The Ventilation Approaches of Thermal Comfort in the Main Prayer Hall of Mosque & Hostel Room, USM Engineering Campus

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***Abstract*—This study was conducted to determine users' satisfaction with the building's indoor environment. This study was carried out in Pusat Islam (i.e. mosque) and hostel room in USM Engineering Campus, Penang. It involved determining the compliance level of thermal comfort parameters (i.e. air temperature and relative humidity) at both locations and establishing relationships between ventilation systems with the predicted mean vote (PMV) and predicted percentage of dissatisfaction (PPD) according to ASHRAE Standard-55. The study was conducted from 1.00 - 2.00 P.M. and 5.00 – 6.00 P.M. in two days to assess the thermal conditions of the mosques and hostel rooms. An active ventilation system (i.e. fans) was operating during prayer times, while only passive ventilation (windows and doors) was available during the non-prayer time (i.e. before and after prayer times). Overall, the results indicate that most thermal comfort parameters measured do not comply with the Industry Code of Practice (ICOP) standard limit, whereby the PMV is not within the range of -0.5 <PMV< +0.5 and PPD is >10%. This is due to poor façade design and inadequate building ventilation systems.**

***Keywords*— Mosque, PMV, PPD, thermal comfort, ventilation**

I. Introduction

In our daily lives, we spend most of our time inside buildings. While spending an unusual amount of time indoors might lead to health issues, thermal comfort is primarily concerned with building occupants [1]. Good thermal comfort is necessary for any building to increase occupants' productivity and satisfaction. The mosque is one of the examples of buildings that need to be given great concern due to its function. A mosque is a symbolic place for Muslims where they can come together for prayers. Mosques are not only used for prayers but also serve as a centre of education and information for events during the month of Ramadan and other religious activities. Because of the large number of people that visit mosques, particularly during prayer times, good thermal comfort is necessary.

Thermal comfort can be defined as the state of mind which express satisfaction with the thermal environment [2]. It is essential to determine the quality of the indoor environment in the urban mosque. A good indoor environment in the mosque can increase people's occupancy and concentration levels [3]. Thermal comfort inside a building is influenced by several factors, such as air temperature, relative humidity, and air movement of the surrounding space. The essential aspects that will determine users' overall experience within the mosque are the mosque's facade design. The facade is the first and most impactful connection between humans and the built environment. The outer shell of a building is not only a reflection of the architectural character of a region but also a representation of local cultural, social, climatic, political, and economic circumstances [4]. Poor design, which only considers the aesthetic value of the mosque, will lead to thermal discomfort for the users.

Thermal discomfort makes the occupants feel stressed, annoyed and distracted. Other than that, lack of thermal comfort also hurts the health of the occupants [5]. A sound ventilation system is required to provide thermal comfort in the mosque. Ventilation is a process that brings fresh outdoor air into the building and removes the contaminated indoor air [6]. The ventilation system is divided into two types: natural and mechanical ventilation systems. Natural ventilation is preferable because it can lower costs and protect the environment [5]. Despite the aesthetic value of the space, the mosque's design should provide the best environmental experience to the users while promoting a sustainable energy consumption approach [7]. Besides that, allowing natural lighting and ventilation into the building interior will reduce energy usage and mechanical maintenance costs [8].

Most mosques are poorly designed for indoor temperatures, requiring excessive energy and electrical equipment to maintain the ideal indoor temperatures. The students also face this situation at the hostel, where the rooms have poor design and inadequate ventilation systems. When the temperature is exceptionally high, the energy consumed will also be increased to provide thermal comfort to the occupants [9]. This problem occurs inside the mosque because of the minimal openings and lack of thermal insulation in the mosque's main hall. The gaps near the ceilings are frequently closed, allowing the warm indoor air to remain at the upper levels [5]. The mosque's design provides aesthetic value to the building but lacks satisfaction in the environmental aspect.

Thus, the objective of this study was to measure air temperature and relative humidity in the hostel room and mosque's main prayer hall and compare the physical comfort parameters in the hostel room and prayer hall with the Industry Code of Practice on Indoor Air Quality 2010 and determine the compliance of thermal comfort and the effect of the ventilation system in reducing the temperature in both buildings.

II. MATERIALS AND METHODS

A. *Sampling Location*

This study was conducted at two locations which are the hostel room and prayer hall at Pusat Islam USM, Engineering Campus. USM is situated in three neighbouring states; Nibong Tebal, Pulau Pinang, Bandar Baharu, Kedah and Parit Buntar, Perak. The mosque has a longitude of N5.144724 and a latitude of E100.493959. This mosque uses passive (i.e. doors and windows) and mechanical ventilation (i.e. fan) within the main prayer hall. The standard ventilation system in the hostel room is natural ventilation, in which the outdoor airflow goes into the indoor spaces naturally without using mechanical ventilation like fans. The data were measured in these two locations to obtain the result of various ventilation strategies.

B. *Monitoring Instrument*

The Temperature-Relative Humidity (T-Rh) Data Logger was used to measure the temperature (ºC) and humidity (RH %) inside the mosque's main prayer hall and hostel room. The T-Rh Data Logger is placed at 1.2 m above the floor at one sampling point and at least 0.5m from walls, corners or any vertical surfaces and not within 2 m of the doors. The data for indoors and outdoors were measured simultaneously. Readings of all the parameters were obtained after 1 hour of monitoring using T-Rh software.

C. *Sampling Method*

The monitoring at the mosque and hostel room was conducted based on two slots which are 1.00 P.M. to 2.00 P.M. and 5.00 P.M to 6.00 P.M. for two days. The first slot (1.00 P.M. to 2.00 P.M.) was the hottest time of the day, and more occupants would be in the mosque to perform the Zuhr prayer. During the monitoring at Pusat Islam, windows and doors are kept open, and fans are only switched-on during prayer time. All the windows are kept open at 45°. Meanwhile, the fans are switched on for the hostel room, and only windows are held open during the monitoring. Table 1 shows the monitoring schedule within the mosque's main prayer hall and hostel room.

TABLE I. MONITORING SCHEDULE FOR MOSQUE AND HOSTEL ROOM

Location	Time (h)	Parameters monitored
Pusat Islam & Hostel room	1:00 -2:00 pm	Temperature (ºC) Humidity (%)
	5.0 -6.00 pm	

D. *Analysis Method*

The PMV and PPD calculations were carried out using the CBE Thermal Comfort Tool for ASHRAE-55. It is a free online tool that complies with the ASHRAE 55-2017, ISO 7730:2005, and EN 16798-1:2019 requirements for thermal comfort calculations and visualisations. With the PMV and PPD methods, five parameters were used in this tool: air temperature, air speed, humidity, metabolic rate and clothing level. PMV has seven thermal sensation scales ranging from -3 (cold) to +3 (hot). The definition of the ASHRAE thermal sensation scale, which depicts people's thermal perception inside the building, is shown in Table 2. Figure 1 shows the correlation between PMV and PPD (PMV–PPD chart). Based on the chart above, PPD rises as PMV deviates from zero in either a positive or negative direction. According to ASHRAE Standard, a PMV score between -0.5 and +0.5 and a PPD score < 10 are acceptable ranges for general comfort, as indicated in Table 3.

TABLE II. PMV AND ITS RELATION TO THE THERMAL SENSATION SCALE

Value	Sensation
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

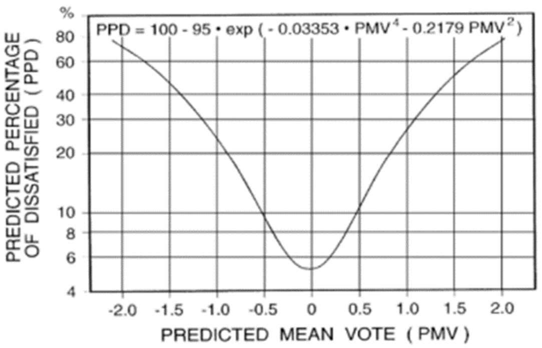


Fig. 1. *PPD as a function of PMV*

TABLE III. ACCEPTABLE THERMAL ENVIRONMENT FOR GENERAL COMFORT

PPD	PMV range
<10%	-0.5 < PMV < +0.5

III. RESULT AND DISCUSSION

A. *Results*

Tables 4 and 5 illustrate the minimum, maximum and average value of air temperature (°C) and relative humidity (%) within the mosque's prayer hall by ICOP's permissible limit. All temperatures recorded from 1.00 P.M. – 2.00 P.M. and 5.00 P.M. -6.00 P.M. on Day 1 and Day 2 exceeded the limit set by ICOP. Meanwhile, the relative humidity recorded on Day 1 and Day 2 comply with the ICOP limit.

TABLE IV. MONITORING RESULTS AT THE MOSQUE'S PRAYER HALL FROM 1 P.M. -2 P.M. ON DAY 1 AND DAY 2

Parameter	Temperature, T (°C)			Relative humidity, RH (%)		
ICOP limit	23-26 °C			40-70%		
	Min.	Max.	Avg.	Min.	Max.	Avg.
Day 1	31.6	33.8	32.7	54.1	61.5	57.8
Day 2	32.4	33.2	32.8	55.0	57.9	56.5

TABLE V. RESULTS OF MONITORING AT THE MOSQUE'S PRAYER HALL FROM 5 P.M. -6 P.M. ON DAY 1 AND DAY 2

Parameter	Temperature, T (°C)			Relative humidity, RH (%)		
ICOP limit	23-26 °C			40-70%		
	Min.	Max.	Avg.	Min.	Max.	Avg.
Day 1	32.4	33.2	32.8	57.5	60.2	58.9
Day 2	28.4	29.7	29.1	64.2	66.7	65.5

Based on Table 4, the average temperature recorded on Day 1 and Day 2 was very high. This could be due to the higher number of occupants (i.e. ~ 60) present during the monitoring. They were performing the Zuhr prayer in the mosque's hall. Even though active ventilation (i.e. fan) was operating, the temperature was still the highest. Besides, this also could be due to the thermal load from sunlight that penetrates the indoor spaces of the mosque through building materials. The weather was sunny that day, as the outdoor temperature influenced the indoor temperature.

Meanwhile, the minimum, maximum, average temperature and relative humidity values for the hostel room are tabulated in Tables 6 and 7. The temperatures recorded from 1.00 P.M. – 2.00 P.M. and 5.00 P.M. -6.00 P.M. on Day 1 and Day 2 also exceeded the ICOP limit. Meanwhile, the relative humidity recorded on Day 1 and Day 2 comply with the ICOP limit. This condition might be due to a lack of a ventilation system inside the room. There was no opening on the opposite side of the window as the door was opposite the window. Therefore, cross-ventilation cannot happen unless the door is open. Cross ventilation occurs when there is a wind pressure difference. Besides, the high outdoor temperature also influenced the high indoor temperature.

TABLE VI. MONITORING RESULTS IN A HOSTEL ROOM FROM 1 P.M. -2 P.M. ON DAY 1 AND DAY 2

Parameter	Temperature, T (°C)			Relative humidity, RH (%)		
ICOP limit	23-26 °C			40-70%		
	Min.	Max.	Avg.	Min.	Max.	Avg.
Day 1	31.2	33.4	32.3	50.6	60.8	55.7
Day 2	29.9	31.2	30.6	62.4	65.5	64.0

TABLE VII. MONITORING RESULTS IN A HOSTEL ROOM FROM 5 P.M. -6 P.M. ON DAY 1 AND DAY 2

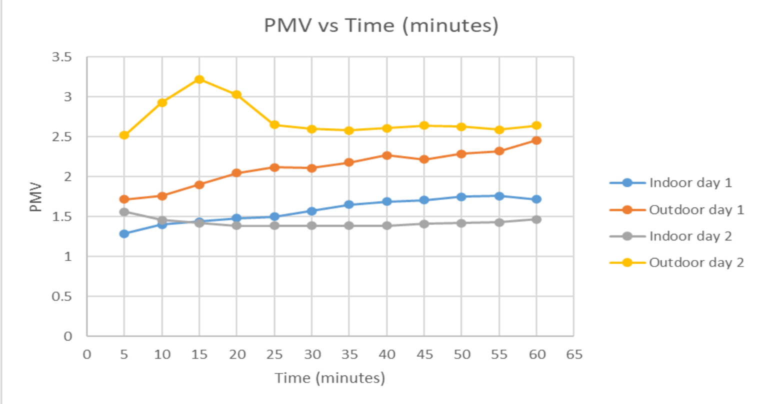
Parameter	Temperature, T (°C)			Relative humidity, RH (%)		
ICOP limit	23-26 °C			40-70%		
	Min.	Max.	Avg.	Min.	Max.	Avg.
Day 1	32.5	33.4	33.0	53.0	58.3	55.7
Day 2	30.4	31.9	31.2	63.1	64.4	63.8

B. *PMV and PPD*

Based on Table 8, most of the result from 1.00 P.M. – 2.00 P.M. shows that ASHRAE seven-point scale ranges from slightly warm to hot. Meanwhile, for the 5.00 P.M. – 6.00 P.M. monitoring session, only Indoor Day 2 was within acceptable limits ranging from -0.5 to +0.5. The thermal sensation scale ranges from slightly warm to neutral. The other thermal sensation scales went from somewhat warm to warm. Among all of the PMV values calculated inside the mosque, the highest PMV was about 1.76, whereas the lowest was 0.39.

Table 9 illustrates the PMV plotted against time from 1.00 P.M. – 2.00 P.M. and 5.00 P.M. – 6.00 P.M. in the hostel room. Based on the graph, it can be seen that most of the results do not comply with the permissible limit set (i.e. -0.5 to +0.5) by the ASHRAE-55 except for Outdoor Day 2 from 1.00 P.M. – 2.00 P.M. The thermal sensation scale for Indoor Day 1, Outdoor Day 1, and Indoor Day 2 were from neutral to warm. Meanwhile, for the evening session (i.e. 5.00 P.M. – 6.00 P.M.), the environment in the room ranged from slightly warm to warm on the seven-point ASHRAE scale.

TABLE VIII. THE GRAPH OF PMV VALUE AGAINST TIME FOR MONITORING AT PUSAT ISLAM ON DAY 1 AND DAY 2.

<table>
<tr><th>Time</th><th>Graph of PMV vs Time</th></tr>
<tr><td>1.00 P.M. – 2.00 P.M.</td><td>


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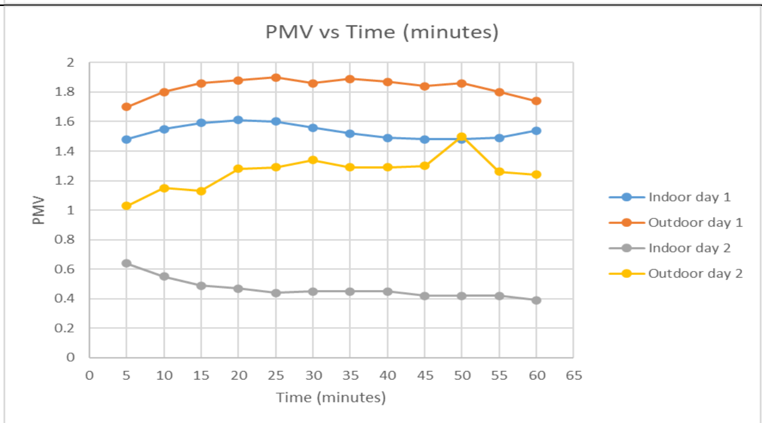
<tr><td>5.00 P.M. – 6.00 P.M.</td><td>


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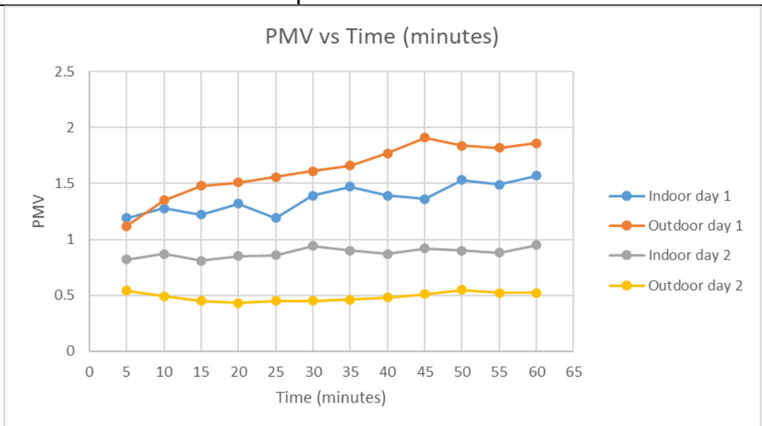
TABLE IX. THE GRAPH OF PMV VALUE AGAINST TIME FOR MONITORING IN THE HOSTEL ROOM ON DAY 1 AND DAY 2.

<table>
<tr><th>Time</th><th>Graph of PMV vs Time</th></tr>
<tr><td>1.00 P.M. – 2.00 P.M.</td><td>


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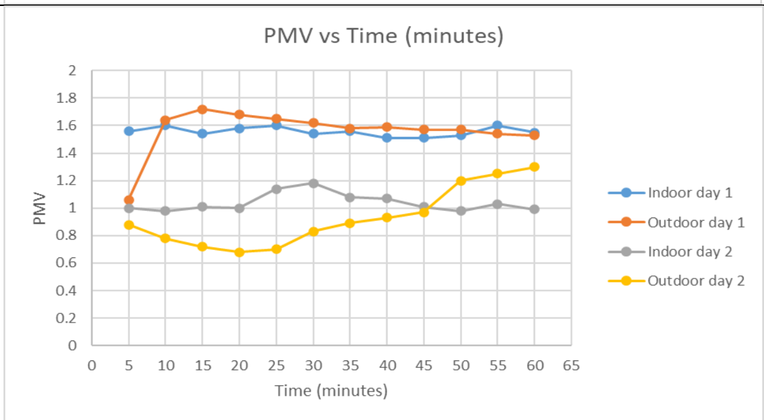
<tr><td>5.00 P.M. – 6.00 P.M.</td><td>


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For monitoring at Pusat Islam from 1.00 P.M. – 2.00 P.M., none of the results is within the permissible limit or even worse. Most of the PPD values obtained are greater than 20%. This indicates that the occupants are dissatisfied with the environment in the mosque. Figure 2 shows the PPD result for the evening session in Pusat Islam. The PPD value for Day 2 complies with the ASHRAE standard limit since the percentage is less than 10%. Even though about 30-40 occupants inside the main prayer hall perform the Asr prayer, the indoor temperature is still within the acceptable limit. This is because active ventilation (fans) is in operation during the monitoring.

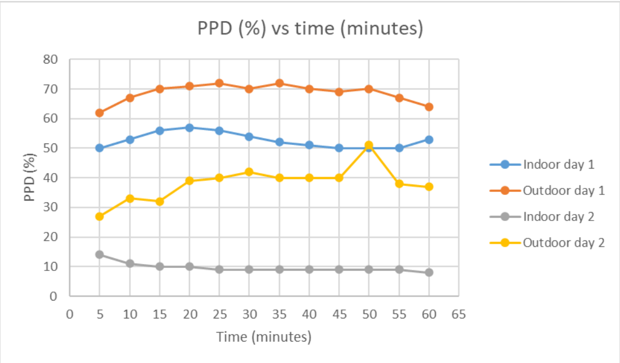

Fig. 2. *Graph of PPD vs Time for 5 P.M. - 6 P.M. monitoring at the mosque's main prayer hall*

CONCLUSION

This study was conducted to determine the compliance of thermal comfort and the effect of the ventilation system in reducing the temperature in the hostel room and mosque's main prayer hall. The ICOP limit is compared to the physical parameters of temperature and relative humidity, while the PMV and PPD were computed using CBE Thermal Comfort Tools for ASHRAE-55. The average temperature at both the mosque's main prayer hall (i.e. 29.1°C – 32.8 °C) and the hostel room (i.e. 31.2 °C – 33.0 °C) on Day 1 and Day 2 exceeded the ICOP limit of (23 – 26 °C), while the relative humidity complied with the ICOP limit of 40 – 70 %. The high indoor temperature caused the PMV and PPD values also exceed the ASHRAE-55 Standard limit. Besides, most of the thermal sensation scale of PMV values for the main prayer hall and the hostel room were from slightly warm to hot and from neutral to warm, respectively. This indicates that the occupants were unsatisfied with the environment inside the building. This study shows that even though the physical criteria for thermal comfort are not within the limit, better thermal comfort occurs when active and cross-ventilation are used. A ladder should open the upper-level windows for future research to get more accurate results. The number of monitoring rooms must also be increased to compare the measured parameters. However, other results monitoring in Pusat Islam exceed the acceptable limit due to inadequate ventilation and the design of the building.

ACKNOWLEDGMENTS

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