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Evaluation Thermal Comfort based on PMV and PPD using CBE Tool for Three Non-Air-Conditioned Pre School: A Case Study in Melaka Tengah, Malaysia District Area

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ABSTRACT

Thermal comfort plays an important role in educational environments, which has a profound effect on the physical and mental health of children. The objective of this study is to assess the thermal comfort levels, specifically the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD), in three non-air-conditioned preschools (Pre-school A, B and C) situated in the residential region of Melaka Tengah, Malaysia. The ASHRAE Standard 55 (2023) were used for evaluation of PMV and PPD based on Fangers Model. Data on indoor temperature, relative humidity, and air velocity were collected in three preschools from 08:00 to 14:00 in accordance with the Industry Code of Practice of Indoor Air Quality by the Department of Occupational Safety and Health 2010 (ICOP, DOSH Malaysia). The PMV and PPD were calculated using the CBE tool version 2.5.6. The calculations were based on a metabolic rate of 1.0 met for the activity of "Seated, relaxed" and a clothing insulation level of 0.61 clo (trousers and long-sleeve t-shirt). The findings suggest that the air temperatures in all three preschools are constantly above the suggested comfort range of 27°C to 35.5°C. Overall, the environmental conditions found in these preschools indicate a notable level of thermal discomfort based on PPD, which is above 95% PPD for all the preschools. The high PMV and PPD highlight the urgent requirement for better ventilation, adjustments in building design, and improved environmental controls to guarantee a healthier and more comfortable interior environment for preschool children and staff.

1.0 INTRODUCTION

The issue of thermal comfort and indoor air quality (IAQ) is a significant concern that often arises in relation to comfort. The primary concern for both the environment and the occupants is ensuring optimal comfort (Merabtine et al., 2018). According to the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE, 2020), thermal comfort refers to a mental state of being satisfied with the temperature of the surroundings, and it is evaluated subjectively. Thermal comfort is crucial in all areas as it directly impacts productivity and health. In general, inadequate thermal comfort typically results in reduced productivity, health issues, and minimal satisfaction with the temperature among occupants (Rahman et al., 2020; Sahimi et al., 2024).

Individuals generally experience improved well-being when the ambient temperature ranges from 23℃ to 26℃, accompanied by a relative humidity of 40% to 70% (DOSH Malaysia, 2010). The level of thermal comfort significantly impacts the productivity of individuals occupying a space. According to the study conducted by Kaushik et al., (2020), the ambient temperature impacted the productivity of the individuals present. The ideal temperature range for occupant comfort in a building is from 21℃ to 25℃, if the temperature exceeds 25℃, the productivity of the people will decrease.

Thermal comfort in a classroom is crucial for optimal academic performance (de Abreu-Harbich et al., 2018). The well-being and comfort of children are influenced by thermal comfort. They exhibit greater sensitivity to elevated temperatures compared to adults (Rahman et al., 2019). The majority of the pupils' time is spent in the classroom. According to a study by Jiang et al., (2018), there is a correlation between discomfort and the surrounding temperature, whether it is hot or cold. This correlation has a negative impact on the well-being of inhabitants. The students may experience pain if the clothing they wear is very thick or thin. Therefore, it is necessary for them to don attire that is both comfy and suitable for the prevailing environmental conditions to prevent any discomfort. The academic performance of pupils, including their attention, focus, and learning abilities, can be influenced by the environmental conditions in the classroom (Zhang et al., 2022). Regardless of whether it is in primary, secondary, or tertiary education institutions, it is inconsequential.

In Malaysia, the Ministry of Education (MOE) has established guidelines for student attire based on the need for comfort in the country's hot and humid tropical climate. This is because the attire that was worn can impact the learning process, aptitude, and enthusiasm for academic engagement in school (Cen et al., 2024). Furthermore, the presence of a pleasant fabric might provide a more conducive learning environment for kids. MOE reports that there are a total of 10,225 schools in Malaysia, including preschools, primary schools, and secondary schools. The annual student enrolment is 4,795,600, while the number of teachers is 413,022. Malaysia has a total of 6,214 preschools, with 170 of them located in Malacca (Educational Planning and Research Division, 2022). The preschool aims to facilitate students' acquisition of fundamental skills, such as learning and exploration, in preparation for their transition to primary school. The Ministry of Education Malaysia stipulates that the age range for students to enter preschools is from four to six years old. This institution is primarily divided into two sectors: government institutions and private institutions.

Preschools are typically situated in areas such as roadside locations, residential areas, or even within school premises (Alif et al., 2020). Usually, private kindergartens provide an air conditioning system in the classrooms to ensure comfortable conditions for various activities. In contrast, government institutions rely solely on fans for ventilation.The Predicted Mean Vote (PMV) model, initially introduced by Fanger, (1967), is a highly acknowledged and frequently used approach in the field of thermal comfort. The equation is a mathematical model that relates thermal comfort to the ambient circumstances in the region. It considers important factors such as clothing insulation, metabolic rate, air velocity, and mean radiant temperature. The PMV model offers a prognostic indicator that approximates the average thermal experience of a sizable population on a seven-point thermal sensation scale, spanning from -3 (cold) to +3 (hot). PMV value of zero indicates a state of thermal neutrality when the thermal conditions are neither excessively hot nor excessively cold. PMV value between -0.5 and +0.5 is deemed to indicate a satisfactory level of thermal comfort (ter Mors et al., 2011). This online tool is adaptable, as it supports multiple thermal comfort models essential for studying and applying environmental ergonomics. These include PMV model, the adaptive comfort model, the Standard Effective Temperature (SET) model, and several discomfort models.

The CBE Thermal Comfort Tool is a valuable resource for individuals seeking to enhance indoor environmental quality, as it provides distinct perspectives on how environmental elements impact human comfort (Almagro-Lidón et al., 2024). The CBE Thermal Comfort Tool is an advanced, free web-based program specifically developed to do comprehensive thermal comfort calculations and produce visual representations that comply with the most recent ASHRAE 55-2020 and EN 16798 Standards (Tartarini et al., 2020). This website has been meticulously developed using recent online technologies, such as JavaScript, HTML, and CSS to ensure its accessibility and ease of use for a range of users, including researchers, engineers, architects, and facility managers.

In addition to the PMV model, the CBE Thermal Comfort Tool includes the adaptable comfort model, which is especially beneficial for buildings that rely on natural ventilation. This model operates under the assumption that individuals are capable of acclimating to a broader spectrum of temperatures provided they possess the ability to manipulate their surroundings, for as by opening windows or modifying their attire. The SET model, a component of the tool, provides a comprehensive assessment of thermal comfort by considering variables such as air circulation and moisture levels in addition to temperature.

This paper aims to evaluate the predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) for three non-air-conditioned pre-schools in the Melaka Tengah district. The study employed the online platform CBE Tool to visually represent and compute the PMV and PPD for preschools A, B, and C during the learning period from 8:00 am to 2:00 pm. This investigation explores the relationship between temperature adaptation in preschool kids and the specific parameters in their surroundings. The improvement of ventilation and thermal comfort levels can assist building owners, departments, and teachers in enhancing student productivity.

2.0 METHODOLOGY

The field investigation was carried out in the district region of Melaka Tengah, Malaysia. This study investigated three preschools, namely Preschool A, Preschool B, and Preschool C, located around 10 kilometres away from the city centre of Melaka. Figure 1 depicts the preschools included in this study, namely Preschool A, Preschool B, and Preschool C. Table 1 presents the detailed specifications of the building in this preschool. Preschool A, B and C occupies a total area of 60 m^2, 72 m^2 and 52 m^2 respectively. The ceiling height for pre-school A and B is 2.9 meters, whereas pre-school C has a ceiling height of 2.8 meters. The preschool is a government building that is without air conditioning and relies on four ceiling fans for each school. Each preschool has an approximate student population of 15 to 20. These preschools are situated in residential areas and along roadsides. The environmental factors chosen for indoor sampling include air temperature (˚C), relative humidity (%), and air speed (m/s), which are measured using the TSI Velocicalc. Indoor sampling was conducted for a duration of 6 hours, in accordance with the operating hours of the preschool. The instruments were positioned at the center of the classroom using a tripod. Each probe was positioned at the height of 1 meter on the tripod to prevent any obstructions that could impede the flow of air. The techniques used to measure the levels of indoor air pollutants (such as samples interval time, sampling position, sampling duration, and the method used for sampling) were conducted in accordance with the Industry Code of Practice on Indoor Air Quality 2010 (DOSH Malaysia, 2010).

(a) (b) (c)

Figure 1. Pre-school involved in data collection (a) Pre-school A, (b) Pre-school B, and (c) Pre-school C.

Table 1. Specifications of Pre-school A, B and C

Specifications	Pre-school A	Pre-school B	Pre-school C
Metabolic rate	1	1	1
Clothing level	0.61	0.61	0.61
Activity	Seated, quiet	Seated, quiet	Seated, quiet
Population	16	15	16
Size (m^2)	60	72	52
Ceiling height (m)	2.9	2.9	2.8

The PMV is a mathematical model or equation proposed by Fanger (1967) that correlates thermal comfort with the surrounding environment. The equation demonstrates how multiple factors, such as clothing insulation, metabolic rate, air velocity, and mean radiant temperature, can affect the value of thermal sensation. When the PMV is equal to zero, it indicates thermal balance. Additionally, according to Ter Mors et al., (2011), the recommended limit for PMV is -0.5 < PMV < +0.5. The PMV, is an index used to estimate the average value of a larger population's thermal sense on a seven-point scale. The measurement can be determined using the seven-point thermal sensation scale, ranging from -3 (indicating cold) to +3 (indicating hot). The equations were derived based on the association between PMV (Predicted Mean Vote) and heat load, as demonstrated at Equation 1 below:

$$PMV = (0.303\exp{-0.0336M} + 0.028) \times \{(M - W) - 3.5 \times 10{-3} [5733 - 6.99 (M - W) - pa] - 0.42(M - 58.5) - 1.7 \times 10{-5} \times M (5867 - pa) - 0.0014M (34 - ta) - 3.96 \times 10{-8}\, fcl\, [(tcl + 273)4 - (tr +273)4] - fcl \times hc\, (tcl - ta)] \quad \text{(Eq. 1)}$$

Where;

M: is the metabolic rate, in Watts per square meter of the body surface area
W: is the effective mechanical power, inWatts per square meter, equal to zero for most activities
fcl: is the ratio of surface area of the body with clothes to the surface area of the body without clothes
ta: is the air temperature, in degree Celsius
tr: is the mean radiant temperature, in degree Celsius
Pa: is the water vapor partial pressure, in Pascal
hc: is the convective heat transfer coefficient, in Watts per square meter degree Celsius
tcl: is the clothing surface temperature, in degree Celsius
L = Thermal load (the difference between the internal heat production and the heat loss to the actual environment - for a person at comfort skin temperature and evaporative heat loss by sweating at the actual activity level.

Using the PMV, the estimation of the thermal perception of a group of people. However, it is important to note that this method does not provide a complete understanding of the situation. The reason is the people's level of satisfaction in the specific area and how to attain thermal comfort. Fanger continues with developing a further equation to determine the relationship between the PMV and the PPD. It is used to quantify the proportion of individuals who experience discomfort in their immediate surroundings, as stated by Ekici (2013). PPD, is a quantitative measure used to forecast the level of discomfort or dissatisfaction experienced by occupants who feel either too cold or too warm (Fang et al., 2018). That is precisely the purpose of the PPD index. The PPD can be determined as a function of the PMV using the equation 2 below:

$$PPD = 100 - 95\ X\ e\ (-0.3353\ x\ PMV4 - 0.2179\ x\ PMV2) \quad \text{(Eq. 2)}$$

Table 2 illustrates the average data collected in the Preschool A, B, and C. Temperature, air speed and relative humidity were inserted into CBE tool web. In this research, CBE tool version 2.5.6 was used, and the interface of the CBE tool is presented in Figure 2 below. An assessment of the students' clothing was carried out throughout the ongoing investigations. Observations of preschool students revealed that their clothing choices were aligned with traditional gender norms, with some students wearing long sleeves and others wearing short sleeves. Female students are identified by their attire of long sleeves and long trousers, whereas male students are distinguished by their short sleeves. Aside from that, a few pupils were attired in skirts, scarves, and socks. It is crucial for students to wear clothing insulation (clo) that complies with ASHRAE 55-2023 criteria, namely 0.61, during the learning process as it directly affects their comfort levels. The metabolic rate in metabolic equivalents (met) for the category "Seated, relaxed" (met = 1.0) can be determined by performing calculations and utilising the CBE tool (Zhao et al., 2019).

Table 2. Temperature, air velocity and relative humidity collected at Pre-school A, B and C.

	Pre School A			Pre School B			Pre School C		
Time	Temp (˚C)	Air speed (m/s)	RH (%)	Temp (˚C)	Air speed (m/s)	RH (%)	Temp (˚C)	Air speed (m/s)	RH (%)
08:00	27.5	0.481	85.44	27.0	0.516	88.6	27.2	0.504	87.8
09:00	28.0	0.475	81.06	28.2	0.398	85.6	28.1	0.410	85.5
10:00	28.8	0.357	81.48	28.5	0.270	88.8	29.8	0.343	79.3
11:00	29.3	0.320	79.94	29.8	0.176	79.3	30.1	0.271	75.1
12:00	30.0	0.242	78.79	30.3	0.113	77.0	32.2	0.240	69.4
13:00	31.4	0.196	77.98	31.4	0.141	76.0	33.1	0.187	67.9
14:00	32.6	0.176	76.00	32.5	0.152	73.2	33.5	0.150	67.02

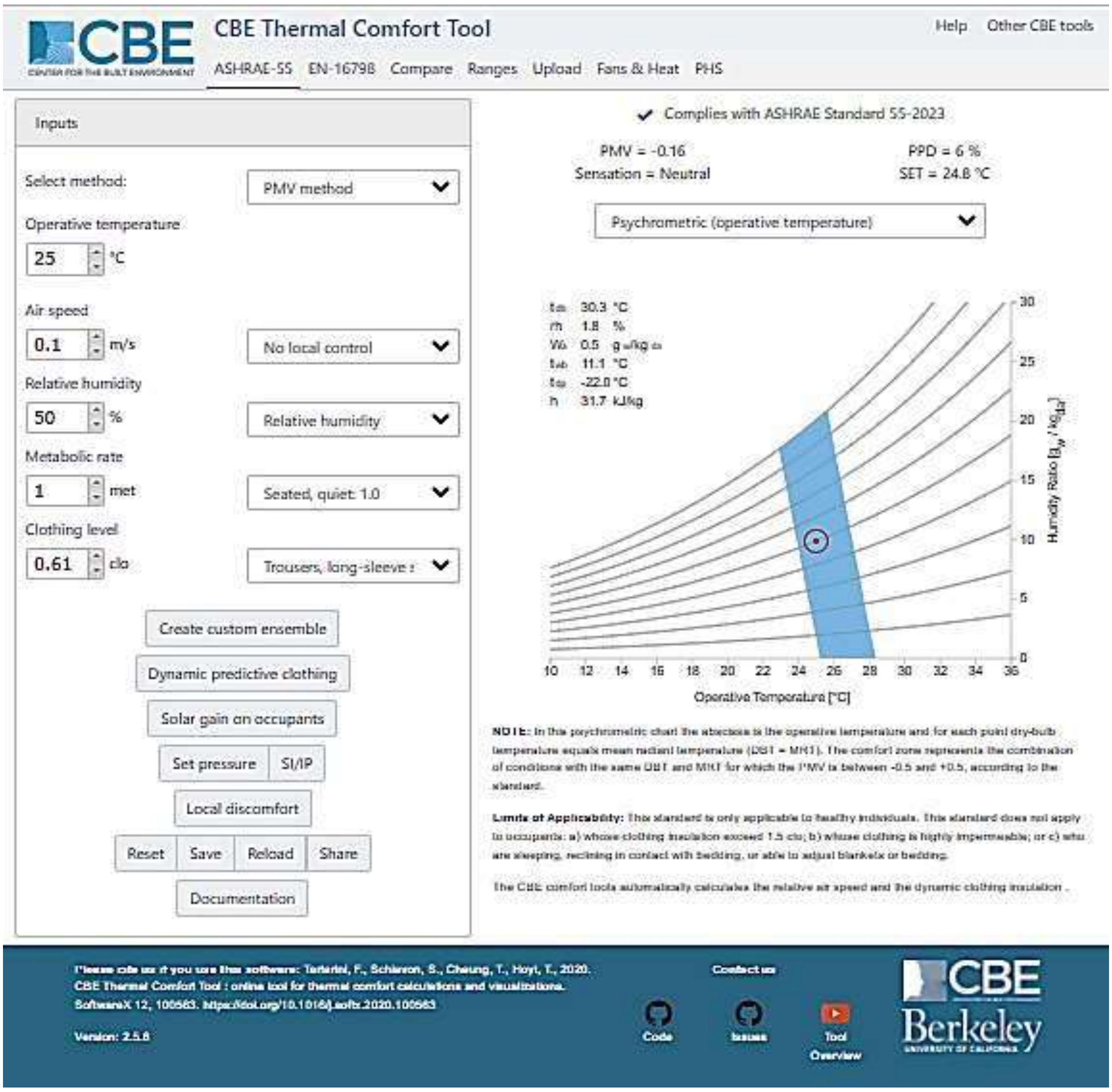

Figure 2. Interface of CBE tool use for PMV and PPD evaluation.

3.0 RESULT AND DISCUSSION

Figure 3 shows the temperature of preschools A, B, and C. Overall, the air temperature of these preschools is above the acceptable range, which is between 27 ˚C to 35.5 ˚C. All preschool's temperatures start around 27.5 ˚C at 8.00 am and start to increase until 2 pm, with each preschool experiencing different rates of increase. Pre-school B shows the highest temperature obtained at 32.5 ˚C. Preschool A shows the lowest temperature collected among Preschool B and C. Preschool C shows the highest temperature collected, especially at 10.00 am. All temperatures for all pre-schools are above recommended limit by ICOP DOSH 2010 Malaysia, which set around 23-26 ˚C. Figure 4 shows the relative humidity at three different preschools. At the beginning of the monitoring period at 08:00, the relative humidity is at its peak in all preschools, with values ranging from 84% to 88%. As the day goes on, the relative humidity declines in all three locations, although each preschool experiences a different rate of decline. Between 08:00 and approximately 11:00, the relative humidity consistently decreases in all three preschools. Preschool C, experiences the most significant decline, dropping from approximately 86% at 08:00 to nearly 78% at 11:00. Preschool B has a more gradual decrease, consistently retaining elevated levels of humidity in comparison to the other two preschools during the morning. At 11:00, the humidity remains above 80%. Preschool A exhibits a correlation between Preschool B and C, as its relative humidity steadily decreases, but not as dramatically as in Preschool C. The observed pattern indicates that Preschool C is undergoing a more rapid decrease in humidity, possibly as a result of its specific environmental or structural factors, such as increased exposure to direct sunlight or more efficient ventilation, which may be facilitating faster evaporation of moisture (Cen et al., 2024). During the afternoon, specifically from 11:00 to 14:00, all three preschools still have a decrease in relative humidity, albeit it is happening at a slower pace than in the morning. At 14:00, Preschool C has the lowest relative humidity, measuring at 72%. Preschool A follows with an approximate humidity of 74%, while Preschool B has a humidity level of about 76%. The variations in relative humidity levels among the preschools can be ascribed to several reasons, such as disparities in construction materials, insulation, ventilation systems, and surrounding environment (de Abreu-Harbich et al., 2018). These findings emphasise the need of considering environmental controls and building design when it comes to maintaining optimal indoor humidity levels (Zaraa Allah et al., 2023). This is especially crucial in educational settings, where air quality can have a substantial impact on the comfort and health of occupants. Figure 5 depicts the temporal fluctuations in air velocity at three distinct preschools, denoted as Preschool A, Preschool B, and Preschool C, between the hours of 08:00 and 14:00. At the beginning of the observation period at 08:00, the air velocity is relatively high in all preschools, especially in Preschool A, where it surpasses 0.45 m/s. Nevertheless, it shows gradual decrease in air speed in all three preschools.

During the morning hours, specifically from 08:00 to approximately 11:00, there is a substantial reduction in air velocity. Preschool A exhibits the highest starting air velocity but undergoes a swift decrease, reaching a stable value of approximately 0.25 m/s by 11:00. Preschool C, exhibits a comparable pattern but with a significantly reduced speed, decreasing from around 0.35 m/s to 0.2 m/s over the same time frame. Preschool B begins with the lowest air velocity and has a progressive decrease, reaching around 0.15 m/s by 11:00. These trends indicate that the airflow in Preschool A and C starts off stronger but decreases more quickly, either because of alterations in ventilation systems, environmental conditions, or less movement of outdoor air as the day goes on.

During the afternoon, specifically from 11:00 to 14:00, the speed of air movement continues to drop, albeit at a reduced pace compared to the morning. At 14:00, the air velocities in all three preschools decrease. Preschool A has somewhat higher levels at around 0.2 m/s, Preschool C is just below 0.2 m/s, and Preschool B is around 0.1 m/s. The persistent drop in air velocity seen in all preschools may be attributed to variables such as reduced wind speed outdoors, decreased mechanical ventilation, or increased stability of indoor conditions as the day progresses. The variations in air velocity observed among the preschools suggest that Preschool A may possess superior ventilation or location, enabling a slightly higher airflow. Conversely, Preschool B, exhibiting the lowest velocity, may be situated in a more confined space or have less efficient ventilation. Comprehending these air velocity patterns is essential for evaluating the quality of air and level of comfort indoors, especially in settings such as preschools where sufficient airflow is vital for sustaining a healthy and pleasant indoor environment (Daghigh, 2015).

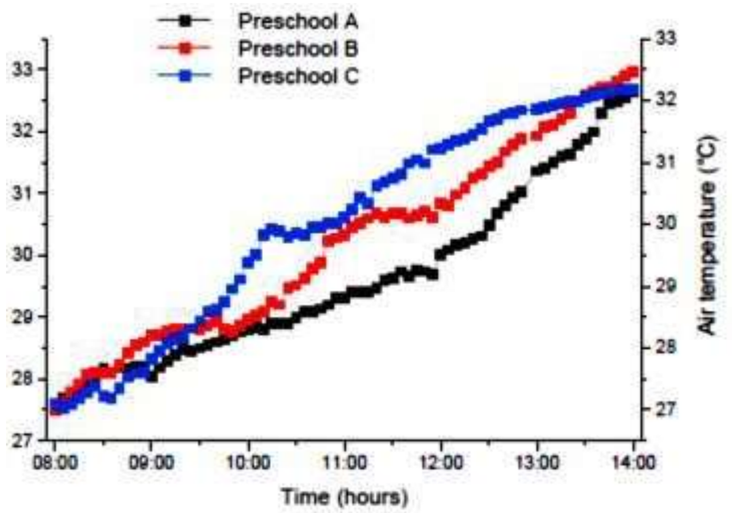

Figure 3. Temperature distribution for Preschool A, B and C

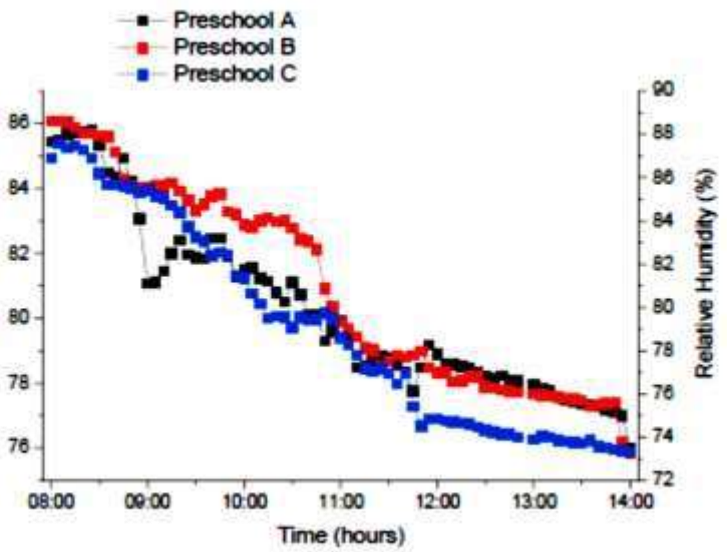

Figure 4. Relative humidity distribution for Preschool A, B and C

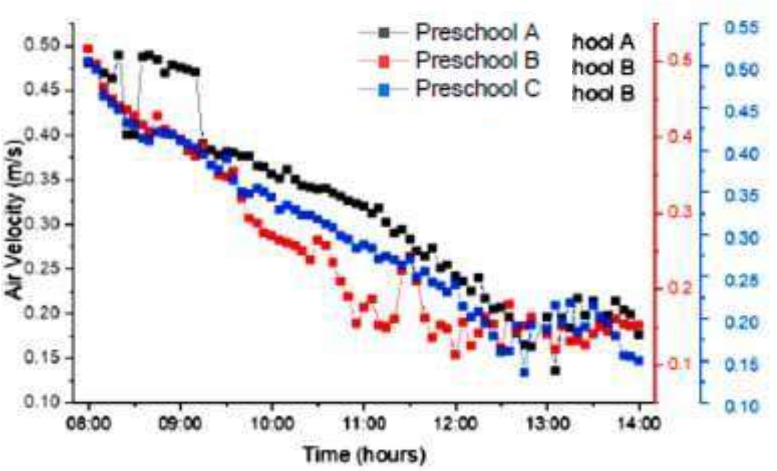

Figure 5. Air speed distribution for Preschool A, B and C

Table 3 displays data on PMV and PPD at all three preschools (A, B, and C) over different time intervals from 08:00 to 14:00 hours. At 08:00, the PMV readings for all three preschools are reasonably low, suggesting that the conditions in the surroundings are generally pleasant and comfortable. Preschool A has a PMV of 0.32, while Preschool B and C have even lower PMVs of 0.12 and 0.21, respectively. The PPD for Preschool A, Preschool B, and Preschool C at 08:00 are 7%, 5%, and 6%, respectively, indicating that only a minority of individual's experience discomfort. This is corresponded to ambient temperature that is low in the morning. Nevertheless, starting at 09:00 and particularly at 10:00, the PMV values experience a substantial increase in all preschools. At 10:00, Preschool C has the PMV value of 1.36, which corresponds to a PPD value of 43%. This indicates that the occupants are experiencing increasing discomfort (Fabbri, 2013; ter Mors et al., 2011). The tendency persists as the day advances as per temperature rise in the preschools, with PMV values experiencing a significant increase by 11:00.

Preschool C has the highest PMV of 1.76, with Preschool B following behind at 1.70. The PPD scores for these preschools are 65% and 62% respectively, indicating that a considerable proportion of the individuals there are expected to experience discomfort. At 12:00, the PMV values increase even more, with Preschool C attaining a PMV of 2.30 and a corresponding PPD of 88%. This suggests that almost 90% of individuals are unhappy with the heat rise. Preschool B is characterised by a high level of discomfort, shown by a PMV of 2.02 and a PPD of 77%. On the other hand, Preschool A, although slightly lower, nonetheless exhibits a PMV of 1.54 and a PPD of 53%. During the afternoon, there is a significant increase in thermal discomfort in all preschools. At 13:00, Preschool C has the highest PMV value of 2.73 and a PPD of 97%, indicating that almost everyone is unhappy with the temperature. Preschool B has a PMV of 2.40 and a PPD of 91%. Preschool A, albeit being lower, nevertheless exhibits notable unease with a PMV score of 2.18 and a PPD score of 84%. By 14:00, all preschools experience a significant degree of discomfort, as seen by Preschool C's PMV of 3.02 and a PPD of 99%, which is close to the highest amount of discomfort imaginable. Preschools A and B both demonstrate significant discomfort, as indicated by PMV values of 2.72 and 2.71, and corresponding PPDs of 97% (Azli et al., 2022; Cen et al., 2024).

Table 3. PMV and PPD value based on CBE tool evaluation for Preschool A, B and C.

	Pre School A		**Pre School B**		**Pre School C**	
Time	PMV	PPD (%)	PMV	PPD (%)	PMV	PPD (%)
08:00	0.32	7	0.12	5	0.21	6
09:00	0.46	9	0.67	14	0.62	13
10:00	0.90	22	0.96	25	1.36	43
11:00	1.13	32	1.70	62	1.76	65
12:00	1.54	53	2.02	77	2.30	88
13:00	2.18	84	2.40	91	2.73	97
14:00	2.72	97	2.71	97	3.02	99

4.0 CONCLUSION

This study examined the assessment of thermal comfort using the CBE instrument in three distinct non-air-conditioned preschools situated in the Melaka Tengah district. Indoor sampling was undertaken in pre-schools to analyse the PMV and PPD depending on certain criteria such as temperature, relative humidity, and air speed. The evaluation of the environmental factors in the three preschools, namely A, B, and C, reveals a distinct and worrisome pattern of discomfort caused by temperature during the entire day. All the measured variables surpass the acceptable criteria for comfort. The ambient temperature in all preschools constantly exceeds the permissible range of 23-26°C set by ICOP DOSH 2010 Malaysia. It reaches a maximum of 32.5°C in Preschool B by 14:00. The continuous rise in temperature is accompanied by a notable decrease in relative humidity, especially in Preschool C, where humidity decreases from 86% at 08:00 to 72% by 14:00. The significant decrease in humidity levels, along with increasing temperatures, indicates that the indoor conditions in these preschools grow progressively uncomfortable and potentially detrimental to health as the day goes on. Moreover, the examination of air velocity demonstrates a consistent reduction in airflow in all preschools. Preschool A exhibits the highest air velocity, which diminishes immediately and then stabilises at lower levels by lunchtime. The decrease in air speed, along with elevated temperatures and decreased humidity, results in an oppressive indoor atmosphere, especially in Preschool C, where the combination of these environmental conditions causes the most severe degrees of thermal discomfort. The disparity in air velocity among the preschools also contribute to the potential lack of ventilation that could impact air quality and level of comfort. PMV and PPD levels quantify the level of heat discomfort that the occupants experience. In the afternoon, all preschools have PMV values significantly higher than +2, indicating a hot and uncomfortable environment. Preschool C has PPD close to 100%. These findings indicate that the existing environmental conditions in these preschools are insufficient to ensure thermal comfort, especially during the hottest periods of the day. Therefore, it is crucial to implement interventions that focus on enhancing ventilation, optimising building design, and implementing more efficient temperature and humidity controls. This will ensure a healthier and more comfortable indoor environment for the children and staff in educational settings.

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