also examined to identify changes during the monitoring period. Each measured parameter was compared with the relevant benchmark listed in Table 1.

For CO_2, peak values were considered important because ICOP-IAQ 2010 defines 1000 ppm as a ceiling limit rather than only an average value. Therefore, short-duration exceedances were retained in the interpretation because they may indicate insufficient ventilation during periods of high occupancy. For illuminance, the 100-point grid measurements were used to determine the average lighting level and spatial distribution across the hall.

The final interpretation was based on triangulation between benchmark comparison, descriptive measurement results and occupant feedback. Parameters that exceeded the benchmark and were supported by user complaints were identified as dominant deficiencies. These findings were then used to develop a prioritised improvement plan for Dewan Jubli Perak.

3. Results and Discussion

3.1 Walkthrough Inspection

The walkthrough inspection confirmed that Dewan Jubli Perak is a large, mechanically conditioned multipurpose hall whose indoor comfort depends strongly on the performance of the ventilation, cooling and lighting systems. The hall is frequently used for long-duration examinations, ceremonies and institutional activities, which may involve different occupancy levels and internal heat loads. During high-occupancy events, the increase in occupant density is expected to raise carbon dioxide (CO_2), heat and moisture generation inside the hall.

The inspection also indicated that housekeeping practices, air-conditioning operation and filter condition may influence particulate concentration and perceived air quality. In addition, the large floor area and high ceiling may affect the distribution of air movement and lighting across the occupied zone. These observations provide useful context for interpreting the measured IEQ parameters presented in the following subsections.

3.2 Quantitative Measurement Results

Table 3 summarises the measured IEQ parameters and compares them with the selected benchmark values. Overall, most air-quality and physical parameters were within or close to acceptable limits. Air temperature, air velocity, PM_{10} and $PM_{2.5}$ were generally acceptable based on the adopted references. CO_2 was mostly below the 1000 ppm ceiling limit, although short exceedances above 1100 ppm were observed during peak occupancy. The main deficiencies identified were relative humidity and illuminance. Relative humidity partly exceeded the recommended upper limit, while illuminance was substantially below the minimum lighting requirement.

The results indicate that Dewan Jubli Perak achieved acceptable performance for several measured IEQ indicators during the monitoring period. However, the exceedance of relative humidity and the very low illuminance level show that the hall is not fully compliant with the selected IEQ benchmarks. Therefore, the results should be interpreted as a selected-parameter screening assessment, particularly because the IAQ data were collected from a single primary monitoring point.

Table 3 Summary of measured IEQ parameters and benchmark comparison

Parameter	Measured Result	Benchmark	Status
Air temperature	22.51–26.12 °C	23–26 °C	Mostly acceptable
Relative humidity	64.97–73.67%	40–70%	Partly exceeded
Air velocity	0.172–0.200 m/s	0.15–0.50 m/s	Acceptable
CO_2	Mostly < 1000 ppm; peaks > 1100 ppm	1000 ppm ceiling	Mostly acceptable
PM_{10}	3.76–13.52 µg/m³	100 µg/m³, 24-h	Acceptable
$PM_{2.5}$	15.65 µg/m³	35 µg/m³, 24-h	Acceptable
Illuminance	77 lux, average	200 lux, minimum	Not acceptable

3.3 Thermal Conditions: Temperature and Air Velocity

Air temperature ranged from 22.51 °C to 26.12 °C, which was generally close to the 23–26 °C range recommended by ICOP-IAQ 2010 [13]. The minimum value was slightly below the lower limit, while the maximum value slightly exceeded the upper limit. This indicates that the air-conditioning system was generally able to maintain near-acceptable temperature conditions, although minor fluctuations occurred during the monitoring period. These fluctuations may be associated with changes in occupancy, cooling system operation and the large internal volume of the hall.

Air velocity ranged from 0.172 to 0.200 m/s, which was within the recommended range of 0.15–0.50 m/s. However, the measured values were close to the lower limit, suggesting that air movement inside the occupied zone was relatively low. Although this condition still complied with the benchmark, low air velocity may contribute to a perception of stagnant air, especially during long-duration occupancy or high-density events.

The temperature and air velocity results suggest that thermal conditions were generally acceptable. However, thermal comfort should not be judged based on temperature alone. Relative humidity also plays an important role in perceived comfort, particularly in tropical climates. Therefore, the temperature, air velocity and relative humidity results should be interpreted together, consistent with the thermal comfort approach described in ASHRAE Standard 55-2020 [14].

3.4 Relative Humidity

Relative humidity ranged from 64.97% to 73.67%, with the maximum value exceeding the 70% upper limit recommended by ICOP-IAQ 2010 [13]. Although the exceedance was moderate, relative humidity above 70% may reduce perceived comfort and may increase the possibility of condensation or microbial growth if the condition occurs repeatedly over time. This is particularly important in tropical educational buildings, where outdoor humidity is naturally high and latent load can increase during occupied periods.

The relative humidity trend is shown in Fig. 3. The observed pattern suggests that moisture control was less stable than temperature control. While the cooling system was generally able to maintain air temperature close to the acceptable range, it was less effective in keeping relative humidity consistently below the recommended upper limit. This condition may be related to insufficient dehumidification, low sensible cooling load, high outdoor moisture infiltration, door opening during events, or maintenance-related issues such as cooling coil and condensate drainage performance.

Therefore, relative humidity should be considered a genuine IEQ deficiency in Dewan Jubli Perak. Improvement should focus not only on cooling capacity but also on moisture removal and air-conditioning system maintenance.

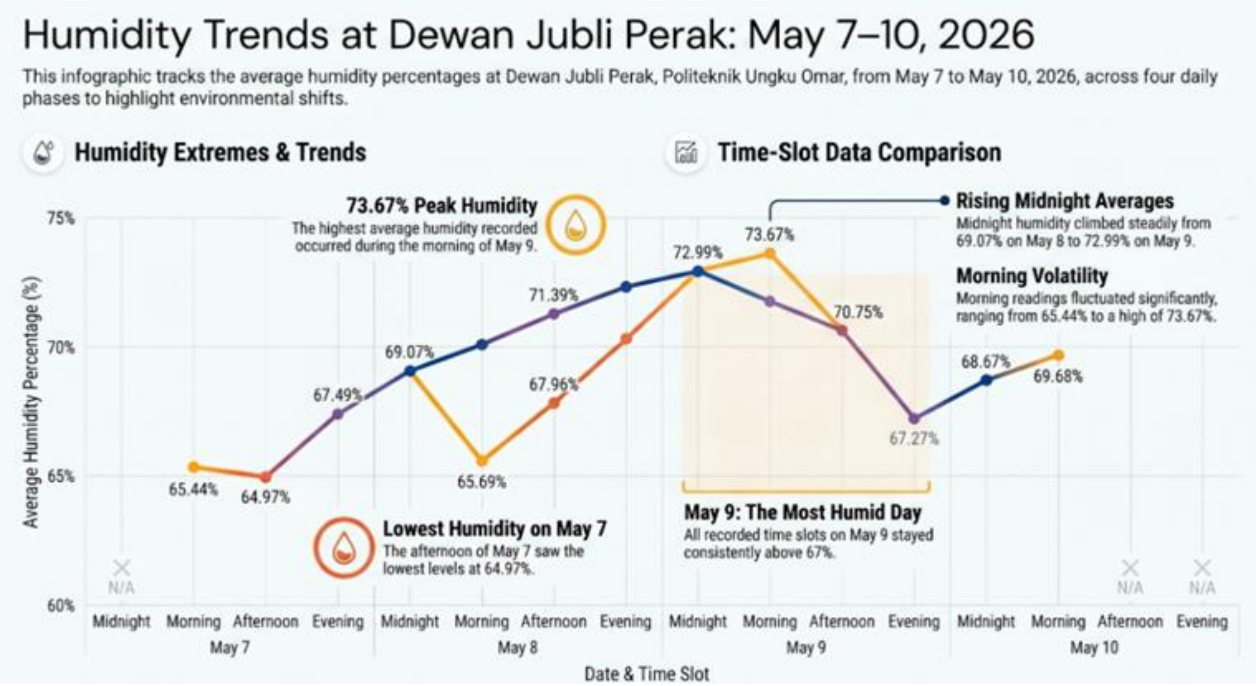

Fig. 3 Relative humidity trends in Dewan Jubli Perak, 7–10 May 2026

3.5 Carbon Dioxide and Particulate Matter

CO_2 concentration remained below the 1000 ppm ceiling for most of the monitoring period, indicating that the hall generally received adequate ventilation under normal operating conditions. However, short peaks above 1100 ppm were observed during higher-occupancy intervals, particularly during periods when the hall was more heavily used. Since ICOP-IAQ 2010 treats 1000 ppm as a ceiling limit, these temporary exceedances should not be ignored [13]. Although CO_2 was not the most critical issue in this study, the peaks suggest that fresh-air supply may not fully respond to changes in occupancy.

This finding indicates the need for ventilation monitoring before and during crowded activities. For long-duration examinations and formal events, pre-ventilation or occupancy-based ventilation control may help reduce CO_2 accumulation and maintain better perceived air freshness.

Particulate matter levels were within acceptable limits during the measurement period. PM_{10} ranged from 3.76 to 13.52 µg/m³, which was well below the 100 µg/m³ reference limit. $PM_{2.5}$ was recorded at 15.65 µg/m³, which was also below the 35 µg/m³ reference limit under NMAAQS [16]. These results indicate that particulate pollution was not a major concern during the monitoring period. The low particulate concentrations may reflect effective filtration, limited indoor dust sources and acceptable housekeeping practices.

However, particulate levels may vary depending on outdoor air quality, haze conditions, cleaning activities, event preparation and filter maintenance. Therefore, routine filter cleaning and housekeeping should be maintained to ensure that particulate concentrations remain within acceptable limits.

3.6 Illuminance

Illuminance was the most critical deficiency identified in this study. Based on the 100-point measurement grid, the average illuminance was only 77 lux, with measured values ranging from 66 to 89 lux. This is substantially below the 200-lux minimum requirement specified by MS 1525 for relevant non-residential and assembly spaces [15]. The average illuminance was approximately 61.5% lower than the required level, indicating that the hall lighting system did not provide sufficient brightness for sustained visual tasks.

The illuminance distribution across the measurement points is shown in Fig. 4, while the comparison between measured illuminance and the Malaysian lighting requirement is shown in Fig. 5. The relatively narrow range of 66–89 lux indicates that the lighting distribution was fairly uniform, but the overall level was too low. This suggests that the main issue is insufficient total luminous output rather than poor luminaire spacing alone.

For an examination hall, inadequate illuminance may contribute to visual discomfort, eye strain, fatigue and reduced concentration during reading and writing activities. Previous research has also linked classroom lighting parameters with visual fatigue [11]. Therefore, lighting improvement should be treated as the highest-priority intervention in Dewan Jubli Perak. Retrofitting the existing system with higher-efficacy LED luminaires is recommended because LED lighting can improve illuminance while supporting energy-efficient building operation [12]. After any lighting upgrade, the illuminance level should be re-measured using the same 100-point grid to confirm compliance with the minimum requirement.

100 Data Lux – Purata 77 LUX

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P1	66	69	71	73	75	76	78	79	81	84
P2	68	70	72	74	76	77	78	80	82	85
P3	69	71	73	75	76	78	79	81	83	86
P4	70	72	74	75	77	78	79	82	84	87
P5	71	72	74	76	77	78	80	82	85	88
P6	72	73	75	76	77	78	80	83	85	89
P7	72	73	75	76	78	79	80	83	86	89
P8	71	72	74	76	77	78	79	82	85	88
P9	69	71	73	75	76	77	78	80	83	87
P10	66	69	71	73	75	76	77	79	81	83
Jumlah (Sum)	7,700									
Purata (Average)	77									

Fig. 4 Illuminance distribution across 100 measurement points, average 77 lux

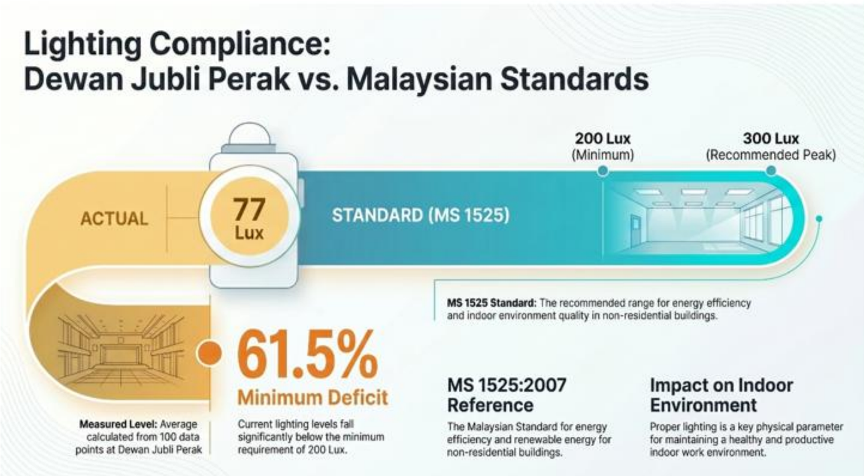

Fig. 5 Measured illuminance versus Malaysian lighting requirements, MS 1525

3.7 Occupant Feedback

The questionnaire results generally supported the instrument measurements, as shown in Fig. 6. Occupant feedback indicated that most users were generally satisfied with air quality and thermal comfort, with approximately 90% reporting overall satisfaction and about 78% indicating that the temperature was comfortable. This is consistent with the measured temperature and air velocity results, which were generally within or close to the recommended ranges.

However, several comfort-related concerns were reported during prolonged or high-occupancy use. Approximately 35% of respondents reported breathing difficulty when the hall was full, while 22% reported drowsiness during extended stays. These responses are consistent with the observed temporary CO_2 peaks and elevated relative humidity. Although CO_2 and humidity were not continuously outside the benchmark limits, the occupant responses suggest that comfort may deteriorate during crowded events or long-duration occupancy.

Lighting feedback also supported the measured illuminance deficiency. Although some respondents perceived the brightness as acceptable for general use, 44.9% reported uneven lighting distribution and noticeably darker areas. This perception agrees with the low measured average illuminance and confirms that visual comfort should be prioritised. The combination of objective measurement and occupant feedback strengthens the conclusion that the lighting system requires improvement.

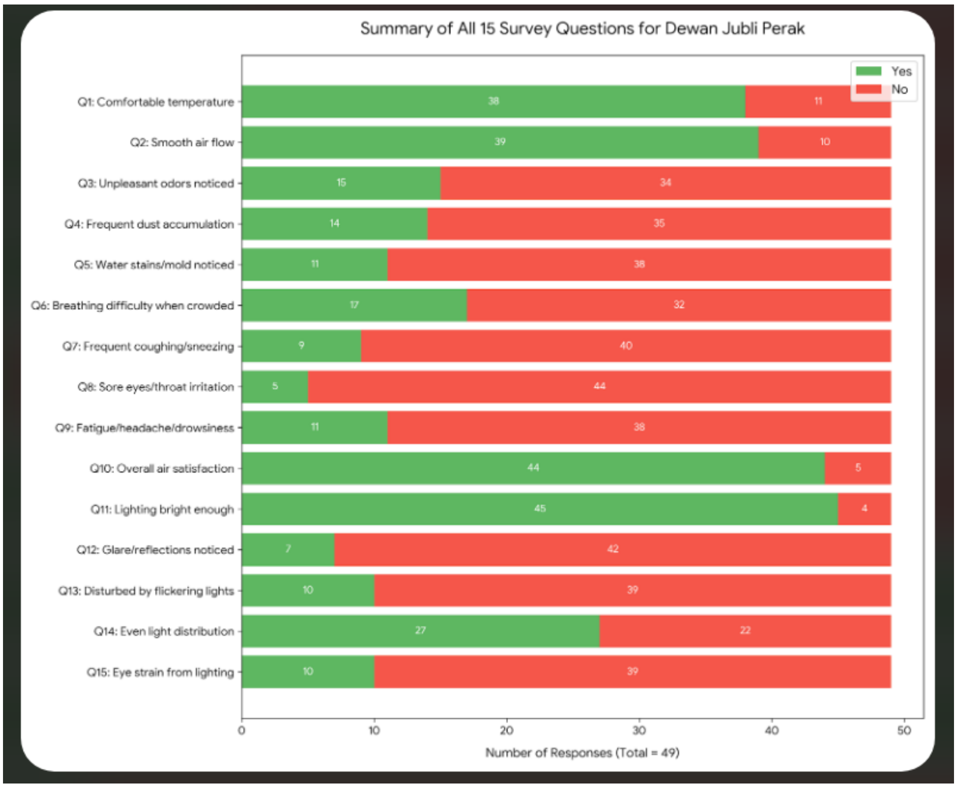

Fig. 6 Summary of occupant responses across the 15 questionnaire items

3.8 Overall IEQ Performance

Overall, Dewan Jubli Perak demonstrated acceptable performance for air temperature, air velocity and particulate matter during the monitoring period. CO_2 control was also generally acceptable, although short exceedances occurred during high-occupancy conditions. The two main deficiencies were elevated relative humidity and insufficient illuminance. Among these, illuminance was the most critical issue because the measured average value was far below the minimum requirement.

The mixed-method approach provided consistent evidence. Parameters that exceeded or approached benchmark limits were also reflected in occupant feedback, particularly in relation to lighting discomfort, breathing difficulty and drowsiness during prolonged use. This agreement between measured data and user perception increases confidence in the screening-level findings, although the limitation of a single IAQ sampling point should be recognised.

Based on the results, the recommended improvement hierarchy is lighting upgrade as the highest priority, followed by humidity control, ventilation monitoring during high-occupancy events and routine particulate control. The prioritised improvement plan is summarised in Table 4.

Table 4 Prioritised improvement plan for Dewan Jubli Perak

Issue	Recommended Action	Target	Priority
Low illuminance	Retrofit high-efficacy LED luminaires; review layout; re-survey using the 100-point grid	≥ 200 lux average	Very high
High humidity	Service cooling coils and condensate drainage; balance the air-conditioning system; add dehumidification if required	RH 40–70%	High
CO_2 peaks	Pre-cool or pre-ventilate before events; monitor CO_2 during high occupancy	< 1000 ppm	Moderate
Particulate control	Maintain housekeeping and filter-cleaning schedule	< NMAAQS limits	Low
Ongoing assurance	Conduct periodic IEQ monitoring with occupant feedback	≥ 2 sessions/year	Low

4. Conclusion

This study assessed the Indoor Environmental Quality (IEQ) of Dewan Jubli Perak, Politeknik Ungku Omar, using a selected-parameter mixed-method approach. Seven parameters were evaluated, namely air temperature, relative humidity, air velocity, carbon dioxide (CO_2), particulate matter (PM_{10} and $PM_{2.5}$) and illuminance. The measured data were benchmarked against ICOP-IAQ 2010, ASHRAE Standard 55-2020, MS 1525 and NMAAQS, while occupant perception was used to support the interpretation of the measured results.

The findings showed that several IEQ parameters were within or close to the selected benchmark limits during the monitoring period. Air temperature ranged from 22.51 to 26.12 °C, while air velocity remained between 0.172 and 0.200 m/s. PM_{10} ranged from 3.76 to 13.52 µg/m³, and $PM_{2.5}$ was recorded at 15.65 µg/m³, indicating acceptable particulate levels. CO_2 concentration was generally below the 1000 ppm ceiling limit, although short exceedances above 1100 ppm occurred during high-occupancy periods. These results suggest that the hall generally performed acceptably for temperature, air movement and particulate matter under the measured conditions.

However, two important deficiencies were identified. Relative humidity reached 73.67%, exceeding the 70% upper limit recommended by ICOP-IAQ 2010. This indicates that moisture control should be improved, particularly during prolonged or high-occupancy use. Illuminance was the most critical deficiency, with an average value of only 77 lux, approximately 61.5% below the 200 lux minimum requirement specified by MS 1525. The low illuminance level is a major concern for a hall used for examinations, where sustained reading and writing activities require adequate visual comfort.

The questionnaire results supported the instrument findings. Occupant feedback indicated concerns related to breathing difficulty during full occupancy, drowsiness during prolonged use and uneven or insufficient lighting. The agreement between measured data and occupant perception strengthens the conclusion that lighting improvement, humidity control and ventilation monitoring should be prioritised.

Overall, Dewan Jubli Perak demonstrated acceptable performance for several selected air-quality indicators but did not fully comply with the adopted IEQ benchmarks. The recommended improvement hierarchy is to retrofit high-efficacy LED luminaires, improve air-conditioning moisture removal, monitor CO_2 during high-occupancy events, maintain filter cleaning and housekeeping, and conduct periodic IEQ reassessment. Since this study was limited by a single IAQ monitoring point, a short monitoring period and a modest respondent sample, future work should include multiple sampling locations, longer monitoring duration, occupancy profiling, additional IEQ parameters such as acoustics and gaseous pollutants, and a larger respondent group to improve representativeness.

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References

[1] Pulimeno M, Piscitelli P, Colazzo S, Colao A, Miani A. Indoor air quality at school and students' performance: Recommendations of the UNESCO Chair on Health Education and Sustainable Development & the Italian Society of Environmental Medicine (SIMA). Health Promot Perspect. 2020 Jul 12;10(3):169-174. https://pubmed.ncbi.nlm.nih.gov/32802752/

[2] P. Wargocki, J. A. Porras-Salazar, S. Contreras-Espinoza, and W. Bahnfleth, "The relationships between classroom air quality and children's performance in school," Build. Environ., vol. 173, p. 106749, 2020. https://doi.org/10.1016/j.buildenv.2020.106749

[3] Brink HW, Loomans MGLC, Mobach MP, Kort HSM. Classrooms' indoor environmental conditions affect the academic achievement of students and teachers in higher education: A systematic literature review. Indoor Air. 2021 Mar;31(2):405-425. https://doi.org/10.1111/ina.12745

[4] Tran, M.T.; Wei, W.; Dassonville, C.; Martinsons, C.; Ducruet, P.; Mandin, C.; Héquet, V.; Wargocki, P. Review of Parameters Measured to Characterize Classrooms' Indoor Environmental Quality. Buildings 2023, 13, 433. https://doi.org/10.3390/buildings13020433

[5] Toyinbo, O. (2023). Indoor Environmental Quality, Pupils' Health, and Academic Performance: A Literature Review. Buildings, 13(9), 2172. https://doi.org/10.3390/buildings13092172

[6] S. Sadrizadeh et al., "Indoor air quality and health in schools: A critical review for developing the roadmap for the future school environment," J. Build. Eng., vol. 57, p. 104908, 2022. https://doi.org/10.1016/j.jobe.2022.104908

[7] Grassie, D., Milczewska, K., Renneboog, S., Scuderi, F., & Dimitroulopoulou, S. (2025). Impact of Indoor Air Quality, Including Thermal Conditions, in Educational Buildings on Health, Wellbeing,

and Performance: A Scoping Review. Environments, 12(8), 261. https://doi.org/10.3390/environments12080261

[8] Jia, L.-R., Han, J., Chen, X., Li, Q.-Y., Lee, C.-C., & Fung, Y.-H. (2021). Interaction between Thermal Comfort, Indoor Air Quality and Ventilation Energy Consumption of Educational Buildings: A Comprehensive Review. Buildings, 11(12), 591. https://doi.org/10.3390/buildings11120591

[9] Dimitroulopoulou S, Dudzińska MR, Gunnarsen L, Hägerhed L, Maula H, Singh R, Toyinbo O, Haverinen-Shaughnessy U. Indoor air quality guidelines from across the world: An appraisal considering energy saving, health, productivity, and comfort. Environ Int. 2023 Aug;178:108127. https://doi.org/10.1016/j.envint.2023.108127

[10] Mustață, D.-M., Bisorca, D., Ionel, I., Adjal, A., & Balogh, R.-M. (2025). Real-Time Insights into Indoor Air Quality in University Environments: PM and CO2 Monitoring. Atmosphere, 16(8), 972. https://doi.org/10.3390/atmos16080972

[11] R. Dang, Y. Liu, and S. Chang, "The impact patterns of classroom lighting parameters on visual fatigue and a mathematical model," Build. Environ., vol. 234, p. 110193, 2023. https://doi.org/10.1016/j.buildenv.2023.110193

[12] M. J. Booysen, J. A. Samuels, and S. S. Grobbelaar, "LED there be light: The impact of replacing lights at schools in South Africa," Energy Build., vol. 235, p. 110736, 2021. https://doi.org/10.1016/j.enbuild.2021.110736

[13] Department of Occupational Safety and Health Malaysia, Industry Code of Practice on Indoor Air Quality 2010. Ministry of Human Resources Malaysia, 2010.

[14] ANSI/ASHRAE Standard 55-2020: Thermal Environmental Conditions for Human Occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2020.

[15] MS 1525: Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings. Department of Standards Malaysia, 2019.

[16] Department of Environment Malaysia, New Malaysia Ambient Air Quality Standard (NMAAQS). Ministry of Environment and Water, 2020.

[17] Toyinbo, O., Hägerhed, L., Dimitroulopoulou, S., Dudzinska, M., Emmerich, S., Hemming, D., Park, J.-H., Haverinen-Shaughnessy, U. and the Scientific Technical Committee 34 of the International Society of Indoor Air Quality, Climate (2022), Open database for international and national indoor environmental quality guidelines. Indoor Air, 32: e13028. https://doi.org/10.1111/ina.13028

[18] Toyinbo, O., Jengo, E., Peralta, X. V., & Haßler, B. (2025). Indoor Environmental Quality in Tanzanian Secondary Schools: Objective Baseline Measurements. Atmosphere, 16(8), 902. https://doi.org/10.3390/atmos16080902