JAITA

JOURNAL OF ADVANCED INDUSTRIAL TECHNOLOGY AND APPLICATION
e-ISSN: 2716-7097

Vol. 7 No. 1 (2026) 131-144
https://publisher.uthm.edu.my/ojs/index.php/jaita

Indoor Air Quality Index–Based Assessment and Improvement Strategies for Selected Kindergarten Classrooms in Pagoh, Johor

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DOI: https://doi.org/10.30880/jaita.2026.07.01.010

Article Info

Received: 12 January 2026
Accepted: 4 May 2026
Available online: 19 June 2026

Keywords

Indoor air quality, indoor air quality index, carbon dioxide, IAQ improvement strategies

Abstract

Indoor air quality (IAQ) in kindergarten classrooms is critical due to children's vulnerability to environmental pollutants and thermal discomfort. This study assessed IAQ conditions and determined the Indoor Air Quality Index (IAQI) status of two private kindergartens in Pagoh, Johor namely S1 and S2, using a quantitative field measurement–based approach. Temperature, relative humidity, CO_2, TVOC, $PM_{2.5}$, and PM_{10} were monitored over two school days and evaluated against Department of Occupational Safety and Health (DOSH) and Singapore Standard (SS 554) guidelines, and IAQI values were calculated using linear interpolation, where the lowest IAQI value represented the overall indoor air quality status. The results showed that chemical pollutants generally complied with the recommended limits; however, dominant parameters affecting IAQ differed between the two kindergartens. S1 was classified as Unhealthy due to elevated temperature (34.5°C) and RH (87%), with IAQI values of 39.1 and 42.7, respectively. In contrast, S2 was classified as Hazardous due to high CO_2 concentrations (2755 ppm) associated with limited ventilation which recorded a critically low IAQI value of 9.0. These findings highlight the need for improved ventilation and thermal management in kindergarten classrooms.

1. Introduction

The state of the air inside buildings and their environs is referred to as indoor air quality (IAQ), and it has a significant impact on the comfort, health, and well-being of occupants. According to studies, the buildup of pollutants from indoor activities, building materials, and poor ventilation can make indoor air more contaminated than outdoor air [1]. Maintaining optimal indoor air quality (IAQ) levels is crucial since indoor air pollution is one of the top five environmental health concerns [2].

Due to their developing respiratory systems and faster breathing rates than adults, children are especially susceptible to poor indoor air quality. Children's health problems, diminished cognitive function, and respiratory symptoms have all been linked to indoor air pollution exposure [3]. In educational buildings such as kindergartens, poor IAQ conditions may negatively affect children's comfort, concentration, and learning efficiency.

The efficiency of the ventilation system, the temperature, and the daily activities of the classroom all have a significant impact on the indoor air quality in kindergarten classrooms. The presence and concentration of indoor air pollutants are mostly determined by variables like temperature, humidity, air movement, and ventilation effectiveness [4]. Due to confined indoor spaces and continuous occupancy, IAQ conditions in kindergartens may fluctuate throughout the day, potentially increasing exposure risks for young children who spend prolonged periods indoors [5].

Ensuring a safe and healthy indoor environment is essential for young children's overall well-being and development, particularly in kindergarten settings where prolonged indoor exposure occurs [6]. According to Mainka A. et al., approximately 40% of indoor $PM_{2.5}$ originates from outdoor sources, primarily fossil fuel combustion related to heating and transportation, while the remaining 60% is generated by indoor activities. In kindergarten environments, indoor $PM_{2.5}$ sources such as cooking activities, inadequate ventilation, insufficient cleaning practices, and overcrowding can contribute to elevated particulate concentrations. These conditions increase children's exposure to airborne contaminants and may elevate the risk of respiratory problems and other adverse health effects [7].

While IAQ conditions in elementary and secondary schools have been the subject of numerous studies, there is still a dearth of research, especially on kindergarten classrooms in Malaysia. Thus, this study uses field measurements and the Indoor Air Quality Index (IAQI) technique to evaluate indoor air quality conditions in a subset of kindergarten classes in Pagoh, Johor. The study evaluates compliance with established guidelines, identifies dominant IAQ parameters affecting indoor conditions, and provides insight into appropriate improvement strategies to support healthier indoor environments for young children.

2. Literature Review

The literature review focuses on IAQ conditions in kindergarten and educational environments, including key indoor pollutants, thermal comfort parameters, associated health impacts on children, and relevant IAQ standards and assessment approaches. Previous local and international studies are reviewed to provide context for the evaluation of IAQ conditions and the application of the Indoor Air Quality Index (IAQI) in kindergarten classrooms.

2.1 Overview of IAQ in the Malaysian Kindergartens

In kindergarten settings, where extended indoor occupancy occurs, indoor air quality (IAQ) is crucial for promoting children's health, comfort, and cognitive development. Previous studies have reported that classroom environments often contain multiple air pollutants, with concentrations in some cases exceeding recommended exposure limits [8][9]. Poor IAQ in educational settings has been associated with increased respiratory illnesses, reduced school attendance, and decreased learning performance among young children [10][11][12].

Research has also shown that personal exposure is largely influenced by indoor environments, which may at times be more polluted than outdoor air, particularly for children who spend most of their time indoors [13][14][15]. Despite the growing demand for early childhood education facilities in Malaysia, studies focusing on IAQ conditions in kindergarten environments remain limited. This highlights the need for systematic assessment of indoor air quality in Malaysian kindergarten classrooms to support healthier and more conducive learning environments.

2.2 Health Impacts of IAQ on Children

Indoor air quality (IAQ) has a major impact on children's health and development, particularly in kindergarten settings where prolonged indoor exposure occurs. Children are especially susceptible to the negative effects of indoor air pollution because of their growing respiratory systems and faster breathing rates. To lower health hazards, guidelines for indoor air pollution have been established by the World Health Organization (WHO), the US Environmental Protection Agency (US EPA), the Department of Occupational Safety and Health (DOSH)

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Malaysia, and other organizations. Table 1 summarizes the recommended exposure limits and associated health impacts of key indoor air pollutants on children.

Table 1 *Recommended exposure limits and associated health impacts of key indoor air pollutants on children*

Pollutant / Parameter	Recommended Limit	Health Impacts on Children	Reference / Guideline
$PM_{2.5}$	≤ 15 µg/m^3	Asthma, bronchitis, reduced lung function, long-term respiratory disease	WHO (2021); US EPA (2023)
PM_{10}	≤ 45 µg/m^3	Upper respiratory tract irritation, increased asthma attacks	WHO (2021); US EPA (2023)
CO_2	≤ 1000 ppm	Drowsiness, headaches, impaired concentration and cognitive function	DOSH (2010); ASHRAE Standard 62.1
TVOC	≤ 3 ppm	Eye, nose, throat irritation; headaches; allergic reactions; long-term exposure linked to organ and CNS damage	DOSH (2010); WHO (2010)
Temperature	23°C–26°C	Discomfort, distraction, fatigue; extreme heat affects cognitive performance in children	DOSH (2010); ASHRAE (2017)
RH	40%–70%	Mold growth, allergen increase (if too high); dry throat/skin, irritation (if too low	WHO (2010); ASHRAE (2017); DOSH (2010)

2.3 IAQ National and International Standards and Guidelines

IAQ standards and guidelines provide benchmark values for assessing the safety and health of indoor environments. These guidelines, developed by national and international agencies, specify recommended limits for key parameters such as particulate matter ($PM_{2.5}$, PM_{10}), carbon dioxide (CO_2), total volatile organic compounds (TVOCs), temperature, and relative humidity (RH). In sensitive environments such as kindergartens, these standards serve as important references to protect children from potential health risks associated with poor indoor air quality. Table 2 presents the recommended IAQ values according to DOSH (2010), Singapore Standards, SS 554 (2016), WHO (2021), and American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and European (EU) Guidelines. Singapore adopts a performance-based indoor air quality approach through SS 554 and National Environment Agency (NEA) guidelines, providing numerical contaminant limits similar to Malaysia's ICOP IAQ 2010. WHO guidelines are health-based exposure references, while ASHRAE standards do not prescribe numerical IAQ limits and instead highlight ventilation adequacy, source control, and occupant acceptability.

Table 2 *Recommended level for IAQ*

Parameter	DOSH ICOP IAQ Malaysia (2010)	SS 554 (2016) / NEA	WHO (2021)	ASHRAE / EU Guidelines
$PM_{2.5}$	–	≤ 15 μg/m^3	≤ 15 μg/m^3	–
PM_{10}	≤ 0.15 mg/m^3	≤ 50 μg/m^3	≤ 45 μg/m^3	–
CO_2	≤ 1000 ppm	≤ 1000 ppm	–	≤ 1000 ppm (ASHRAE 62.1)
TVOC	≤ 3 ppm	≤ 3 mg/m^3	Compound-specific	< 300 μg/m^3 (Germany UBA)
Temperature	23°C – 26°C	23 – 25 °C	Climate dependent	23°C – 26°C (ASHRAE 55)
RH	40% – 70%	≤ 65 %	≤ 65 %	30% – 60% (ASHRAE 55); < 70% (WHO 2009)

3. Methodology

To assess the conditions of indoor air quality in selected kindergarten classes in Pagoh Johor, Malaysia, this study used a quantitative field measuring approach. Two private kindergartens were selected, representing different ventilation strategies: S1, which operates under natural ventilation with a total floor area of 39.6 m^2 while S2, which is air-conditioned with a total floor area of 29.2 m^2. During regular classroom operations, an Air Quality Monitor (YES-AIR-D) was used to evaluate indoor air quality, including temperature, relative humidity, carbon dioxide (CO_2), total volatile organic compounds (TVOC), $PM_{2.5}$, and PM_{10}.

3.1 Air Quality Monitoring Instrument

Indoor air quality measurements were conducted using a portable multi-parameter indoor air quality monitor, YES-AIR-D (Diffusion model) manufactured by Critical Environment Technologies Canada Inc. The instrument is designed for real-time indoor air quality monitoring in occupied environments and is suitable for classroom-based field measurements.

The YES-AIR-D monitor was used to measure temperature, RH, CO_2, TVOC, and $PM_{2.5}$ and PM_{10}. According to the manufacturer's technical datasheet, the instrument supports temperature measurement in the range of 5°C to 50°C, relative humidity from 0 to 99 % RH, carbon dioxide concentration up to 5,000 ppm. TVOC concentration up to 30 ppm and $PM_{2.5}$ and PM_{10} was measured using another air quality monitor.

All sensors were factory-calibrated by the manufacturer prior to deployment, and the instrument was operated in accordance with the manufacturer's operating guidelines. Instrument stabilisation was allowed before each monitoring session to ensure reliable and consistent data acquisition.

3.2 Data Collection Method

Indoor air quality data were collected through direct, instrument-based field measurements using portable indoor air quality monitoring devices. This approach was adopted to obtain quantitative, real-time data on key IAQ parameters in selected kindergarten classrooms during normal operating hours, without any experimental manipulation.

Two monitoring instruments were used in this study. An Air Quality Monitor was employed to measure $PM_{2.5}$ and PM_{10} and TVOC, providing continuous data on airborne particulates and indoor chemical pollutants. In addition, another portable air quality monitor (YES-AIR-D) was used to measure CO_2, air temperature, RH, where CO_2 served as an indicator of ventilation adequacy, while temperature and RH were used to assess thermal comfort conditions. Both instruments were positioned at breathing-zone level within the classrooms and placed away from direct airflow obstructions or localized pollutant sources.

3.2.1 Field Measurement

Field measurements were conducted in selected kindergarten classrooms located in Pagoh Johor. $PM_{2.5}$ and PM_{10}, CO_2, TVOC, temperature, and relative humidity were among the indoor air quality characteristics that were assessed in this study. Measurements were taken indoors within classroom areas where children spend most of their time.

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Data collection was carried out during normal school operating hours from 9 a.m. to 5 p.m. for eight hours to capture variations in indoor air quality associated with occupancy and classroom activities. Measurements were conducted over two monitoring days for each kindergarten. The selection of two monitoring days was considered sufficient to represent typical indoor air quality conditions during normal classroom operation. Short-term monitoring over multiple days is commonly adopted in indoor air quality field studies to capture day-to-day variations associated with occupancy, classroom activities, and ventilation conditions. All recorded data were tabulated and used for subsequent Indoor Air Quality Index (IAQI) analysis.

3.2.2 Sampling Strategy

The sampling strategy for this study followed the general recommendations outlined in the ICOP on Indoor Air Quality [19]. During on-site data collection, monitoring devices should be placed at designated sampling points in accordance with the general criteria outlined in ICOP IAQ 2010. Table 3 shows the number of sample points for the IAQ evaluation, as well as the minimum needed number of sampling points.

Table 3 *Suggested minimum number of sampling points for evaluating indoor air quality [19]*

Total floor area (served by MVAC system) (m^2)	Minimum number of samplings points
< 3,000	1 per 500 m^2
3,000 – < 5,000	8
5,000 – < 10,000	12
10,000 – < 15,000	15
15,000 – < 20,000	18
20,000 – < 30,000	21
30,000	1 per 1,200 m^2

3.3 Data Analysis Method

The data analysis involves calculating the IAQI for each measured pollutant ($PM_{2.5}$, PM_{10}, CO_2, and TVOC) based on standard IAQI computation methods. The IAQI system provides a clear classification of air quality levels using color-coded categories: Good, Moderate, Unhealthy and Hazardous.

3.3.1 Indoor Air Quality Index (IAQI)

This study applies the modified IAQI approach proposed by Saad, S. M. et al. (2017), which is specifically developed for indoor environments [16]. In this approach, higher IAQI values represent better indoor air quality, contrary to the conventional AQI system. The IAQI classification is simplified into four categories: Good (76–100), Moderate (51–75), Unhealthy (26–50), and Hazardous (0–25), allowing clearer interpretation of indoor air quality conditions. Each measured parameter ($PM_{2.5}$, PM_{10}, CO_2, TVOC, temperature, and relative humidity) was assigned an IAQI value based on predefined concentration breakpoints adapted from international and local indoor air quality guidelines [16]. These breakpoints were used to determine IAQI values through linear interpolation, as shown in Table 4. The IAQI value for each parameter is calculated using the following linear interpolation formula:

$$I_p = (C_P - BP_{Lo}) \times \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}} + I_{Lo} \tag{1}$$

Table 4 *Breakpoint table for indoor environment [16]*

CO_2 (ppm)	PM_{10} (mg/m^3)	VOC (ppm)	Temp (°C)	RH (%)	IAQI	IAQI Status	Improvement Strategies
340-600	0.000-0.020	0.000-0.087	20.0-26.0	40.0-70.0	100-76	Good	Maintain
601-1000	0.021-0.150	0.088-0.261	26.1-29.0	70.1-80.0	75-51	Moderate	Improve
1001-1500	0.151-0.180	0.262-0.43	29.1-39.0	80.1-90.0	50-26	Unhealthy	Intervention
1501-5000	0.181-0.600	0.44-3.00	39.1-45.0	90.1-100.0	25-0	Hazardous	Remediation

The improvement strategies corresponding to each IAQI status provide general guidance for indoor air quality management. A Good status indicates that existing conditions should be maintained through routine cleaning, ventilation, and Heating, Ventilation and Air-conditioning (HVAC) maintenance [20]. Moreover, regularly maintain Air Conditioning and Mechanical Ventilation (ACMV) systems. This entails examining and cleaning exhaust and supply fans to guarantee peak performance, evaluating air ducts and dampers to make sure there are no obstructions or leaks, and examining filter seals to prevent air bypass [30]. Similarly, preventive HVAC maintenance and routine cleaning are effective in maintaining acceptable indoor air quality and reducing pollutant accumulation [20]. Then, continuous maintenance and monitoring are essential to sustain acceptable indoor air quality [32].

While a Moderate status requires improvements such as enhanced ventilation and thermal control by install shading devices or blinds to minimize solar heat gain and maintain comfortable indoor temperatures [21][22]. On the other hand, a study by Rawat, N. & Kumar, P. indicate that improving classroom ventilation by bringing in as much outside air as the HVAC system would safely permit and updating filtration to the greatest efficiency filters, possibly MERV 13 that can lower the risk of respiratory infections in schools [31].

An Unhealthy status calls for implementing targeted interventions including thorough HVAC cleaning, filter replacement and upgrades including consider using effective filters (at least MERV14, F8, or ePM1 70-80% is advised), [30] and pollutant source control [23]. Similarly, a study by Vijayan et al. stated that high-efficiency filtration (MERV 13 and above) significantly reduces indoor particulate matter concentrations [23]. Other than that, unless the outside air quality is poor, open movable windows and doors as often as possible and to save energy, switch off or minimize the air conditioning when windows or doors are open [30].

Whereas Hazardous conditions require comprehensive remediation, ventilation upgrades with filtration, temporary occupancy control, and post-mitigation monitoring to ensure safe indoor conditions. For severe indoor air quality issues, occupancy control and post-remediation testing are necessary to ensure safe re-entry [24][25]. Moreover, hazardous IAQ often originates from persistent sources such as mold growth, stored chemicals, or deteriorated materials, which must be fully removed rather than masked. WHO emphasizes that eliminating pollution sources is the most effective long-term IAQ control strategy [28].

4. Result and Discussion

This section presents the results and discussion of the indoor air quality assessment in relation to the research objectives. The measured physical and chemical IAQ parameters address Objective 1, which focuses on assessing IAQ conditions in kindergarten classrooms. IAQI classification addresses Objective 2 by integrating measured parameters into overall IAQ status. The identification of dominant IAQ parameters forms the basis for improvement strategies discussed under Objective 3.

4.1 Current Status IAQ in Kindergarten Building

Figure 1 presents the indoor CO_2 concentrations measured in the selected kindergarten classrooms. CO_2 concentrations in S2 reached a maximum of 2755 ppm, which is substantially higher than levels commonly reported in classroom IAQ studies, reflecting severe ventilation inadequacy despite the presence of air-conditioning. Although S2 was air-conditioned, CO_2 concentrations exceeded the recommended limit and it was attributed to the use of split-unit air-conditioning systems that recirculate indoor air without adequate fresh air

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intake. Closed-window conditions combined with high occupancy density led to CO_2 accumulation, indicating insufficient ventilation effectiveness. Moreover, a comparison between Day 1 (Week 1) and Day 2 (Week 2), indicates that CO_2 levels in both kindergartens exhibited similar daily patterns, with slightly higher concentrations recorded on Day 2. These variations are likely influenced by differences in occupancy levels, classroom activities, and ventilation practices during the monitoring periods.

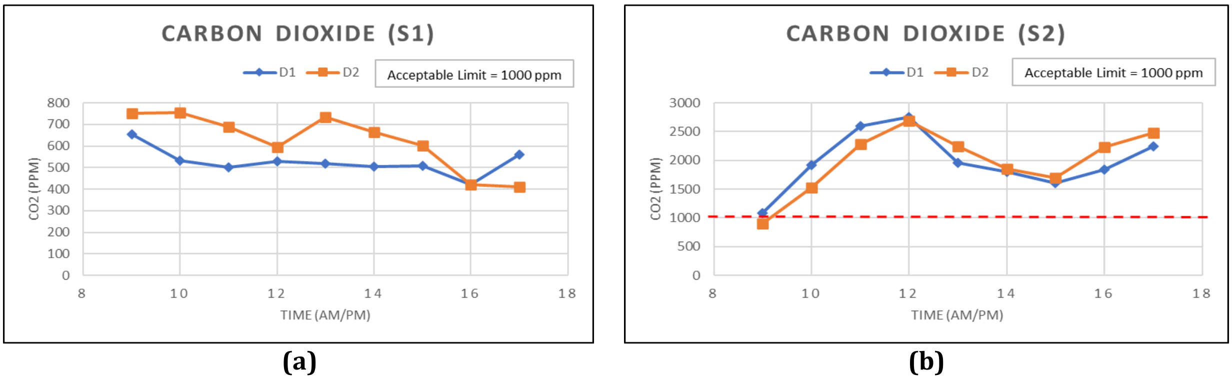


Fig. 1 *Graph of carbon dioxide for Day 1 and Day 2 (a) S1; (b) S2*

Figure 2 below shows the indoor temperature conditions for both classrooms. The maximum temperature recorded in S1 reached 34.5 °C, which is higher than values reported in previous Malaysian kindergarten studies (approximately 30–32 °C). This suggests more severe thermal discomfort in the naturally ventilated classroom under tropical climatic conditions. Other than that, a comparison between Day 1 and Day 2 shows that indoor temperature patterns were generally consistent, with slightly higher values observed on Day 2. These minor variations are likely influenced by changes in outdoor conditions, occupancy levels, and classroom activity duration during the monitoring periods.

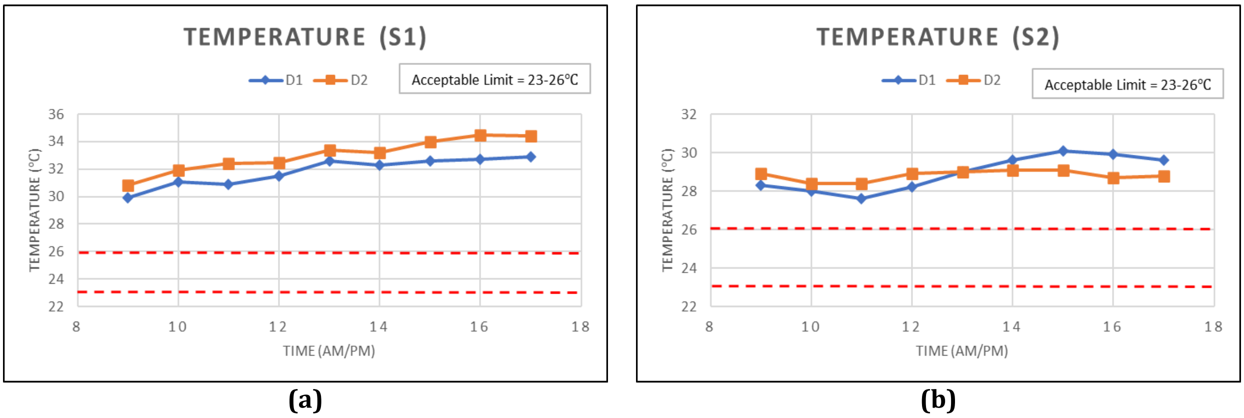
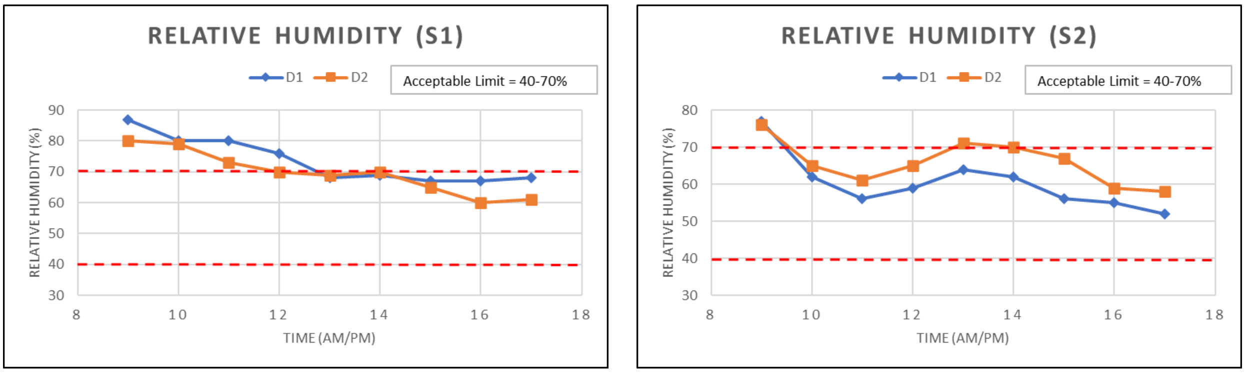


Fig. 2 *Graph of temperature for Day 1 and Day 2 (a) S1; (b) S2*

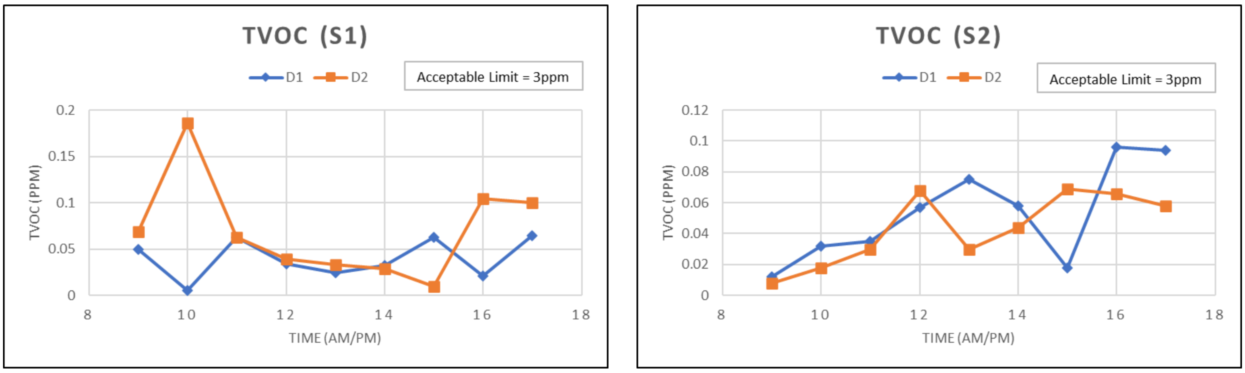
As shown in Figure 3, S1 recorded higher RH values reached up to 87%, with several readings exceeding the acceptable limit, particularly during midday and afternoon periods. This was mainly influenced by natural ventilation and the ingress of humid outdoor air. In contrast, S2 maintained lower and more stable RH levels due to the use of air-conditioning, which aided in moisture removal, although minor increases were observed during periods of high occupancy and activity. A comparison between Day 1 and Day 2 showed generally consistent RH trends with only slight variations likely related to outdoor weather conditions and occupancy levels. Overall, elevated RH in S1 may contribute to thermal discomfort and increase the potential for moisture-related indoor air quality issues.



(a) **(b)**

Fig. 3 *Graph of relative humidity for Day 1 and Day 2 (a) S1; (b) S2*

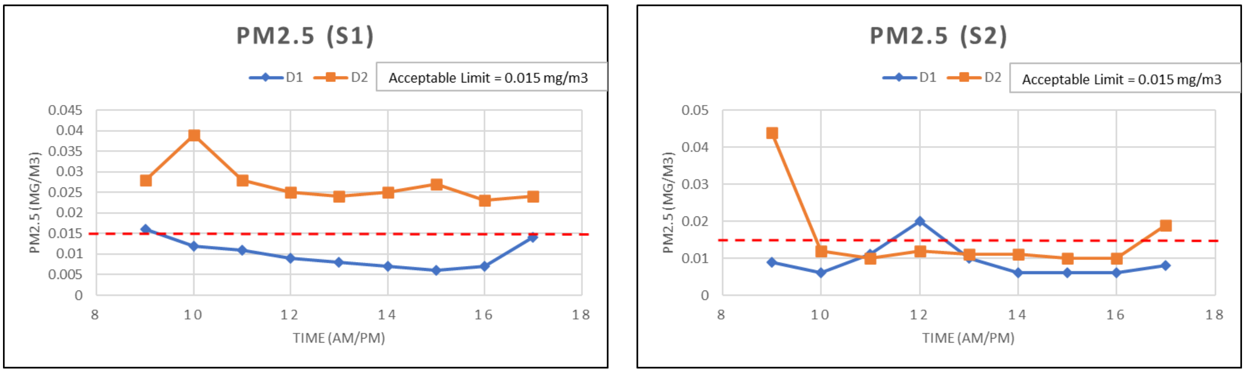
Figure 4 below illustrates the variation of TVOC concentrations in S1 and S2 over the two monitoring days. Overall, TVOC levels in both classrooms remained well below the recommended limit of 3 ppm, indicating low levels of chemical pollution during the monitoring period. S1 exhibited slightly higher and more variable TVOC concentrations, likely influenced by natural ventilation and indoor activities such as cleaning, use of teaching materials, and children's movement. In contrast, S2 showed lower and more stable TVOC levels, which may be attributed to its enclosed, air-conditioned environment that limits outdoor air infiltration. A comparison between Day 1 and Day 2 shows that TVOC trends were generally consistent, with only minor variations observed. These short-term fluctuations are likely related to differences in daily classroom activities and cleaning schedules rather than structural or ventilation issues.



(a) **(b)**

Fig. 4 *Graph of TVOC for Day 1 and Day 2 (a) S1; (b) S2*

Figure 5 shows the $PM_{2.5}$ concentration trends measured in S1 and S2 over the two monitoring days. Overall, $PM_{2.5}$ levels in both classrooms were generally within or close to the DOSH (2010) recommended limit of 0.015 mg/m^3, with short-term increases observed during periods of active classroom use. S1 exhibited higher and more variable $PM_{2.5}$ concentrations, mainly influenced by natural ventilation, outdoor particle infiltration, and dust resuspension caused by children's movement and cleaning activities. In contrast, S2 recorded lower and more stable $PM_{2.5}$ levels due to its enclosed, air-conditioned environment, which limited outdoor particle ingress. A comparison between Day 1 and Day 2 indicates generally consistent $PM_{2.5}$ patterns, with slightly higher levels observed on Day 2, likely related to differences in classroom activities, cleaning schedules, or outdoor air conditions.

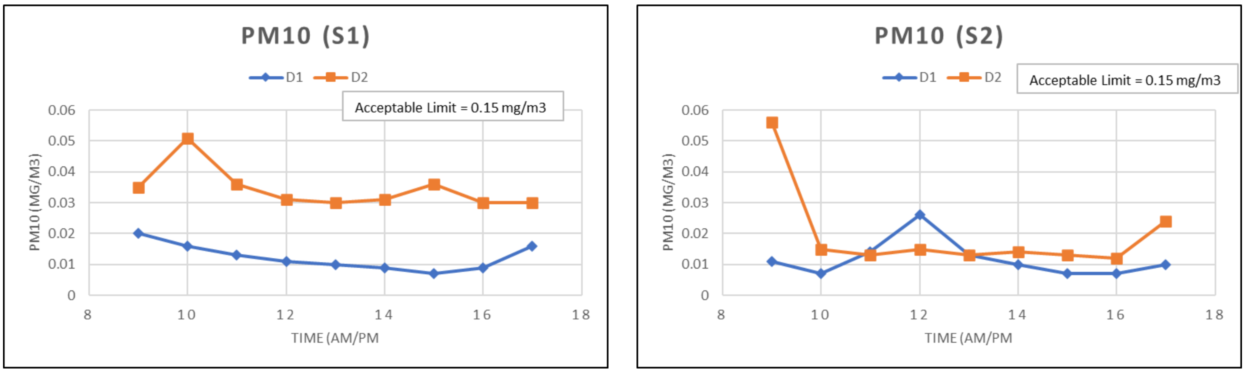


(a) **(b)**

Fig. 5 *Graph of $PM_{2.5}$ for Day 1 and Day 2 (a) S1; (b) S2*

Last but not least, Figure 6 shows PM_{10} concentrations in both S1 and S2 remained below the DOSH (2010) recommended limit of 0.15 mg/m^3, indicating that coarse particulate pollution was generally well controlled during the monitoring period. Higher PM_{10} levels were observed in S1, particularly during periods of increased classroom activity. This is mainly attributed to dust resuspension caused by children's movement and cleaning practices, as well as the influence of natural ventilation that allows outdoor coarse particles to enter the classroom. In contrast, S2 recorded lower and more stable PM_{10} concentrations due to its enclosed, air-conditioned environment, which limited outdoor particle ingress and reduced dust resuspension.

Minor increases were still observed during peak occupancy periods, reflecting the influence of occupant activity on indoor PM_{10} levels. PM_{10} trends were generally consistent across Day 1 and Day 2 for both classrooms, suggesting that variations were driven primarily by daily activity patterns rather than measurement timing.



(a) **(b)**

Fig. 6 *Graph of PM10 for Day 1 and Day 2 (a) S1; (b) S2*

4.1.1 Comparison Data with DOSH ICOP IAQ 2010

Table 5 above compares indoor air quality parameters measured over two monitoring days in S1 and S2 against the recommended limits set by DOSH (2010). Inferential statistical analysis was not applied due to the limited monitoring duration and exploratory nature of the study, with emphasis placed on descriptive statistics and IAQI-based classification. Overall, chemical pollutants in both kindergartens generally complied with the applicable standards, while physical parameters, particularly indoor temperature and relative humidity, frequently exceeded recommended comfort ranges [19][26].

Both kindergartens recorded indoor temperatures above the recommended range of 23–26°C. Higher temperatures were observed in S1 (29.9–34.5°C), reflecting reliance on natural ventilation and limited thermal control under tropical climatic conditions. Although S2 was air-conditioned, indoor temperatures still exceeded the comfort range, likely due to internal heat gains from occupancy and classroom activities. Relative humidity in S1 also exceeded the recommended limit of 70%, influenced by high outdoor humidity and open-window ventilation, while S2 showed comparatively better humidity control. Higher indoor temperatures observed in S1 are consistent with previous studies reporting limited thermal control in naturally ventilated classrooms under tropical conditions [4][27]. Moreover, elevated relative humidity can be attributed to high outdoor humidity and open-window ventilation as stated by WHO 2009 [28].

For chemical parameters, S1's carbon dioxide (CO_2) concentrations stayed within the permissible range of 1000 ppm. indicating adequate air exchange through natural ventilation. In contrast, S2 recorded CO_2 concentrations exceeding the guideline value, suggesting insufficient ventilation in the enclosed, air-conditioned classroom. TVOC concentrations in both kindergartens were well below the recommended limit, indicating low indoor chemical emissions. Similarly, $PM_{2.5}$ and PM_{10} concentrations complied with WHO and DOSH standards in both locations, with slightly higher particulate variations in S1 attributed to occupant movement and outdoor particle infiltration. Korsavi et. al. reports that naturally ventilated classrooms generally maintain CO_2 concentrations close to or below 1000 ppm due to effective air exchange [4]. On the other hand, previous study indicated that due to natural ventilation, which allows outdoor air and indoor emissions from classroom activities, cleaning, and materials to mix, contributing to low-level VOC presence [11]. $PM_{2.5}$ and PM_{10} concentrations also attributed to occupant activity and outdoor particle infiltration as stated in previous study [29].

Overall, IAQ trends between Day 1 and Day 2 were generally consistent in both kindergartens, with minor variations likely influenced by daily activities and occupancy patterns rather than changes in building performance.

Table 5 *Comparison between data obtained for 2 days and Standards*

	S1			S2			DOSH ICOP IAQ (2010)
Physical Parameter	Mean	Max	Ranges	Mean	Max	Ranges	Acceptable ranges
Temperature (°C)	32.4	34.5	29.9 – 34.5	28.9	30.1	27.6 – 30.1	23 – 26°C
RH (%)	72	87	60 – 87	63	77	52 – 77	40 – 70%
Chemical Parameter	Mean	Max	Ranges	Mean	Max	Ranges	Acceptable ranges
Carbon Dioxide (ppm)	566	756	409 – 756	1971	2755	898 – 2755	1000 ppm
TVOC (ppm)	0.044	0.186	0.005 – 0.186	0.052	0.096	0.008 – 0.096	3 ppm
$PM_{2.5}$ (mg/m^3)	0.019	0.039	0.006 – 0.039	0.011	0.044	0.006 – 0.044	0.015 mg/m^3
PM_{10} (mg/m^3)	0.023	0.051	0.007 – 0.051	0.014	0.056	0.007 – 0.056	0.15 mg/m^3

4.2 Indoor Air Quality Index Classification Results

IAQI values were calculated using the linear interpolation in section 3.2.1, based on breakpoint values adapted from Mad Saad et al. [16]. For each kindergarten, the highest measured concentration recorded over the two monitoring days was selected to represent worst-case conditions for each parameter. Each parameter was classified into Good, Moderate, Unhealthy, or Hazardous categories. As higher IAQI values indicate better indoor air quality, the lowest IAQI value among all parameters was used to determine the overall IAQ classification for each kindergarten.

Based on Table 6 above, temperature recorded the lowest IAQI value among all parameters measured at S1, indicating that thermal discomfort was the most critical IAQ issue in this classroom. Although chemical pollutants remained within acceptable limits, elevated temperature and relative humidity reduced overall indoor comfort. Therefore, the overall IAQI classification for S1 is Unhealthy.

On the other hand, as shown in Table 7 for S2, CO_2 recorded the lowest IAQI value, indicating a Hazardous condition. This result reflects insufficient ventilation in the air-conditioned classroom where windows remained closed during operation. Although other parameters showed moderate or unhealthy conditions, CO_2 was identified as the dominant pollutant. Consequently, the overall IAQI classification for S2 is Hazardous.

Table 6 *IAQI results for S1*

Parameter	Highest Measured Value	IAQI Value	IAQI Status
Temperature	34.5°C	39.1	Unhealthy
RH	87%	42.7	Unhealthy
CO_2	756 ppm	60.3	Moderate
TVOC	0.186	64.6	Moderate
PM_{10}	0.051 mg/m^3	56.6	Moderate

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Table 7 *IAQI results S2*

Parameter	Highest Measured Value	IAQI Value	IAQI Status
Temperature	30.1°C	28.4	Unhealthy
RH	77%	67.7	Moderate
CO_2	2755 ppm	9.0	Hazardous
TVOC	0.096 ppm	52.1	Moderate
PM_{10}	0.056 mg/m^3	57.6	Moderate

4.2.1 Discussion of IAQI Classification and Improvement Strategies

Table 8 summarizes the IAQI classification results for S1 and S2 based on the highest measured using linear interpolation and classified according to the IAQI categories defined in Table 4. For each kindergarten, the parameter with the lowest IAQI value was used to determine the overall indoor air quality classification, representing worst-case indoor conditions.

For S1, the overall IAQI status was classified as Unhealthy, primarily influenced by elevated indoor temperature and relative humidity levels. Although chemical parameters such as PM_{10} and TVOC were classified as Moderate, thermal comfort parameters showed lower IAQI values, indicating insufficient control of indoor thermal conditions in the naturally ventilated classroom. As the severity level does not require immediate remediation, improvement strategies focus on intervention measures aimed at enhancing thermal comfort. thermal comfort can be improved by short-term operational strategies include improving air movement through the use of ceiling or wall fans, optimising window opening schedules to enhance cross-ventilation, and adjusting classroom activities to reduce heat accumulation during peak periods [4]. Moreover, long-term structural strategies include the installation of shading devices to reduce solar heat gain, improvement of building envelope design, and consideration of passive ventilation enhancements to improve indoor thermal conditions [4].

In contrast, S2 was classified as Hazardous, with CO_2 identified as the dominant parameter due to very low IAQI values. This result reflects inadequate ventilation in the air-conditioned classroom despite better control of temperature and relative humidity. Other parameters, including particulate matter and TVOC, remained within acceptable or moderate IAQI categories. Given the higher IAQI severity level, improvement strategies require immediate remediation with priority given to ventilation performance. To improve indoor air quality in air-conditioned classrooms, ventilation effectiveness should be enhanced through increased fresh air supply, such as short-term operational strategies include scheduled window opening during suitable outdoor conditions, reducing occupancy density, and ensuring proper operation and maintenance of the air-conditioning system to enhance air circulation. While, for long-term structural strategies include the introduction of mechanical or hybrid ventilation systems to provide adequate fresh air supply, such as exhaust ventilation or energy recovery ventilation, and redesign of ventilation layouts to prevent CO_2 accumulation in enclosed classrooms [3][17][18].

In general, the IAQI findings show that chemical pollutants generally complied with recommended limits in both kindergartens, while inadequate ventilation and thermal comfort conditions were the primary factors affecting overall indoor air quality. These findings highlight the importance of improving ventilation effectiveness and thermal management in kindergarten classrooms, particularly in tropical climates.

Table 8 *Summary of overall IAQI status*

Parameter	IAQI (S1)	Status	IAQI (S2)	Status
CO_2	60.3	Moderate (51 – 75)	9.0	Hazardous (0 – 25)
PM_{10}	56.6	Moderate (51 – 75)	57.6	Moderate (51 – 75)
TVOC	64.6	Moderate (51 – 75)	52.1	Moderate (51 – 75)
Temperature	39.1	Unhealthy (26 – 50)	28.4	Unhealthy (26 – 50)
RH	42.7	Unhealthy (26 – 50)	67.7	Moderate (51 – 75)
Overall Status	39.1	Unhealthy	9.0	Hazardous
Improvement Strategies		Intervention		Remediation

5. Conclusion

This study evaluated IAQ conditions in two private kindergartens in Pagoh Johor which are S1 and S2 using quantitative field measurements. Key IAQ parameters were measured over two monitoring days and assessed against DOSH (2010) guidelines. Overall IAQ trends were consistent across monitoring days, with minor variations attributed to occupancy and classroom activities. Chemical pollutants (TVOC, $PM_{2.5}$, and PM_{10}) generally complied with recommended limits at both sites. However, S1 experienced elevated temperature and relative humidity due to reliance on natural ventilation, resulting in an Unhealthy IAQI classification, while S2 recorded excessive CO_2 levels caused by limited fresh air intake in an air-conditioned environment, leading to a Hazardous IAQI classification.

Finally, this study contributes to indoor air quality research in the Malaysian kindergarten context by applying the IAQI as an integrated assessment and decision-support tool. Unlike conventional IAQ evaluations that assess parameters individually, the IAQI approach consolidates multiple physical and chemical parameters into a single classification, allowing the identification of dominant indoor air quality issues. The application of IAQI in this study provides a clearer basis for prioritising improvement strategies according to severity level, particularly in early childhood education environments where research remains limited. The findings demonstrate that IAQI is a practical and effective tool for supporting evidence-based decision-making in indoor air quality management for kindergarten classrooms.

Acknowledgement

This research was supported by the Ministry of Higher Education through the Fundamental Research Grant Scheme (FRGS-EC/1/2024/WAS02/UTHM/03/3). The author would like to thank the Faculty of Engineering Technology at UTHM for providing the necessary resources that contributed to the success of this endeavor and would like to thank the managements and staffs of kindergartens who participated in this research and provided support in the research project. Additionally, appreciation is extended to the supervisor for his unwavering commitment to assist and guide throughout the project, generously sharing his knowledge and expertise.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design**: Huril Ain Asrin, Mohd Syafiq Syazwan Mustafa; **data collection:** Huril Ain Asrin, Hamzah Hajono; **analysis and interpretation of results:** Huril Ain Asrin, Azian Hariri, Abdul Murad Zainal Abidin; **draft manuscript preparation:** Huril Ain Asrin, Mohd Syafiq Syazwan Mustafa, Amir Abdullah Muhamad Damanhuri, Maranatha Wijayaningtyas. All authors reviewed the results and approved the final version of the manuscript.*

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