Recent Trends in Civil Engineering and Built Environment Vol. 5 No. 1 (2024) 262-271

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

The Investigation of Ventilation Strategies on Indoor Thermal Comfort for a Classroom

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DOI: https://doi.org/10.30880/rtcebe.2024.05.01.026
Received 23 June 2022; Accepted 01 January 2024; Available online 30 June 2024

Abstract: Classroom ventilation is paramount when it comes to building a successful learning environment, there are several advantages for both students and teachers in terms of comfort and productivity. Through this study, thermal performance was investigated under ventilation strategies which are combined ventilation, full natural ventilation, fan-assisted natural ventilation. Field measurements were conducted at classroom by considering thermal comfort parameters such as relative humidity, air temperature and ventilation rate. Analysis of thermal comfort for the study cases were performed based on the Predictive Mean Vote index. The results showed that the combined ventilation cases (Case 4) provided the most comfortable hours during the measurement period compared to the other cases with PMV range of -0.91 to 0.85 Meanwhile the case full natural ventilation with fan-assist (Case 3) provided comfortable condition at until the noon time with PMV value of -0.07 to 0.45, while at the later hours the condition become slightly warm (PMV 0.53 to 1.01). The rest of cases, no ventilation (Case 1) and full natural ventilation (case 2) showed non comfortable condition with PMV value more than 0.5 throughout the day. This study showed that the combined ventilation mode is useful when the combination of the continuous comfortable hours under hot outdoor and high air change rate condition is required throughout the day. Meanwhile, if energy efficiency for ventilation is a concern, the application of natural ventilation with higher rate of fan assist can be as the other potential alternative for indoor comfort.

Keywords: Indoor Thermal Comfort, Classroom Ventilation

1. Introduction

Classroom ventilation is vital for creating an effective learning environment, as it helps both learners and educators in terms of comfort and performance. It will not only improve the quality of the air, but it will boost the students' focus and productivity too. Since the rapid spread of pandemic COVID-19 in recent years, there is a substantial risk of inhaling viruses in minute respiratory droplets at short to medium distance [1]. This is even more important for protecting the health and well-being of students and educators. The primary goal of classroom ventilation is to establish indoor environmental

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conditions which lower the threat of health problems among students and reduce their discomfort, as well as to eliminate any unfavourable learning impacts. Inadequate ventilation rates in classrooms have been linked to a high prevalence of acute health complaints in recent studies [2].

Malaysia, a hot and humid tropical climate country, the ventilation is crucial to reach thermal comfort. American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE stated thermal comfort as that condition of mind which is a subjective judgement that reflects satisfactory to the thermal environment [3]. The temperature in the classroom, the air movement or velocity in the classroom, and the humidity in the classroom, radiant temperature and all the factors which considered will affect the student's productivity and studies performance. Therefore, thermal performance of a classroom with the proposed ventilation strategy must be considering at the same time.

It is crucial to evaluate thermal comfort in educational buildings on different educational stage [4]. The aim of this studies is to investigate the thermal performance of the recommended ventilation strategy (natural and combined ventilation) via field investigation in a classroom and to evaluate the thermal comfort of a classroom for each study case.

2. Ventilation Modes for Classroom

2.1 Ventilation

The classroom ventilation modes which were used as case studies in the field measurement are unventilated control, full natural ventilation, natural ventilation with additional fan and combined ventilation. No ventilation is selected as a base line for the ventilation modes. Full natural ventilation is the ventilation that open both doors and windows while combined ventilation is natural ventilation with the presence of air conditioner in 24°C.

2.2 Ventilation Standard/Guide

Based on the previous studies, there are three ventilation strategies which are natural ventilation, that users opened and closed the windows according to the reported indoor carbon dioxide content; mechanical ventilation with continuous airflow and a wind driven exhaust fan (extractor) positioned in the classroom ceiling; and basic ventilation. It is found that there are nasal symptoms among the occupants in mechanically ventilated classroom than in naturally ventilated classroom although the former has the higher ventilation rate and thermal performance [2].

2.3 Thermal Comfort

Thermal comfort indices are commonly employed to forecast occupants' thermal sensation. The Predicted Mean Vote (PMV) index is a useful tool for predicting thermal sensation when levels of physical activity, clothing value, and other thermal comfort criteria are considered [5]. PMV and Predicted percentage dissatisfied (PPD) are used to calculate the measured environmental parameters including air temperature, mean radiant temperature, air velocity, relative humidity and the estimated personal parameters which are clothing level and metabolic rate from the respondents [6]. When compared to the PMV/PPD model with reduced energy use, a field trial in an air-conditioned office building revealed that the adaptive model enhanced occupant thermal acceptability [7].

3. Methodology

The field measurement was conducted in a full-scale building room involve measurement of air temperature, relative humidity and windspeed based on ventilation modes, natural and combined ventilation. The location of case study that is selected for carrying out field assessment of thermal comfort is the typical classroom, BKE1 in G3 building. This room which located on the ground floor of the building at west direction was selected to consider as the worst thermal condition. It is one of the academic buildings in Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja, Batu Pahat district, Johor which has a tropical hot and humid climate all over the years which the average temperature is between 24°C and 32°C. The dimension of selected classroom for field measurement is 9.9 m long, 10.8 m width and height of 2.85 m. It is a concrete structure containing two doors and three windows with total opening ratio of 11%.

(a)

(b)

Figure 3.1: The view of classroom facing (a) at back (b) in front

The field measurement parameters that were recorded in this case study is air temperature, relative humidity, windspeed and globe temperature. A TR-72U sensor was used to record the data for air temperature and humidity during the measurement while HOBO 4-Channel Analog Data Logger and TR-52 with black globe were used for windspeed and globe temperature respectively. The sensors were installed at the centre of the classroom. In this assessment, the each of the ventilation modes were conducted three days in the classroom during daytime (10.00 am to 4.00 pm). The ventilation modes including no ventilation, full natural ventilation, natural ventilation with fan and combined ventilation were assessed as Case 1, 2, 3 and 4 respectively. The classroom consists of two doors located in front of the classroom and three windows with five openings on each window at the back as shown in Figure 3.2.

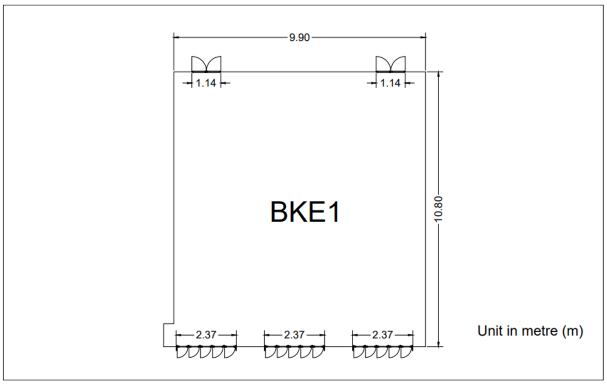


Figure 3.2: The layout of the selected classroom

4. Results and Discussion

4.1 Analysis Based on Ventilation Modes

There are four case studies based on the selected ventilation modes which are no ventilation (base line), full natural ventilation, fan-assisted natural ventilation, and combined ventilation. Each of the ventilation modes were tested three days and the field test were carried out around one months from 18 April 2022 to 23 May 2022. The time of the field measurements was set from 10.00 am to 4.00 pm.

4.1.1 Air Temperature and Mean Radian Temperature

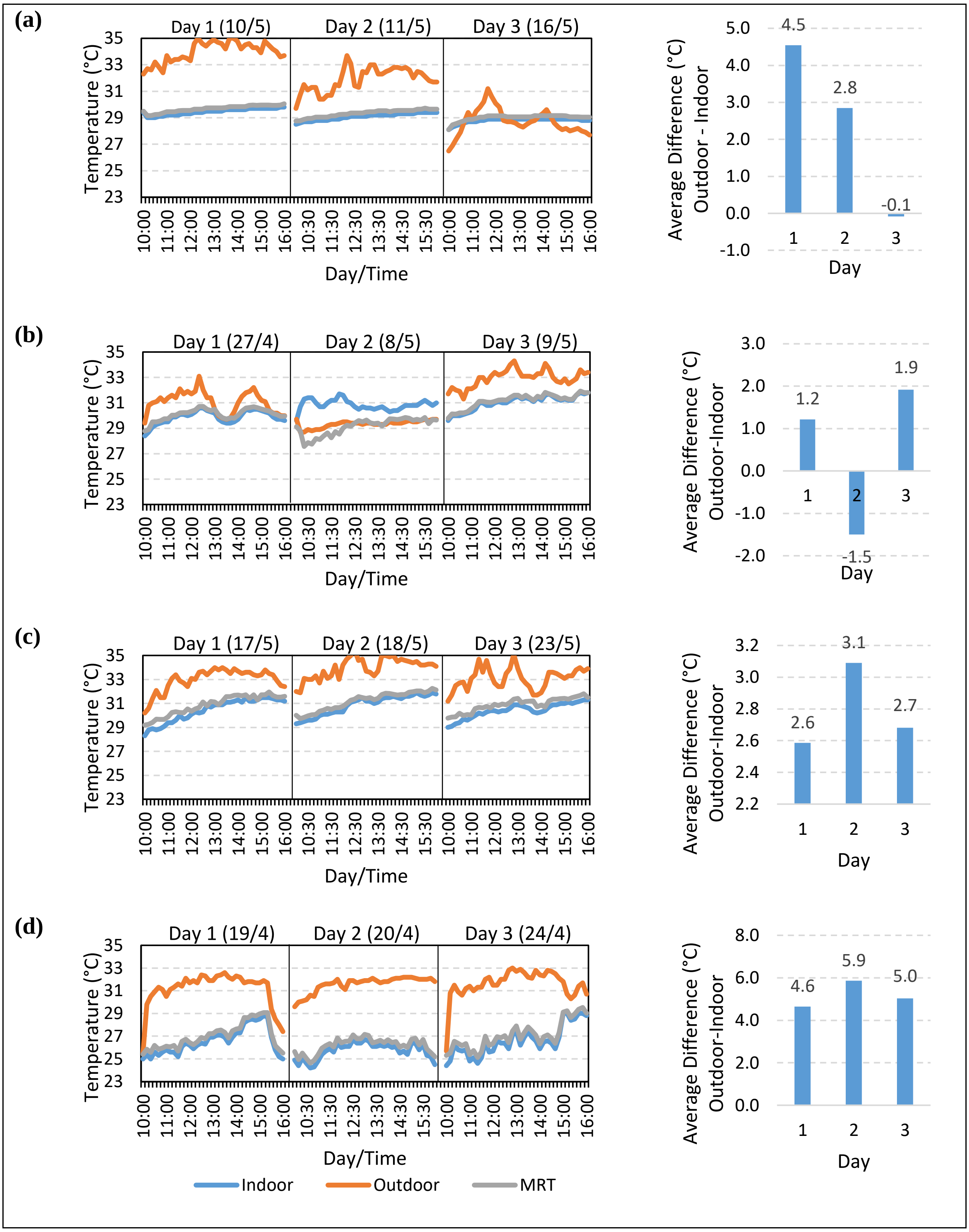


Figure 4.1: Temporal variation of outdoor, indoor, MRT and average difference for each case (a) Case 1 (b) Case 2 (c) Case 3 and (d) Case 4

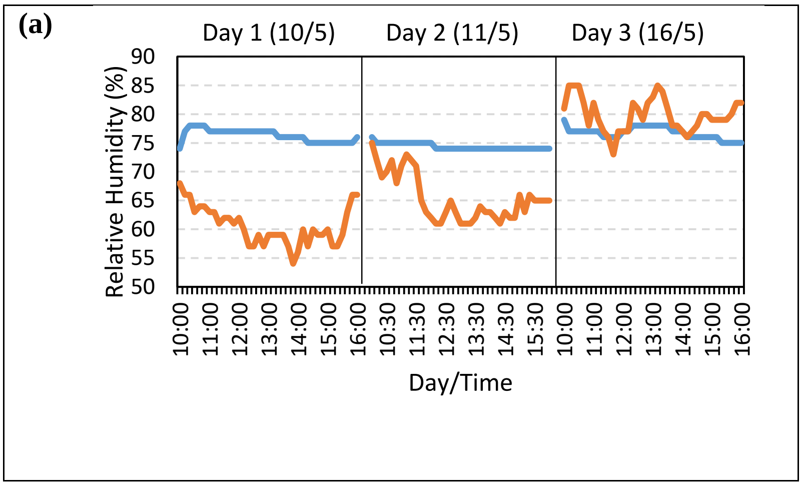
Based on the graph (a) above, it is recorded that the indoor air temperature has not many changes that is around 29°C in average since there is no wind supply, the classroom in this case study in enclosed and there is no any other ventilation system existed. The difference between maximum and minimum value is around 2 degrees due to slight heat radiation of the building. While outdoor air temperature recorded a maximum of 35°C and minimum of 26.5°C with an average 31.5°C. There is a reduction of 2.4°C among indoor and outdoor air temperature. It shows the average of MRT 29.3°C which is almost same with the indoor air temperature. This is due to the reason of low radiant effect since there is no ventilation occurring therefore the heat cannot be released.

Based on the graph (b) above, the second day of the field test shows outdoor has a lover temperature throughout the day. This proof that there is less heat radiation on the day and the weather is cooler. It this recorded maximum and minimum indoor air temperature 31.8°C and 28.4°C respectively. Whereas outdoor temperatures range from 28.7°C to 34.3°C. As expected, indoor air temperature is close linear to outdoor air temperature, and it is proven by the plot graph (a) above there is only 0.5°C reduction between indoor and outdoor temperature. There is no huge significance different of air temperature between morning and afternoon. The mean radian temperature recorded average of 30.1°C whereas the average of indoor air temperature is 30.6°C with an only difference of 0.5°C.

Based on the graph (c) in Figure 4.1, it marks the maximum indoor air temperature 31.9°C and minimum of 28.3°C with an average of 30.6°C. To compare this result with full natural ventilation mode, there is no difference between the average indoor air temperature which is also 30.6°C. While it is recorded that maximum of outdoor air temperature is n the range of 30.2°C to 35.5°C with an average of 33.4°C. There is reduction of 2.8°C between outdoor and indoor air temperature. In terms of mean radiant temperatures, it recorded average of 31.0°C and it is also not much different from the average of indoor air temperature.

According to the graph (d) it is the case where there is air conditioner on with opening of doors and windows. The air conditioner is set as 24°C along the day. However, the indoor air temperature ranges from 24°C to 29°C due to infiltration of hot air from cross ventilation in the classroom with an average of 26.3°C. While the outdoor air temperature ranges from 25.5°C to 33°C with an average of 31.5. There is a reduction of 5.2°C between indoor and outdoor air temperature. The presence of air conditioner has effectively improved the air flow in the classroom. The average of MRT is 26.7°C which is more than the average of indoor air temperature.

4.1.2 Relative Humidity



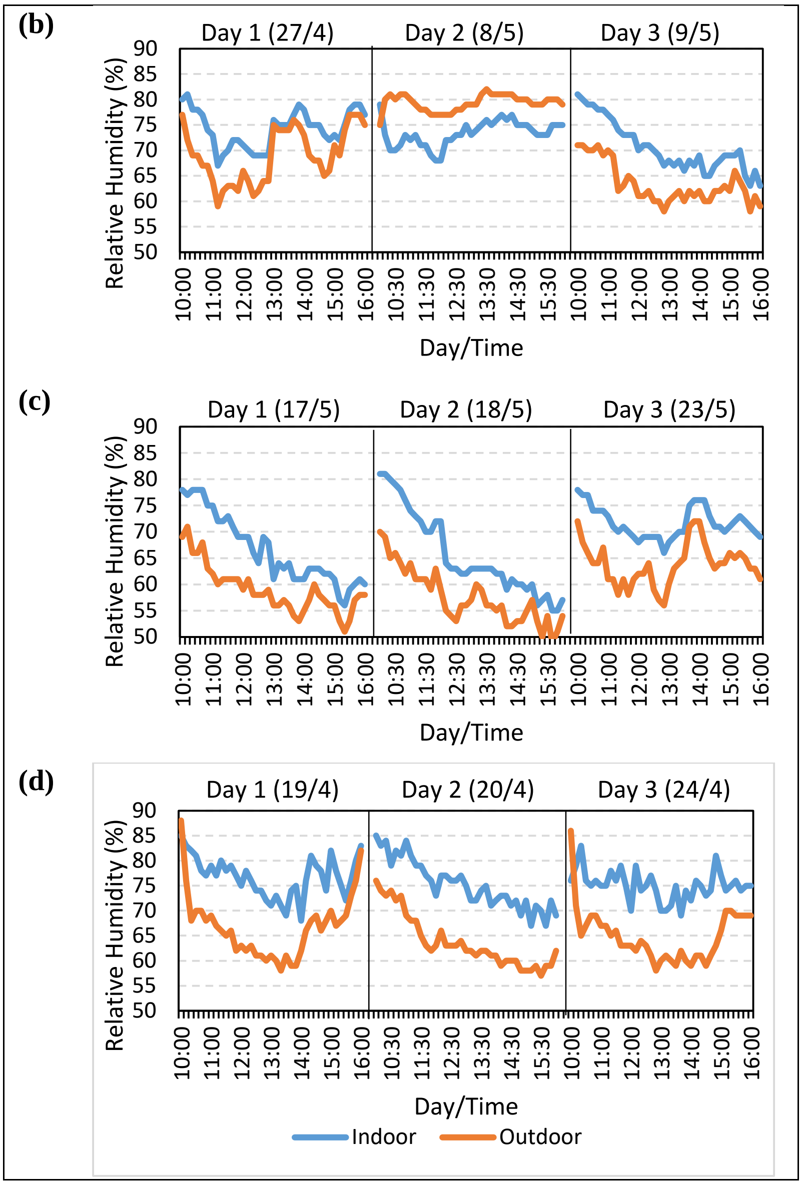


Figure 4.2: Outdoor and indoor relative humidity for each case (a) Case 1 (b) Case 2 (c) Case 3 and (d) Case 4

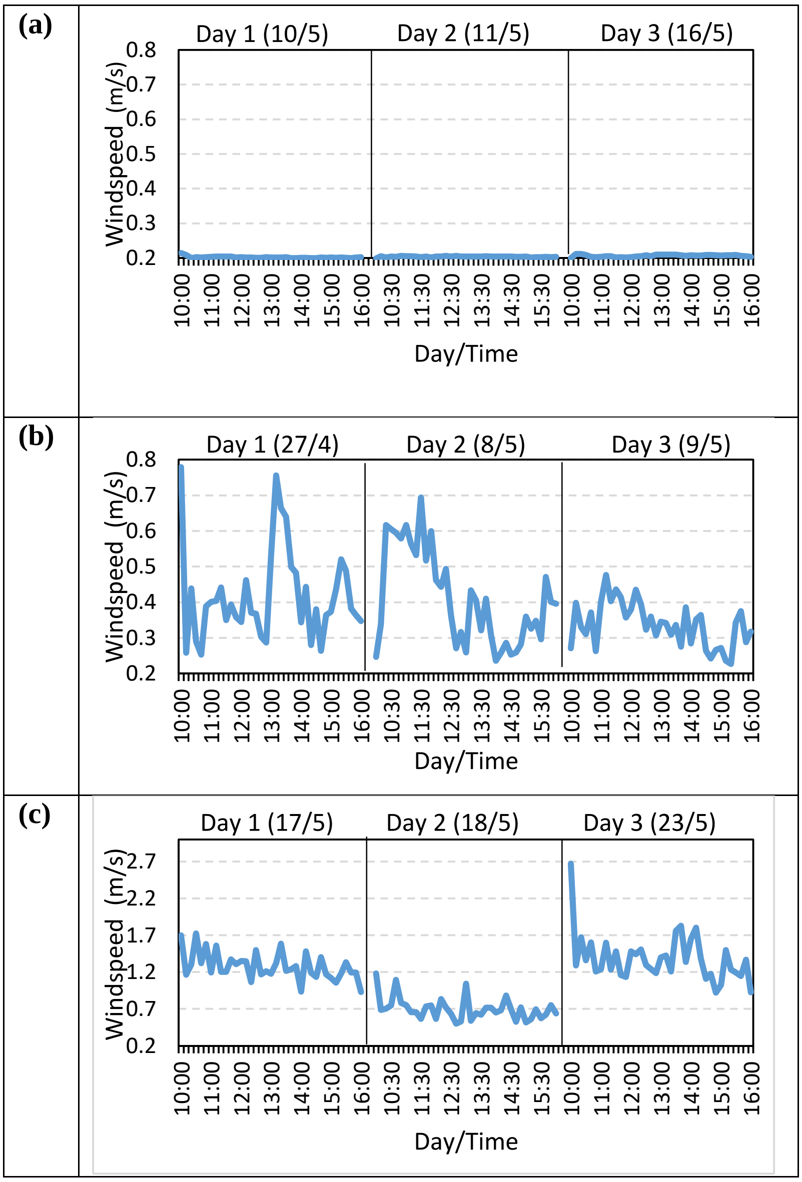
The sensor located at the centre of the classroom stated that the maximum and minimum humidity of classroom indoor is 79% and 74% respectively whereas the outdoor has the higher humidity range from 54% to 85% with an average 68.6%. The unexpected higher humidity is due to the third field measurement day for this case study is raining day. It can be shown that the outdoor temperature is lower on 16 May 2022. When there is higher air temperature at the surrounding, the air expands therefore the ability for the air to hold moisture is lower. The air can store more water molecules as the temperature rises, reducing the relative humidity.

According to graph (b), the graph of relative humidity against time shows similar trend between outdoor and indoor humidity. The maximum and minimum of relative humidity of outdoor and indoor is 82% and 58%, and 81% and 63% severally. This marks a reduction of 2% between the humidity of outdoor and indoor since there is no extra ventilation system set indoor of the classroom.

Based on the graph (c), fan has not much effect to humidity. The maximum and minimum relative humidity for classroom indoor is 81% and 55 with an average of 47.9%. Whereas the maximum and minimum relative humidity for classroom outdoor is 72% and 49% with an average of 60.1%. There is a reduction of 12.2% between the indoor and outdoor relative humidity.

From the graph (d) in Figure 4.2, the relative humidity ranges between 57% and 88% while 67% to 85% for indoor. The average relative humidity for outdoor and indoor is 65% and 76% and 65%. There is more than 10% of difference between outdoor and indoor due to the presence of air conditioner that lower the indoor air temperature. The lower the air temperature, the greater the relative humidity.

4.1.3 Windspeed



(d)

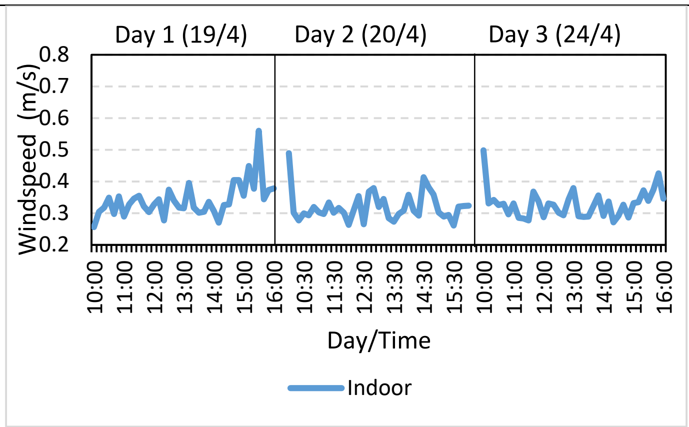


Figure 4.3: Windspeed for each case
(a) Case 1 (b) Case 2 (c) Case 3 and (d) Case 4

Based on the graph (a), since there is not ventilation at all, there is only small infiltration for the wind speed as shown in the graph (d) above. It marks constant of data along the time. From the graph (b), the wind speed presents there is wind gust several times among three days and the wind speed range between 0.2 m/s to 0.8 m/s with an average of 0.4 m/s. Cross ventilation was occurred due to the opposite position of the doors and windows is open. From the graph of (c), the wind shows stable and there are several times of wind gust among three days of field test. Graph (d) recorded the maximum wind speed of 0.56 m/s and minimum of 0.26 m/s with an average of 0.33 m/s. There are also as similar as the previous case studies which have the occurrence of wind gust.

Table 4.1: Summary of indoor climatic parameters

Parameters		Case 1	Case 2	Case 3	Case 4
Indoor Air Temperature (°C)	Average	29.1	30.6	30.6	26.3
	Range	28.1 - 29.8	28.4 – 31.8	28.3 – 31.9	24.2 – 29.0
Indoor Relative Humidity (%)	Average	75.8	72.7	67.9	75.7
	Range	74 - 79	63 – 81	55 – 81	67 – 85
Wind Speed (m/s)	Average	0.2	0.4	1.1	0.33
	Range	0.2 - 0.2	0.2 – 0.8	0.5 – 2.7	0.25-0.56

4.2 Predicted Mean Vote Analysis

Figure 4.4 shows the graph of Predicted Mean Vote against time. The graph represents four case studies based on the ventilation modes. The graph is plot by analysing the data obtained from CBE Thermal Comfort Tool [8]. The data that obtained from this thermal comfort tool including PMV, PPD, sensation, and Standard Effective Temperature (SET). PMV is used to determine whether the case studies have achieved thermal comfort and complied with ASHRAE Standard 55-2020. The set value for metabolic rate is 1.0 met and clothing level is 0.57.

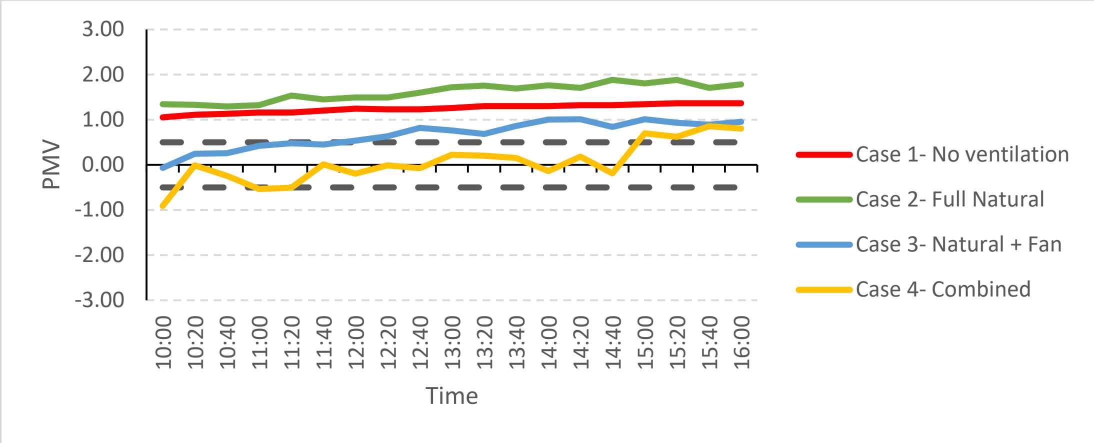


Figure 4.4: Graph of Predicted Mean Vote against time

For the case study 1, the highest recorded value of PMV is 1.36 and the lowest recorded is 1.05. The PPD of case 1 recorded 28% to 45%. The graph shows that during 10 am until 4 pm the sensation was in slightly warm condition. Case study 1 is the base line which is no ventilation. Therefore, the result is expected to be not reached the thermal comfort. It is proven that the PMV and PPD is out of the range of thermal comfort which is between -0.5 to +0.5 and less than 20% respectively.

Based on the graph in Figure 4.5, case study 2 which is full natural ventilation recorded the highest PMV of 1.88 and lowest of 1.29 whereas the PPD is range from 40% to 71% with an interval of 20 minutes. The thermal sensation throughout this ventilation is from slightly warm to warm. It shows that the PMV increase from morning to afternoon since the heat from the outside move into the classroom without any assisted mechanical ventilation system to recirculate the air. The result obtained from this case study also not fulfil the requirement of thermal comfort.

Case study 3 which is natural ventilation with an additional fan, the only difference between this both case studies are the presence of additional fan. Apparently, the existence of fan has significance effect in reaching thermal comfort of classroom in natural ventilation mode at morning. It is suggested to increase the fan speed and number of fans to improve thermal performance. The highest predicted mean vote of this case study is 1.01 and the lowest is -0.07 which the PPD recorded 5% to 26%. This ventilation modes partially comfort through all day evening slightly warm, and it can counter with increasing the fan speed or shading devices.

Case 4 is combined ventilation which is the combination of natural ventilation and air conditioning. It is recorded that the PMV is range from -0.91 to 0.85 which is partially reached thermal comfort as well as PPD which is ranges from 20% to 23%. The thermal sensation is slightly cool from 10.00 am then increase to neutral and slightly warm until 4.00 pm. This is due to the increase of air temperature in at afternoon although there is air conditioner functioning. The hot air flow from the outdoor into classroom indoor. It is recommended that combined ventilation to be selected as one of the classroom ventilations with an increase of set temperature to ensure thermal comfort is achieved in afternoon too. This ventilation modes almost comfortable all day except at late evening but in the morning the benefit of combined can be cancelled by case 3.

5. Conclusion

Thermal performance of the recommended ventilation strategies which are natural ventilation and combined ventilation which is the combination of natural ventilation with air conditioning were done through field investigation in the classroom. Each of the case studies with different ventilation modes in classroom such as no ventilation as a base case, full natural ventilation, fan-assisted natural ventilation, and combined ventilation were evaluated in terms of thermal comfort. The field measurement was carried out and the data was collected in al full-scale building room, which is a ground floor classroom at G3 building, located at UTHM. The thermal comfort was assessed by utilizing Predicted Mean Vote analysis. The results show that the best ventilation mode combined ventilation mode is useful when the combination of the continuous comfortable hours under hot outdoor and high air change rate condition is required throughout the day which is recorded that the PMV is range from -0.91 to 0.85 which is partially reached thermal comfort as well as PPD which is ranges from 20% to 23%. The thermal sensation is slightly cool then increase to neutral and slightly warm. Meanwhile, if energy efficiency for ventilation is a concern, the application of natural ventilation with higher rate of fan assist can be as the other potential alternative for indoor comfort. This ventilation mode which is natural ventilation with the presence of additional fan is the second-best alternative which recorded PMV range from -0.07 to 1.01.

Acknowledgement

We would like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for its support.

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