JOURNAL OF
ENERGY ENGINEERING AND MANAGEMENT

ORIGINAL RESEARCH
ISSN (online): 2838-0223 | Vol. 1, No.1. Pages 1-13, 2026

Monitoring Indoor Air Quality Parameters in School Buildings: A Multi-Parameter Monitoring and Compliance Analysis

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Received: 31 Januari 2026
Revised: 28 March 2026
Accepted: 31 May 2026
Published: 30 June 2026

Indoor air quality (IAQ) in school environments is essential for maintaining students' health, comfort, and academic performance. This study evaluates IAQ conditions in a Malaysian primary school using a multi-parameter monitoring approach and compliance assessment based on the Industry Code of Practice on Indoor Air Quality 2010 (ICOP-IAQ 2010) and MS1525:2019 standards. Measurements were conducted across multiple locations, including Blocks A, B, and C, covering different floor levels and functional spaces. Parameters assessed include air temperature, relative humidity, air velocity, carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), formaldehyde (HCHO), total volatile organic compounds (TVOC), particulate matter (PM2.5 and PM10), and light intensity. The results show that most chemical and particulate parameters complied with recommended limits, showing effective ventilation and low pollutant concentrations. However, air temperature and relative humidity consistently exceeded acceptable ranges, with temperatures above 29°C and humidity exceeding 70%, showing significant thermal discomfort. Light intensity also showed partial non-compliance in several areas. These findings highlight the need for integrated strategies addressing both air quality and thermal comfort to improve indoor environmental quality in school buildings, particularly in tropical climates.

Keywords: Indoor Air Quality, School Buildings, Parameter Monitoring, Student Health, Learning Performance

1. INTRODUCTION

Indoor air quality (IAQ) in Malaysian school environments has emerged as a critical issue due to its direct implications for both student health and academic performance. Numerous studies have reported the presence of key indoor pollutants, including particulate matter (PM), carbon dioxide (CO2), carbon monoxide (CO), volatile organic compounds (VOCs), and microbial contaminants within school buildings. The accumulation of these pollutants has been strongly associated with adverse health outcomes, particularly respiratory problems and symptoms related to Sick Building Syndrome (SBS). Consequently, the growing body of research underscores the urgent need for effective IAQ management strategies in schools to ensure a safe and conducive learning environment for children. A closer examination of IAQ parameters reveals the significant health risks posed by individual pollutants. Elevated concentrations of particulate matter, particularly PM2.5 and PM10, have been linked to the occurrence of SBS symptoms in university environments, suggesting comparable risks in school settings [1]. Similarly, increased levels of carbon dioxide (CO2) and carbon monoxide (CO) are associated with negative health and cognitive outcomes. High CO2 concentrations are indicative of poor ventilation and have been correlated with respiratory discomfort and reduced cognitive performance among students [2-3]. In addition, CO has been identified as a significant predictor of SBS symptoms in indoor environments such as lecture halls [1]. Beyond chemical pollutants, microbial contaminants also contribute substantially to IAQ concerns. Studies conducted in both urban and rural schools have reported elevated bacterial and fungal concentrations exceeding recommended limits, with dominant bacterial genera including Bacillus and Staphylococcus, and common fungal species such as Aspergillus and Penicillium [4], [5]. Environmental and regional factors further influence IAQ conditions in Malaysian schools. Comparative studies show that urban schools generally experience poorer IAQ than their rural counterparts, primarily due to higher exposure to traffic-related emissions and urban pollutants. This disparity has been associated with increased incidences of respiratory illnesses among students in urban settings [2]. In addition, inadequate ventilation remains a widespread issue across many school buildings, contributing to elevated CO2 levels and the accumulation of indoor pollutants. Poor ventilation not only compromises air quality but also negatively affects students' health and their ability to concentrate and perform academically [3]. The importance of implementing effective IAQ interventions in schools cannot be overstated. Poor indoor air quality has been shown to impair both physical health and academic outcomes, reinforcing the need for systematic monitoring and control measures [6]. While much of the existing literature emphasizes the detrimental effects of poor IAQ, it is equally important to recognize that these challenges can be mitigated through practical interventions.

Indoor Air Quality (IAQ) plays a fundamental role in shaping students' health, comfort, and learning performance, as it directly affects cognitive function and overall well-being. In educational environments, poor IAQ typically characterized by elevated pollutant concentrations and insufficient ventilation has been consistently associated with adverse outcomes, including respiratory problems, fatigue, and reduced academic achievement. With the advancement of technology, the integration of intelligent monitoring and management systems, particularly those driven by artificial intelligence, offers a promising approach to enhancing IAQ conditions in schools. Such systems enable real-time detection, prediction, and control of indoor pollutants, thereby supporting healthier and more efficient learning environments. From a health perspective, inadequate IAQ presents significant risks to students. Exposure to indoor pollutants can contribute to the development of respiratory illnesses and other health-related issues, particularly among children who are more vulnerable to environmental contaminants [7]. Furthermore, elevated carbon dioxide (CO2) levels, often resulting from poor ventilation, have been shown to correlate with increased fatigue and diminished cognitive performance, ultimately affecting students' ability to concentrate and process information effectively [8]. These findings highlight the critical importance of maintaining acceptable IAQ levels to protect students' physical health and cognitive functioning. In addition to health implications, IAQ significantly influences the comfort and overall learning environment within classrooms. Effective ventilation strategies, such as decentralized mechanical ventilation systems, have demonstrated substantial reductions in indoor CO2 concentrations, thereby improving both air quality and thermal comfort [9]. A comfortable indoor environment is essential for sustaining students' attention, engagement, and motivation, all of which are key determinants of successful learning outcomes [8]. Poor environmental conditions, in contrast, can lead to discomfort and distraction, negatively impacting classroom performance. The relationship between IAQ and academic performance has also been widely documented. Empirical evidence shows that poor air quality is associated with lower test scores, increased cognitive fatigue, and reduced productivity among students [8]. Conversely, improvements in IAQ through enhanced ventilation and effective air filtration systems have been linked to higher attendance rates and better overall educational outcomes [7]. These findings reinforce the notion that IAQ is not only a health concern but also a critical factor influencing educational success. However, despite the clear benefits of improving IAQ, it is important to acknowledge the practical challenges associated with implementing advanced IAQ management systems in schools.

Indoor air quality (IAQ) issues in Malaysian schools represent a significant concern due to their direct impact on students' health and the overall effectiveness of learning environments. Classrooms are frequently affected by elevated concentrations of indoor pollutants and suboptimal environmental conditions, including high carbon dioxide (CO2) levels, temperature variability, excessive humidity, and the presence of particulate matter (PM). These factors collectively contribute to a range of health problems, such as respiratory illnesses and symptoms associated with Sick Building Syndrome (SBS), thereby highlighting the urgent need for targeted interventions to improve IAQ in educational settings. Among the key IAQ concerns, elevated CO2 levels are particularly prevalent in Malaysian classrooms, often exceeding recommended thresholds due to inadequate ventilation. High CO2 concentrations have been linked to reduced cognitive performance, increased fatigue, and diminished attention span among students [3],[10]. These effects can significantly hinder students' ability to engage effectively in learning activities, ultimately impacting academic outcomes. The persistence of such conditions suggests that ventilation inefficiencies remain a widespread issue in school buildings. Temperature and humidity also play a crucial role in determining indoor environmental quality. In many cases, insufficient ventilation and poor building design contribute to uncomfortable thermal conditions, including excessive heat and high humidity levels. These conditions not only reduce thermal comfort but can also aggravate existing health issues such as asthma and allergies among students [2-3]. Maintaining appropriate thermal conditions is therefore essential for ensuring both student well-being and optimal learning performance. In addition to gaseous pollutants and thermal factors, particulate matter (PM), particularly PM2.5 and PM10, has been identified as a major contributor to poor IAQ in schools. Empirical studies have reported significant concentrations of PM in classroom environments, especially in urban areas where outdoor pollution sources such as traffic emissions can infiltrate indoor spaces [10-11]. Exposure to particulate matter is associated with various adverse health effects, including respiratory irritation and long-term pulmonary issues, making it a critical parameter in IAQ assessment. Furthermore, carbon monoxide (CO), although typically present in lower concentrations, has been associated with SBS symptoms in indoor environments. Research shows that elevated CO levels are more prominent in densely occupied spaces such as lecture halls compared to smaller tutorial rooms, suggesting that occupancy patterns and ventilation effectiveness play a role in pollutant accumulation [1]. Even at relatively low concentrations, prolonged exposure to CO can pose health risks, reinforcing the importance of continuous monitoring. While these IAQ challenges are well-documented, it is important to recognize that effective mitigation strategies are available.

Indoor air quality (IAQ) in Malaysian schools is governed and guided by established regulatory frameworks such as the Department of Occupational Safety and Health Malaysia Industry Code of Practice on Indoor Air Quality 2010 [12], which outlines acceptable limits for key parameters including carbon dioxide (CO2), carbon monoxide (CO), particulate matter (PM), temperature, and relative humidity. These standards serve as important benchmarks for assessing indoor environmental conditions and ensuring that occupied spaces including educational buildings provide a safe and healthy environment for occupants. Even with the availability of such guidelines, many studies have reported that IAQ conditions in Malaysian schools frequently exceed recommended thresholds, particularly in naturally ventilated classrooms where air exchange rates are often insufficient. Existing literature has extensively examined IAQ issues in higher education institutions and secondary schools however, there remains a significant lack of focused research on primary school environments. This gap is significant as younger children are more physiologically at risk to air pollutants due to their developing respiratory systems and higher breathing rates relative to body size. Furthermore, their extend exposure within classroom settings increases the potential for cumulative health effects. The limited number of studies conducted in Malaysian primary schools restricts a comprehensive understanding of IAQ conditions and associated health risks within this critical population group. In addition, many previous studies have primarily concentrated on the measurement of individual IAQ parameters without systematically evaluating compliance against established standards such as ICOP-IAQ 2010 and MS1525:2019. While pollutant concentration data provide valuable insights, the absence of a structured compliance assessment limits the practical applicability of findings for policy-making and building management. A combined approach that include real-time monitoring with standard-based compliance evaluation is therefore essential to bridge this gap and provide more actionable outcomes. Addressing these limitations is important for advancing IAQ research and improving environmental conditions in schools. This study aims to monitor key IAQ parameters and evaluate their compliance with established standards, particularly ICOP-IAQ 2010, in Malaysian primary school environments such as Sekolah Kebangsaan Seri Binjai.

2. METHODOLOGY

2.1. Study Area

Sekolah Kebangsaan Seri Binjai is located at Batu Pahat, Johor in a tropical climate region, where high temperature and humidity may influence indoor environmental conditions. The school is a government primary school comprising multiple academic and supporting buildings within a single compound. The school consists of three main teaching blocks, namely Block A, Block B, and Block C, which accommodate classrooms, teachers' offices, computer laboratories, and other learning spaces. Block C has the largest floor area (1800.00 m²), followed by Block A (1260.00 m²) and Block B (660.00 m²). In addition to the teaching blocks, supporting facilities such as the language room, multipurpose hall, and canteen are available, serving both academic and non-academic activities with varying occupancy patterns throughout the school day.The total gross floor area of the school buildings is approximately 4074.91 m². The buildings are naturally ventilated, with occupancy levels varying depending on the function and schedule of each space. Classrooms are typically enclosed and densely occupied during teaching hours, making them critical locations for indoor air quality (IAQ) assessment. The variation in building functions, occupancy density, and duration of use provides a representative environment for evaluating IAQ conditions, particularly in spaces that directly influence occupants' comfort and health.

2.2. Instrumentation and Measurement Parameters

A range of portable monitoring instruments was employed to measure both chemical and physical indoor air quality (IAQ) parameters as shown in Table 1. The selected devices were capable of providing real-time and continuous measurements with acceptable accuracy for field assessment.

Table 1. List of equipment/device used for IAQ manitoring

Device used	Parameters measured
HCHO, TVOC, and PM measurement devices	The instrument used for measuring formaldehyde (HCHO), total volatile organic compounds (TVOC), and particulate matter ($PM_{1.0}$, $PM_{2.5}$, and PM_{10}). The device operates using semiconductor-based sensors for HCHO and TVOC detection, with measurement ranges of 0.000 – 1.999 mg/m^3 and 0.000 – 9.999 mg/m^3, respectively. Particulate matter concentrations were determined based on particle count per unit volume (particles per litre), enabling the assessment of fine and coarse particles suspended in indoor air.
Smart Sensor Multi Gas Monitor (Model AS8900)	The device was used to measure carbon monoxide (CO) and oxygen (O_2) concentrations. This portable handheld device allows simultaneous monitoring of multiple gases and displays real-time readings on a single LCD interface. The instrument is equipped with configurable alarm settings, including threshold limit values, time-weighted average (TWA), and short-term exposure limit (STEL), with both visual and audible alerts when preset limits are exceeded.
6-in-1 Air Quality Monitor CO2 Meter	Carbon dioxide (CO_2) concentration was measured for a detection range of 350 – 2000 ppm. The instrument is powered by an integrated 1800 mAh lithium battery and is suitable for continuous indoor monitoring.
Habotest H176 Digital Anemometer	The physical parameters of air temperature, relative humidity, and air velocity were measured using this instrument. The device operates within measurement ranges of 0 – 40°C for temperature, 0 – 90% for relative humidity, and 0.10 – 30.00 m/s for air velocity. Airflow measurements were conducted using an angled vane sensor equipped with precision bearings to ensure reliable readings. The device is powered by three 1.5 V AAA batteries and includes an automatic shutdown feature after 10 minutes of inactivity to conserve energy.
Gain Express 8050 Digital Light Lux Meter	The light intensity meter which was used to measure both natural and artificial lighting conditions within the indoor environment. The instrument provides a rapid and reliable assessment of illuminance levels, enabling evaluation against recommended lighting standards.

2.3. Compliance Analysis

The measured indoor air quality (IAQ) parameters were evaluated against the recommended limits specified in the Industry Code of Practice on Indoor Air Quality 2010 (ICOP-IAQ 2010) [12] and follow MS1525:2019 standards established by the Department of Standards Malaysia [13]. This standard provides threshold values for both chemical and physical parameters to ensure acceptable indoor environmental conditions for occupants. Each parameter, including air temperature, relative humidity, air velocity, carbon dioxide (CO2), carbon monoxide (CO), formaldehyde (HCHO), total volatile organic compounds (TVOC), particulate matter (PM2.5 and PM10), oxygen (O2), and light intensity, was compared with the corresponding permissible limits defined in the standard [14]. The compliance status was determined by assessing whether the measured average values fell within the recommended ranges. For the purpose of engineering design, room comfort conditions should consider the following three main factors such as dry bulb temperature, relative humidity, and air movement (air velocity). The indoor design conditions of an air-conditioned space for comfort cooling should follow MS1525:2019 standards established by the Department of Standards Malaysia.

3. RESULTS AND DISCUSSION

3.1. Indoor Air Quality Performance in Block A (Ground Floor)

The measured indoor environmental parameters for Block A (ground floor) are summarised in Table 2. The results show that while most air quality parameters comply with the recommended standards, several key thermal comfort and visual comfort indicators fall outside the acceptable range. Air temperature recorded an average value of 29.03°C, exceeding the recommended range of 23 – 26°C. The Malaysian Standard MS1525:2019 recommends a design dry bulb temperature range of 24°C to 26°C for indoor environments [13]. This range is designed to balance occupant comfort with energy efficiency, ensuring that the indoor temperature is neither too warm nor too cold. Similarly, relative humidity was measured at 74.57%, which is higher than the acceptable limit of 40 – 70% [12], [15]. The recommended design range according to MS1525:2019 standards, which is 50% to 70% [13]. These findings show that the indoor environment is thermally uncomfortable, likely due to the combined effects of tropical climatic conditions, high occupancy density, and insufficient ventilation efficiency. Elevated temperature and humidity levels are commonly associated with reduced thermal comfort and may negatively affect students' concentration and learning performance.

Table 2. Average parameter for Block A Ground Floor

Parameter	Average	Compliance
Air Temperature (23 ∘ C - 26 ∘ C)	29.03	No
Relative Humidity (40 % - 70 %)	74.57	No
Air Movement (0.015 m/s - 0.50 m/s)	0.28	Yes
Carbon Monoxide (10 ppm)	1	Yes
Carbon Dioxide (1000 ppm)	385.33	Yes
Oxygen (19.5 %)	21.11	Yes
Formaldehyde (0.1 ppm)	0	Yes
PM2.5 (0.15 mg/m^3)	0.041	Yes
PM10 (0.15 mg/m^3)	0.047	Yes
TVOC (3 ppm)	0.021	Yes
Light Intensity (300 Lux – 500 Lux)	245.33	No

Air movement was recorded at 0.28 m/s, which falls within the acceptable range (0.15 – 0.50 m/s). The Malaysian Standard MS1525:2019 recommends an air movement also range of 0.15 m/s to 0.50 m/s for indoor environments [13]. Adequate air movement is beneficial in mitigating thermal discomfort by enhancing convective heat loss from occupants. However, even with acceptable air velocity, the high temperature and humidity suggest that air circulation alone is insufficient to maintain optimal thermal conditions. In terms of gaseous contaminants, carbon monoxide (0 ppm) and carbon dioxide (385.33 ppm) concentrations were well within permissible limits. The low CO2 concentration shows adequate ventilation effectiveness and suggests that the occupancy level does not exceed the ventilation capacity of the space. This is an important indicator that, from a ventilation standpoint, the indoor air is not significantly compromised by occupant-generated pollutants. Oxygen concentration was measured at 21.11%, which is within the normal atmospheric range, confirming that the indoor environment is not oxygen-deficient. Additionally, formaldehyde levels were negligible (0 ppm), showing the absence of significant indoor chemical pollution sources such as building materials or furnishings. Particulate matter concentrations, including PM2.5 (0.041 mg/m³) and PM10 (0.047 mg/m³), were also within acceptable limits. These low values suggest minimal infiltration of outdoor pollutants and effective control of indoor particulate sources. Similarly, total volatile organic compounds (TVOC) were recorded at 0.021 ppm, showing good indoor air quality with respect to chemical contaminants. However, light intensity was measured at 245.33 lux, which is below the MS1525:2019 provides recommended illuminance (lux) levels for class room recommended range of 300 – 500 lux. Insufficient lighting can affect visual comfort and may lead to eye strain, reduced productivity, and decreased learning efficiency among students.

3.2. Indoor Air Quality Performance in Block A (First Floor)

The measured indoor environmental parameters for Block A (first floor) are presented in Table 3. Similar to the ground floor, the results show that most air quality parameters comply with recommended limits however, several thermal comfort indicators and lighting conditions remain outside the acceptable range. The average indoor air temperature was 29.13°C, exceeding the recommended range of 23 – 26°C. While The Malaysian Standard MS1525:2019 recommends a design dry bulb temperature range of 24°C to 26°C for indoor environments [13]. This range is designed to balance occupant comfort with energy efficiency, ensuring that the indoor temperature is neither too warm nor too cold. In addition, the relative humidity level was recorded at 79.77%, which is significantly higher than the acceptable range of 40 – 70% [12], [15]. These elevated values show poor thermal conditions, likely influenced by the tropical climate, solar heat gain at higher floor levels, and limited heat dissipation within enclosed classroom spaces. High humidity may also contribute to discomfort, as it reduces the effectiveness of evaporative cooling from occupants. The recommended design range according to MS1525:2019 standards, which is 50% to 70% [13].

Table 3. Average parameter for Block A First Floor

Parameter	Average	Compliance
Air Temperature (23 ∘ C - 26 ∘ C)	29.13	No
Relative Humidity (40 % - 70 %)	79.77	No
Air Movement (0.015 m/s - 0.50 m/s)	0.28	Yes
Carbon Monoxide (10 ppm)	0.833	Yes
Carbon Monoxide (1000 ppm)	403	Yes
Oxygen (19.5 %)	20.883	Yes
Formaldehyde (0.1 ppm)	0.0043	Yes
PM2.5 (0.15 mg/m^3)	0.044	Yes
PM10 (0.15 mg/m^3)	0.047	Yes
TVOC (3 ppm)	0.024	Yes
Light Intensity (300 Lux – 500 Lux)	294.07	No

Air movement was measured at 0.28 m/s, which falls within the acceptable range (0.15 – 0.50 m/s). This suggests that air circulation is adequate; however, similar to the ground floor findings, the acceptable air velocity is insufficient to compensate for the elevated temperature and humidity levels, resulting in overall thermal discomfort. The Malaysian Standard MS1525:2019 recommends an air movement also range of 0.15 m/s to 0.50 m/s for indoor environments [13]. With respect to gaseous pollutants, carbon monoxide (0.0833 ppm) and carbon dioxide (403 ppm) concentrations were well within permissible limits. The CO2 concentration remains relatively low, showing adequate ventilation and air exchange rates, even on the first floor. This suggests that occupancy levels are within the ventilation capacity and that the indoor environment is not significantly impacted by occupant-generated pollutants. The oxygen concentration was measured at 20.883%, which is within the normal atmospheric range, showing no oxygen deficiency. Formaldehyde concentration (0.0043 ppm) was also well below the recommended limit, suggesting minimal emission from indoor materials and a low risk of chemical exposure. Particulate matter levels, including PM2.5 (0.044 mg/m^3) and PM10 (0.047 mg/m^3), were within acceptable limits, showing effective control of airborne particulates and limited infiltration of outdoor pollutants. Similarly, total volatile organic compounds (TVOC) were recorded at 0.024 ppm, reflecting generally good indoor air quality in terms of chemical contaminants. However, light intensity was measured at 294.07 lux, which is slightly below the MS1525:2019 provides recommended illuminance (lux) levels for class room recommended range of 300 – 500 lux. Although the deviation is marginal, it still shows suboptimal visual conditions, which may affect visual comfort and task performance in classroom settings.

3.3. Indoor Air Quality Performance in Block A (Second Floor)

The indoor environmental parameters measured for Block A (second floor) are presented in Table 4. The results show that, consistent with the lower floors, most air quality parameters comply with recommended standards, while thermal comfort indicators remain outside acceptable limits. The average indoor air temperature was recorded at 29.06°C, exceeding the recommended range of 23 – 26°C. The Malaysian Standard MS1525:2019 recommends a design dry bulb temperature range of 24°C to 26°C for indoor environments [13]. This range is designed to balance occupant comfort with energy efficiency, ensuring that the indoor temperature is neither too warm nor too cold. Similarly, relative humidity reached 83.94%, which is substantially higher than the acceptable limit of 40 – 70% [12], [15]. The recommended design range according to MS1525:2019 standards, which is 50% to 70% [13]. These results show significant thermal discomfort, particularly due to excessive humidity. The elevated humidity level on the second floor is notably higher than that observed on the ground and first floors, suggesting increased exposure to roof-level heat gain and reduced moisture dissipation. Air movement was measured at 0.342 m/s, which is within the acceptable range (0.15 – 0.50 m/s) and slightly higher than the lower floors. The Malaysian Standard MS1525:2019 recommends an air movement also range of 0.15

m/s to 0.50 m/s for indoor environments [13]. This increase in air velocity may be attributed to greater exposure to outdoor airflow at higher elevations. Nevertheless, the improved air movement is insufficient to offset the high temperature and humidity, showing that natural ventilation alone is inadequate for achieving thermal comfort under these conditions. In terms of gaseous pollutants, carbon monoxide (0.6 ppm) and carbon dioxide (388.4 ppm) concentrations were well below the recommended limits. The consistently low CO2 levels across all floors show effective ventilation and adequate air exchange, even at higher building levels. Oxygen concentration was measured at 21.18%, remaining within the normal atmospheric range and confirming that the indoor environment is not oxygen-deficient. Formaldehyde concentration (0.0026 ppm) was also significantly below the recommended threshold, showing minimal emission from indoor materials. Particulate matter concentrations, including PM2.5 (0.0366 mg/m^3) and PM10 (0.0416 mg/m^3), were within acceptable limits and slightly lower than those recorded on the lower floors. This suggests reduced particulate accumulation, possibly due to better air dispersion at higher elevations. Similarly, total volatile organic compounds (TVOC) were recorded at 0.01324 ppm, representing the lowest concentration among all floors. This further confirms that chemical pollutant levels are well controlled and do not pose a significant risk to occupants. Unlike the lower floors, light intensity was measured at 400.16 lux, which meets the MS1525:2019 provides recommended illuminance (lux) levels for class room recommended range of 300 – 500 lux. This shows that the second floor benefits from better natural lighting conditions, likely due to increased exposure to daylight.

Table 4. Average parameter for Block A Second Floor

Parameter	Average	Compliance
Air Temperature (23 ∘ C - 26 ∘ C)	29.06	No
Relative Humidity (40 % - 70 %)	83.94	No
Air Movement (0.015 m/s - 0.50 m/s)	0.342	Yes
Carbon Monoxide (10 ppm)	0.6	Yes
Carbon Monoxide (1000 ppm)	388.4	Yes
Oxygen (19.5 %)	21.18	Yes
Formaldehyde (0.1 ppm)	0.0026	Yes
PM2.5 (0.15 mg/m^3)	0.0366	Yes
PM10 (0.15 mg/m^3)	0.0416	Yes
TVOC (3 ppm)	0.01324	Yes
Light Intensity (300 Lux – 500 Lux)	400.16	Yes

3.4. Indoor Air Quality Performance in Block A (Third Floor)

The indoor environmental parameters measured for Block A (third floor) are presented in Table 5. The results show a pattern consistent with the lower floors, where most air quality parameters comply with recommended standards, while thermal comfort conditions remain unsatisfactory. The average indoor air temperature was recorded at 29.85°C, exceeding the recommended range of 23 – 26°C. The Malaysian Standard MS1525:2019 recommends a design dry bulb temperature range of 24°C to 26°C for indoor environments [13]. This range is designed to balance occupant comfort with energy efficiency, ensuring that the indoor temperature is neither too warm nor too cold. Relative humidity was measured at 82.05%, which is significantly higher than the acceptable range of 40 – 70% [12], [15]. These values show substantial thermal discomfort, primarily driven by excessive humidity. Compared to the second floor, the temperature is slightly higher, suggesting continued heat accumulation at upper building levels, likely influenced by roof exposure and limited thermal insulation. The recommended design range according to MS1525:2019 standards, which is 50% to 70% [13]. Air movement was recorded at 0.295 m/s, which falls within the acceptable range (0.15 – 0.50 m/s). This shows adequate airflow within the space; however, similar to the observations on other floors, the air velocity is insufficient to offset the elevated temperature and humidity levels. This further confirms that natural ventilation alone is inadequate for maintaining thermal comfort under tropical climatic conditions. The Malaysian Standard MS1525:2019 recommends an air movement also range of 0.15 m/s to 0.50 m/s for indoor environments [13]. With respect to gaseous pollutants, carbon monoxide (0.5 ppm) and carbon dioxide (403 ppm) concentrations were well within permissible limits. The CO2 concentration remains consistently low across all floors, showing effective ventilation and sufficient air exchange rates, even at higher elevations. Oxygen concentration was measured at 21.6%, which is within the normal atmospheric range, confirming the absence of oxygen deficiency. Formaldehyde concentration (0.0025 ppm) was also well below the recommended threshold, suggesting minimal emission from indoor sources. Particulate matter levels, including PM2.5 (0.0539 mg/m^3) and PM10 (0.0585 mg/m^3), were within acceptable limits but slightly higher than those observed on the second floor. This increase may be attributed to greater exposure to outdoor particulates or internal resuspension due to occupant activities. Similarly, total volatile organic compounds (TVOC) were recorded at 0.0245 ppm, remaining within safe limits and showing low levels of chemical pollutants. In contrast to the lower floors, light intensity was measured at 378.8 lux, which falls within the MS1525:2019 provides recommended illuminance (lux) levels for class room recommended range of 300 – 500 lux. This suggests that the third floor benefits from adequate natural lighting conditions, contributing positively to visual comfort.

Table 5. Average parameter for Block A Third Floor

Parameter	Average	Compliance
Air Temperature (23 ∘ C - 26 ∘ C)	29.85	No
Relative Humidity (40 % - 70 %)	82.05	No
Air Movement (0.015 m/s - 0.50 m/s)	0.295	Yes
Carbon Monoxide (10 ppm)	0.5	Yes
Carbon Monoxide (1000 ppm)	403	Yes
Oxygen (19.5 %)	21.6	Yes
Formaldehyde (0.1 ppm)	0.0025	Yes
PM2.5 (0.15 mg/m^3)	0.053	Yes
PM10 (0.15 mg/m^3)	0.0585	Yes
TVOC (3 ppm)	0.0245	Yes
Light Intensity (300 Lux – 500 Lux)	378.8	Yes

3.5. Indoor Air Quality Performance in Block B (Ground Floor)

The measured indoor environmental parameters for Block B (ground floor) are presented in Table 6. The results show that, similar to Block A, most indoor air quality (IAQ) parameters comply with recommended standards, while thermal comfort indicators remain outside acceptable limits. The average indoor air temperature was recorded at 30.2°C, which exceeds the recommended range of 23 – 26°C. This value represents one of the highest temperatures observed among the monitored locations, showing significant thermal stress within the space. The Malaysian Standard MS1525:2019 recommends a design dry bulb temperature range of 24°C to 26°C for indoor environments [13]. This range is designed to balance occupant comfort with energy efficiency, ensuring that the indoor temperature is neither too warm nor too cold. Relative humidity was measured at 78.033%, which is also above the acceptable range of 40 – 70% [12], [15], further contributing to thermal discomfort. The recommended design range according to MS1525:2019 standards, which is 50% to 70% [13]. The combination of high temperature and humidity suggests inefficient heat removal and moisture accumulation, potentially due to high occupancy density, limited air exchange effectiveness in removing latent heat, or building design constraints. Air movement was measured at 0.33 m/s, which falls within the acceptable range (0.15 – 0.50 m/s). The Malaysian Standard MS1525:2019 recommends an air movement also range of 0.15 m/s to 0.50 m/s for indoor environments [13]. The relatively higher air velocity compared to some areas in Block A suggests better air circulation however, it remains insufficient to mitigate the elevated thermal conditions. This reinforces the observation that adequate airflow alone cannot compensate for excessive heat and humidity in naturally ventilated environments. In terms of gaseous pollutants, carbon monoxide (1 ppm) and carbon dioxide (586 ppm) concentrations were well within permissible limits. Although the CO_2 concentration is higher than that recorded in Block A, it remains below the threshold, showing acceptable ventilation performance and moderate occupancy levels. The slightly elevated CO_2 level may reflect higher occupant density or activity levels in this space compared to Block A. Oxygen concentration was measured at 21.5%, which is within the normal atmospheric range, confirming that the indoor environment is adequately ventilated and not oxygen-deficient. Formaldehyde levels were negligible (0 ppm), showing the absence of significant indoor chemical emission sources. Particulate matter concentrations, including PM2.5 (0.0563 mg/m^3) and PM10 (0.064 mg/m^3), were within acceptable limits, although slightly higher than those observed in Block A. This may be attributed to greater proximity to ground-level pollutant sources, such as dust resuspension, outdoor infiltration, or occupant movement. Even with this, the values remain within safe limits and do not show significant particulate pollution. Similarly, total volatile organic compounds (TVOC) were recorded at 0.0203 ppm, reflecting low levels of chemical pollutants and good overall air quality in terms of gaseous contaminants. Unlike Block A (ground floor), light intensity was measured at 352.6 lux, which falls within the MS1525:2019 provides recommended illuminance (lux) levels for class room recommended range of 300 – 500 lux. This shows adequate visual comfort conditions, likely due to better access to natural lighting or improved lighting design in Block B.

Table 6. Average parameter for Block B Ground Floor

Parameter	Average	Compliance
Air Temperature (23 ∘ C - 26 ∘ C)	30.2	No
Relative Humidity (40 % - 70 %)	78.033	No
Air Movement (0.015 m/s - 0.50 m/s)	0.33	Yes
Carbon Monoxide (10 ppm)	1	Yes
Carbon Monoxide (1000 ppm)	586	Yes
Oxygen (19.5 %)	21.5	Yes
Formaldehyde (0.1 ppm)	0	Yes
PM2.5 (0.15 mg/m^3)	0.0563	Yes
PM10 (0.15 mg/m^3)	0.064	Yes
TVOC (3 ppm)	0.0203	Yes
Light Intensity (300 Lux – 500 Lux)	352.6	Yes

3.6. Indoor Air Quality Performance in Block B (First Floor)

The indoor environmental quality (IEQ) assessment for Block B (First Floor), as summarised in Table 7, reveals a pattern of partial compliance, where indoor air quality (IAQ) parameters generally meet recommended standards, while thermal comfort and lighting conditions fall short of acceptable limits. From a thermal comfort perspective, the average indoor air temperature was recorded at 29.6 °C, exceeding the recommended range of 23 – 26 °C. The Malaysian Standard MS1525:2019 recommends a design dry bulb temperature range of 24°C to 26°C for indoor environments [13]. This elevated temperature suggests that the indoor space is consistently warm and may lead to occupant discomfort, reduced concentration, and decreased productivity. The issue is further intensified by the relative humidity level of 71.2%, which slightly exceeds the acceptable upper limit of the acceptable range of 40 – 70% [12], [15]. The recommended design range according to MS1525:2019 standards, which is 50% to 70% [13]. According to established standards such as MS1525:2019, maintaining both temperature and humidity within prescribed ranges is essential for achieving optimal thermal comfort. Air movement was measured at 0.195 m/s, which falls within the acceptable range of 0.15 – 0.50 m/s. The Malaysian Standard MS1525:2019 recommends an air movement also range of 0.15 m/s to 0.50 m/s for indoor environments [13]. This shows that air circulation within the space is adequate. However, similar to observations in other areas, the presence of acceptable air velocity does not compensate for the elevated thermal conditions. Carbon monoxide concentration was recorded at 1 ppm, well below the permissible limit, showing negligible combustion-related pollution. Carbon dioxide levels were measured at 385 ppm, which is significantly below typical threshold values, suggesting adequate fresh air supply and good ventilation performance. Oxygen concentration remained within the normal atmospheric range at 20.8%, confirming that the indoor environment is not oxygen-deficient. Additionally, formaldehyde concentration was negligible (0 ppm), showing minimal emissions from building materials or indoor furnishings. Particulate matter concentrations, including PM2.5 (0.051 mg/m^3) and PM10 (0.054 mg/m^3), were within acceptable limits, suggesting low levels of indoor particulate pollution and effective filtration or limited external intrusion. The total volatile organic compounds (TVOC) level of 0.016 ppm further supports this finding, as it is substantially below the recommended threshold, showing a low presence of chemical contaminants. However, the evaluation of lighting conditions reveals a notable deficiency. The measured light intensity of 240.6 lux falls below MS1525:2019 provides recommended illuminance (lux) levels for class room range of 300 – 500 lux for educational environments. Insufficient lighting can negatively impact visual comfort, increase eye strain, and reduce task performance, particularly in academic settings where adequate illumination is critical.

Table 7. Average parameter for Block B First Floor

Parameter	Average	Compliance
Air Temperature (23 ∘ C - 26 ∘ C)	29.6	No
Relative Humidity (40 % - 70 %)	71.2	No
Air Movement (0.015 m/s - 0.50 m/s)	0.195	Yes
Carbon Monoxide (10 ppm)	1	Yes
Carbon Monoxide (1000 ppm)	385	Yes
Oxygen (19.5 %)	20.8	Yes
Formaldehyde (0.1 ppm)	0	Yes
PM2.5 (0.15 mg/m^3)	0.051	Yes
PM10 (0.15 mg/m^3)	0.054	Yes
TVOC (3 ppm)	0.016	Yes
Light Intensity (300 Lux – 500 Lux)	240.6	No

3.7. Indoor Air Quality Performance in Block C (Ground Floor)

The indoor environmental quality (IEQ) evaluation for Block C (Ground Floor), as presented in Table 8, shows a similar trend to the previously analysed zones, where most indoor air quality (IAQ) parameters comply with recommended standards, while thermal comfort and lighting conditions remain below acceptable levels. The average indoor air temperature was recorded at 31 °C, which is substantially higher than the recommended range of 23 – 26 °C, making it the highest temperature observed among all monitored locations. The Malaysian Standard MS1525:2019 recommends a design dry bulb temperature range of 24°C to 26°C for indoor environments [13]. This shows severe thermal discomfort and suggests that the space is highly susceptible to heat accumulation. Similarly, the relative humidity level of 76.1% exceeds the acceptable range of 40 – 70% [12], [15], further intensifying the thermal discomfort experienced by occupants. The recommended design range according to MS1525:2019 standards, which is 50% to 70% [13]. Elevated humidity reduces the body's ability to dissipate heat through evaporation, thereby increasing the perceived temperature. The combination of high temperature and humidity shows inefficient removal of both sensible and latent heat, pointing to potential limitations in ventilation effectiveness or the absence of adequate dehumidification mechanisms. Air movement was measured at 0.425 m/s, which lies within the recommended range of 0.15 – 0.50 m/s and is comparatively higher than values recorded in other blocks. The Malaysian Standard MS1525:2019 recommends an air movement also range of 0.15 m/s to 0.50 m/s for indoor environments [13]. This shows relatively strong air circulation within the space. Carbon monoxide concentration was recorded at 1 ppm, showing negligible exposure to combustion-related pollutants. Carbon dioxide levels were measured at 393.5 ppm, which is well below the permissible limit, suggesting effective ventilation and adequate fresh air supply. Oxygen concentration was recorded at 21.95%, remaining within the normal atmospheric range and confirming that the indoor environment is not oxygen-deficient. Formaldehyde concentration was measured at 0.001 ppm, which is extremely low and shows minimal emission from indoor materials or furnishings. Particulate matter concentrations, including PM2.5 (0.0645 mg/m^3) and PM10 (0.0735 mg/m^3), were within acceptable limits, although slightly higher than those observed in Blocks A and B. This may be attributed to the ground floor location, which is more exposed to outdoor pollutant infiltration, dust resuspension, and occupant movement. Despite this, the levels remain within safe thresholds and do not show significant particulate pollution. Similarly, the total volatile organic compounds (TVOC) concentration of 0.0166 ppm reflects very low levels of chemical pollutants, further confirming good IAQ performance. However, lighting conditions in Block C (Ground Floor) are below the recommended standard. The measured light intensity of 207.6 lux is significantly lower than MS1525:2019 provides recommended illuminance (lux) levels for class room range of 300 – 500 lux for educational environments. This limitation suggests inadequate illumination, which may negatively affect visual comfort, increase eye strain, and reduce occupant productivity in class room.

Table 8. Average parameter for Block C Ground Floor

Parameter	Average	Compliance
Air Temperature (23 ∘ C - 26 ∘ C)	31	No
Relative Humidity (40 % - 70 %)	76.1	No
Air Movement (0.015 m/s - 0.50 m/s)	0.425	Yes
Carbon Monoxide (10 ppm)	1	Yes
Carbon Monoxide (1000 ppm)	393.5	Yes
Oxygen (19.5 %)	20.8	Yes
Formaldehyde (0.1 ppm)	0	Yes
PM2.5 (0.15 mg/m^3)	0.051	Yes
PM10 (0.15 mg/m^3)	0.054	Yes
TVOC (3 ppm)	0.016	Yes
Light Intensity (300 Lux – 500 Lux)	240.6	No

3.8. Indoor Air Quality Performance in Block C (First Floor)

The measured indoor environmental parameters for Block C (first floor) are presented in Table 9. The results show that while most indoor air quality (IAQ) parameters comply with recommended standards, thermal comfort and lighting conditions remain below acceptable levels. The average indoor air temperature was recorded at 31.26°C, which significantly exceeds the recommended range of 23 – 26°C. The Malaysian Standard MS1525:2019 recommends a design dry bulb temperature range of 24°C to 26°C for indoor environments [13]. This represents the highest temperature observed among all monitored locations, showing severe thermal stress within the indoor environment. Relative humidity was measured at 71.22%, slightly exceeds the acceptable range of 40 – 70% [12], [15], further contributing to thermal discomfort. The recommended design range according to MS1525:2019 standards, which is 50% to 70% [13]. The elevated temperature and humidity suggest substantial heat accumulation, potentially influenced by building orientation, solar heat gain, and high occupant density. Air movement was measured at 0.36 m/s, which is within the acceptable range (0.15 – 0.50 m/s) and higher than many of the previously assessed locations. The Malaysian Standard MS1525:2019 recommends an air movement also range of 0.15 m/s to 0.50 m/s for indoor environments [13]. This shows relatively good air circulation however, similar to other blocks, the airflow is insufficient to offset the high thermal load. This highlights the limitation of relying solely on natural ventilation for maintaining thermal comfort in tropical climates. In terms of gaseous pollutants, carbon monoxide (0.6 ppm) and carbon dioxide (321.26 ppm) concentrations were well within permissible limits. The relatively low CO2 concentration shows effective ventilation and low occupant-generated pollutant accumulation, suggesting that the space is not overcrowded and that fresh air supply is adequate. Oxygen concentration was recorded at 21.34%, which is within the normal atmospheric range, confirming adequate air quality with respect to oxygen availability. Formaldehyde concentration (0.0014 ppm) was negligible and well below the recommended limit, showing minimal emission from indoor sources. Particulate matter concentrations, including PM2.5 (0.0476 mg/m³) and PM10 (0.0532 mg/m³), were within acceptable limits. These values suggest moderate particulate presence, possibly due to indoor activities or outdoor infiltration, but not at levels that pose significant health risks. Similarly, total volatile organic compounds (TVOC) were recorded at 0.0194 ppm, showing low levels of chemical pollutants and generally good air quality. However, light intensity was measured at 248.8 lux, which is below the recommended range of 300 – 500 lux. The Malaysian Standard MS1525:2019 provides recommended illuminance (lux) levels for class room indoor environments to ensure adequate visibility, safety, and comfort while minimizing energy use. This shows insufficient lighting conditions, which may affect visual comfort, reading ability, and overall learning performance in the classroom environment.

Table 9. Average parameter for Block C Ground Floor

Parameter	Average	Compliance
Air Temperature (23 ∘ C - 26 ∘ C)	31.26	No
Relative Humidity (40 % - 70 %)	71.22	No
Air Movement (0.015 m/s - 0.50 m/s)	0.36	Yes
Carbon Monoxide (10 ppm)	0.6	Yes
Carbon Monoxide (1000 ppm)	321.26	Yes
Oxygen (19.5 %)	21.34	Yes
Formaldehyde (0.1 ppm)	0.0014	Yes
PM2.5 (0.15 mg/m^3)	0.0476	Yes
PM10 (0.15 mg/m^3)	0.0532	Yes
TVOC (3 ppm)	0.0194	Yes
Light Intensity (300 Lux – 500 Lux)	248.8	No

4. CONCLUSIONS

This study evaluated indoor air quality (IAQ) conditions in a primary school environment using a multi-parameter monitoring approach and compliance assessment based on the Industry Code of Practice on Indoor Air Quality 2010 (ICOP-IAQ 2010) and MS1525:2019 standards. The findings demonstrate that, overall, the indoor environment meets acceptable standards for most chemical and particulate pollutants, showing effective ventilation and low levels of contamination across all monitored blocks. However, the results consistently reveal non-compliance in thermal comfort parameters, particularly air temperature and relative humidity. Elevated temperature levels, exceeding 29°C in most locations and reaching above 31°C in certain areas, combined with high relative humidity levels (above 70%), show widespread thermal discomfort. These conditions are more pronounced in upper floors, suggesting the influence of solar heat gain and building design on indoor environmental performance. Even with adequate air movement, natural ventilation alone was insufficient to regulate thermal conditions effectively. In addition, light intensity measurements showed variability across different locations, with several areas failing to meet the recommended illuminance levels. This highlights the importance of considering visual comfort as part of overall indoor environmental quality (IEQ). The study concludes that compliance with IAQ standards for pollutants does not necessarily ensure overall occupant comfort, as thermal and visual factors play equally important roles. Therefore, a more comprehensive approach is required to improve indoor environmental conditions in school buildings.

ACKNOWLEDGEMENTS

Communication of this research is made possible through monetary assistance by Universiti Tun Hussein Onn Malaysia, and this research was also supported by Universiti Tun Hussein Onn Malaysia (UTHM) Research Management Center (RMC) provided through the GPPS (vot J053).

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