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Indoor Thermal Performance of a Retrofitted Air-Conditioned Mosque: Case Study for Penang State Mosque

(Prestasi Terma Dalaman Masjid yang Dinaiktaraf dengan Sistem Penyaman Udara: Kajian Kes Masjid Negeri Pulau Pinang)

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ABSTRACT

In a mosque environment, occupants are temporarily in the situation of various dress and congregate activities which desire comfortable environment. Inappropriate thermal comfort condition in a mosque leads the distraction in fulfilling the religious practice and also causing emotional influence. The proper setting of thermal comfort parameters is important to provide a suitable environment for the mosque occupants. Proper investigations of thermal comfort may help to optimize the usage of the cooling systems such as air conditioning system. The objective of this paper is to investigate the thermal comfort performance of large-scale retrofitted air-conditioned mosques with intermittent operation in Penang, Malaysia. According to the survey, the mosques in this region can be categorized into five groups (G1 –G5) according to floor area (131.55 m^2 to 2,920 m^2). A case study is conducted on a large scale mosque with a floor area of 2,920 m^2 that is equipped with a centralized air-conditioning system. Result shows that the system produces an indoor thermal environment that within the range recommended by ASHRAE Standard 55. Most of the predicted thermal sensation under predicted mean vote (PMV) indices is achieved and within the comfort zone range (-0.5, +0.5). Some thermal strategies need to be applied especially on air conditioning system, operation configuration, handling procedure, zoning section as well as technical knowledge among mosque officials. Hence, the energy consumption of the mosque can be reduced while maintaining thermal comfort level of occupants.

Keywords: Air conditioning; comfort; mosque; thermal environment

ABSTRAK

Di dalam persekitaran masjid, jemaah berada dalam situasi pakaian yang pelbagai dan aktiviti keagamaan yang memerlukan persekitaran yang selesa. Keadaan keselesaan terma yang tidak sesuai di masjid menyebabkan jemaah tidak selesa dalam beribadah di samping mempengaruhi faktor emosi. Penentuan had keselesaan yang betul dapat memberikan persekitaran terma yang sesuai terhadap jemaah masjid. Penilaian terhadap keselesaan terma dapat mengoptimumkan penggunaan sistem penyejukan seperti alat penghawa dingin. Objektif kertas kajian ini adalah untuk menyiasat prestasi keselesaan terma masjid berskala besar yang telah dibuat pengubahsuaian dengan pemasangan sistem penghawa dingin dan beroperasi dengan selang masa tertentu di Pulau Pinang, Malaysia. Berdasarkan kaji selidik terhadap masjid dalam kawasan ini boleh dikategorikan kepada lima kumpulan (G1-G5) berdasarkan keluasan lantai (131.55 m^2 kepada 2,920 m^2). Satu kajian kes telah dijalankan ke atas masjid berskala besar, 2,920 m^2 yang dilengkapi sistem penghawa dingin jenis berpusat. Hasil menunjukkan bahawa sistem menghasilkan persekitaran terma dalaman di dalam julat yang dicadangkan oleh piawaian ASHRAE 55. Kebanyakan ramalan terma sensasi di bawah indeks undi min ramalan (PMV) adalah tercapai dan berada dalam julat zon selesa (-0.5, +0.5). Strategi penambahbaikkan terma persekitaran perlu dilakukan terutamanya melibatkan pengendalian sistem penghawa dingin, konfigurasi pengoperasian, prosedur pengendalian, seksyen pengezonan serta pengetahuan teknikal di kalangan pegawai-pegawai masjid. Oleh yang demikian, penggunaan tenaga masjid dapat dikurangkan serta dapat mengekalkan tahap keselesaan terma di kalangan jemaah.

Kata kunci: Penghawa dingin; keselesaan; masjid; persekitaran terma

INTRODUCTION

Thermal comfort is a condition of mind where one experiences satisfaction with the thermal environment (ISO 7730, 2005) and is assessed by subjective evaluation. This condition is achieved when the individual no longer needs temperature adjustment (colder or warmer than the current temperature). This means that to estimate thermal comfort, it requires not only physical measurements but also subjective tools such as scales (ASHRAE 2013). In a mosque environment, occupants are temporarily in the situation of congregate activities, various dress and intermittent exposure time. It is unrealistic to expect that the same environment will satisfy every occupant. To predict the thermal sensation of the body as a whole, indices such as the predicted mean vote (PMV) or predicted percentage dissatisfied (PPD) are commonly used especially in thermal comfort level in HVAC applications (Fanger 1970).

Recent studies have demonstrated that air conditioning systems represent between 10% and 60% of the total energy consumption of office buildings (Perez-Lombard et al. 2008). The higher demand for cooling during the summertime is caused by the need to lower the temperature and humidity as determined by quality norms for the indoor comfort (Djongyang et al. 2010).

The mosque is important to the Muslim community and represents a central place for Muslim to gather information, education and congregation such as daily prayers and as well as Friday prayer. The common design is usually simple, either rectangular-shape or circle-shape, with a dome roof. The *qibla* wall is facing to the direction of Mecca. The mosque has an intermittent occupancy period at a unique intermittent time from early morning until night. The average of occupancy period is during every prayer time. The occupancy peak load only occurs during the actual prayer time which lasts about 20-30 minutes. The worshiper who comes to the mosque to fulfil the religion need will expect a calm and comfortable environment. Therefore, an architecture of a mosque often differs from other types of buildings.

In hot and humid climate such as Malaysia (Bakhtir & Singh, 2015), old traditional and historic mosques are naturally ventilated and cooled (Ibrahim et al. 2014). Research has shown that building with natural ventilation system has improved occupant satisfaction and operation cost compared to mechanical ventilated equipment such as air conditioning system (Rijal et al. 2008). But climate changes have modified the landscape of the heat load of building including Malaysia (Azman et al. 2018; Yau & Pean 2011). The large nature of the mosque, spatial configuration, as well as floor areas are common factors, which produced the warm environment to occupants. To solve the heat load in mosque, air conditioning system used to maintain indoor thermal performance (Hussin et al. 2015).

A lot of studies have been carried out to improve the indoor thermal comfort in commercials buildings in literature but only a few published researches associated with thermal comfort assessment in air-conditioned mosque buildings. In 2009, Al-Homoud et al. (2009) studied the energy used and indoor environment condition in a number of mosques during occupancy periods in such intermittent operation in the city of Dammam and Al-Khobar, Saudi Arabia. Three different mosques with different size and shape were used as a case study. The split unit conditioning system (floor mounted, wall mounted and window type) and ventilation system (ceiling fan) were installed in the mosques to provide thermal comfort to worshippers. The researchers conclude that in most of the studied mosques, thermal comfort is observed not accomplished during peak thermal load especially the un-insulated types. The addition of thermal insulation material to the mosques leads to improvement in thermal comfort to the acceptable level. Apart from the insulation material, the air conditioning system with intermittent operation and zone can improve the thermal comfort level of worshippers during their staying period.

On the other hand, Al-Ajmi (2010) investigate indoor climate and prayers thermal comfort sensations of six air-conditioned mosques in a dry desert climate in the province of Kuwait (Capital, Hawalli, Aljahra, Alahamidi, Alfarwaniya and Mobarak-Alkabeir). The study was conducted in the summer season at the mean daily maximum temperature of 45°C. Centralized air conditioning system which produces comfort to main prayer hall was evaluated by 140 sets of physical measurements and subjective questionnaires collected from April till the end of October 2007. The indoor air temperature varies from 18.5°C and 28.6°C, while the neutral temperature was found 26.1°C. A good mean air movement found in the main prayer hall at 0.11 m/s to 0.39 m/s. Thermal acceptability of indoor environment from 90% of PMV and 10% of PPD was concluded at 22.4°C till 29.8°C, which was widely accepted by the occupant. The finding does not correlate with ISO 7730 and ASHRAE 55-2004 standards.

Budaiwi & Abdou (2013) investigate the heating, ventilation, air conditioning (HVAC) system operational strategies for reduced energy consumption in mosques with intermittent occupancy. The study was conducted at three different sizes of air-conditioned mosques (different floor area) in eastern province of Saudi Arabia. The zoning schemes were applied in a large mosque and operated based on adjustment intermittent operation hours (1-3 hrs.) under oversized HVAC equipment for most prayers. The overall finding suggested that proper oversized HVAC system with intermittent operation or operation precede occupancy during each prayer can achieve the thermal comfort condition. Moreover, large mosque using operational zoning are able to significantly reduce the annual cooling energy requirement up to 30% while thermal comfort conditions still accepted by the occupant. The level of comfort in operational zoning is more pronounced in Friday and large mosques with partial daily occupancy. However, the effectiveness of the findings may vary according to mosque type, size, location, as well as operational strategies which need to be carefully considered in the design stage and well implemented.

Hussin et al. (2015) conducted a study of the performance of air-conditioned mosque during daily prayer time focus on the reliability of PMV. The case study was conducted in the Penang state of Malaysia during five daily periods of prayers time. PMV was calculated using the Fanger equations while thermal responses gathered from 330 worshippers. The result shows that the thermal responses from worshippers during five daily prayer periods largely recorded in the neutral zone. PMV model calculations underestimated the temperatures at which people could be comfortable (25.9°C) in the mosque when compared to the vote of respondents at 30.4°C. The new comfort temperatures vary from 27°C till 31°C under thermal acceptability of 90% of PMV and 10% of PPD as classified by ISO 7730 and ASHRAE 55-2004 standards. The study concluded that indoor thermal conditions are thermally acceptable at the temperature experienced by the occupants.

Jaafar et al. (2017) conducted numerical investigations of indoor air quality inside Al-Haram mosque in Makkah using CFC simulation techniques. The study was conducted at first floor of Al-Masa'aa between As-Safaa and Al-Marwah. The research focuses on airflow, thermal behavior and carbon dioxide dispersion from a large number of the occupant. To evaluate the PMV/PPD model, 5 different cases of air change hour (ACH) are used such as ACH-6 (case-1), ACH-8 (case-2), ACH-10 (case-3), ACH-12 (case-4) and ACH-14 (case-5). The result shows that overall predicting thermal sensation using modelling and CFD software technique such as Flovent 15 maybe more practical for the HVAC engineer but not totally reliable. PMV/PPD result from Case-1 model shows that thermal performance was slightly warm (1 and 25%), while other PMV and PPD cases were reached to the neutral acceptable range of comfort standard. Case-3 is the best practice because it led to minimizing energy consumption while the good temperature inside the mosque. It is a challenge to determine the thermal comfort from occupant which has past experiences adapted to the natural climatic condition. The variable indoor climatic parameters such as air temperature, air movement and humidity limits are difficult to comply with, especially in a hot and humid climate of Malaysia where the parameter needs to be considered in producing acceptable thermal environments. On the other hands, it is difficult to reduce the energy usage to achieve the thermal comfort requirement for the large mosque with intermittent occupancy. The objective of this study is to investigate the thermal environment distribution and condition of the large-scale air-conditioned mosque with intermittent operation in Penang, Malaysia in order to explore the operational strategies and acceptable thermal environment for occupant comfort.

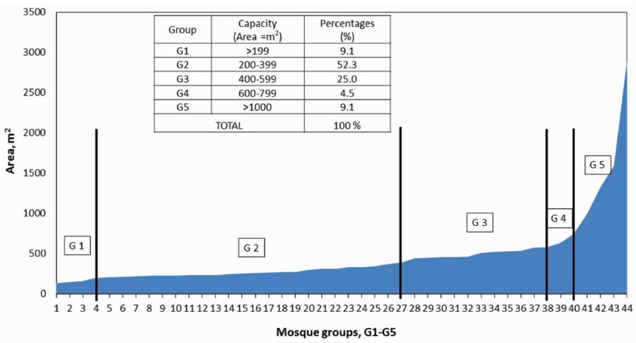
METHODOLOGY

Malaysia has a population of 68.8% Muslim people (Department of Statistics Malaysia, 2017) and was declared as a Muslim country with Islam as its main religion since 1963 by the federation of Malaya, laws of Malaysia. There are about 6426 mosques located within the entire country of Malaysia (JAKIM 2017). It is impossible to cover all mosques in this case study, hence the highest mosque population is compared and within the vicinity of a selected city such as Kuala Lumpur, Penang and Johor Bahru. Based on JAKIM data, Penang has 273 registered mosques compared to Kuala Lumpur (62 mosques) and Johor Bahru (152 mosques). Hence, Penang city was selected as the area of the case study.

In Penang city, old traditional and historic mosques are naturally ventilated and cooled. Some mosques were retrofitted with mechanical ventilated devices such as air conditioning system for maintaining indoor thermal performance. In early work, a survey was conducted through 15% samples of retrofitted air conditioned in mosques located in Penang on January 2017 until March 2017. It focuses on basic data such as built year, floor & cooling area, indoor ventilation, air conditioning system and capacity and electricity usage per month. The results from the survey show that the mosques capacity requirement is between 131.55 m^2 to 2,920 m^2, which can be categorized into five groups (G1 –G5) according to floor areas, as summarized in Figure 1. Based on the comparison of estimated cooling energy with actual horsepower installed in the mosques, it is found that 77.3% of the mosques were installed the cooling energy below the estimated value (Figure 2). The graph shows that most of the dots are located below the estimated line, thus the line slope of the actual horsepower is much lower than the demand of cooling based on floor area. This could result in overuse of compression system and ultimately increases the energy consumption. Furthermore,

Furthermore, it was decided that at least one sample from mosque group in Figure 1 will be selected for case study. The elimination process consists of several aspects such as;

1. Built year > 1980
2. Highest capacity of retrofitted air conditioning system
3. Electrical & power supply system used 3-Phase, 415 V and 50 Hz
4. Fully operates at daily prayer as well as Friday prayer
5. Highest electricity consumption usage per year
6. Use centralize air conditioning system



Group	Capacity (Area =m^2)	Percentages (%)
G1	>199	9.1
G2	200-399	52.3
G3	400-599	25.0
G4	600-799	4.5
G5	>1000	9.1
TOTAL		100 %

FIGURE 1. Mosque group based on floor area, m^2

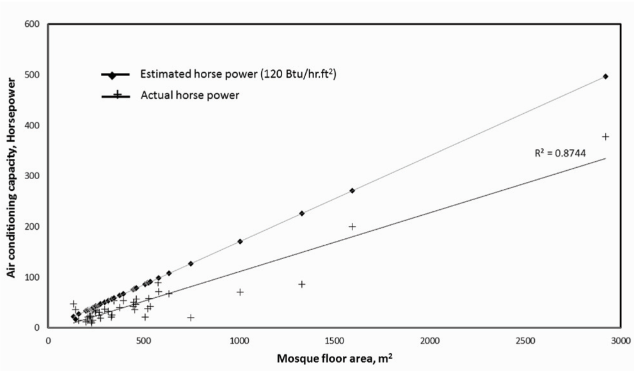


FIGURE 2. Air conditioning cooling capacity compared with floor area, m^2 (Estimation: 1 ft^2 requires a cooling energy of 120 Btu/hr)

By fulfilling the above criteria, only one mosque is qualified in the group which is Penang State mosque. The mosque was selected because it fulfills the above criteria and therefore, it will be selected as the place of case study. Figure 3 shows the picture of the mosque. The mosque is located at the center of Penang Main Island (5.406N, 100.3006E). It is built and opened to the public in 1981. The mosque building is in round shape which consists of ground and mezzanine floor. The total floor area for main prayer hall at the ground level is 2920 m^2, while mezzanine floor area is 65.69 m^2. The ground floor is opened daily for praying purpose, meanwhile mezzanine floor only opened during special events such as Idul Fitri prayer. Each side of the walls uses single-layer shaded glass type. Attached together with the walls are six main entrance doors that used the same type of glass. All the floor areas are fully covered with carpet parallel to the west wall. The dome was used as the roof on top of the grand tower. The main prayer hall can fully accommodate up to 5000 worshippers at one time. The management and supervision of this mosque were directly by Penang Religious Affairs Department.

The Penang State mosque was retrofitted with an air conditioning system in 2003 after 23 years of operation. The three identical air-cooled chillers, with the capacity of 100 RT each was installed to improve the thermal environment as well as thermal comfort inside the main prayer hall. The main system consists of chiller (compressor, condenser, thermal expansion valve and evaporator), air handling unit (AHU), water pump system, air distribution system (ducting and diffusers) and electrical control panel. Air-cooled chiller and its components, functions and benefits are described by Teke & Timur (2014). In the air-cooled chillers component, the reciprocating (semi-hermetic) compressor type was used with the maximum power input of 235 kW, each. The condenser is a component in air conditioning system which uses the surrounding ambient air to cool down the rejected heat. The evaporator is from the shell type and tube flooded evaporator. Cooled water design temperature is 44°C out and 54°C in from shell and tube flooded evaporator, while chilled water is then circulated to the AHU by a 3 nos centrifugal end-suction pump (10 horsepower (HP) motor pump each) at the rate of 255 USGPM. There are 6 units of AHU located in AHU room beside the mosque. The supply air is drawn through the ducting system and distributes the cool air to surrounding space at the main prayer hall using jet diffusers at a constant flow rate. In 2007, a minor modification has been made to air distributions system to relocate the ducting and diffusers. Based on the interview session with mosque officer, the air conditioning system started to operate (ON) at 3.00 PM and shutdown (OFF) at 9.30 PM daily. In Friday prayer, the air conditioning system was ON at 10.00 AM until 9.30 PM. During operation chillers, water pump and all AHU were ON. Table 1 shows the air conditioning system data nameplate.

This study investigates the thermal environment distribution and condition in the Penang State Mosque. Hence, measurement of indoor thermal environment from the air conditioning system was made by using two type of instruments; consists of 2 units of portable Delta OHM HD 32.3 data logger version 0.1.5.31. The instrument was located at the front and center of the main prayer hall of the mosque, remarks number DL-1 and DL-2 as indicated in Figure 4 and 5. All instantaneous data was captured automatically at 5 minutes interval and directly save in the Delta OHM HD 32.3 memory card. All data then were download to a laptop for further analysis. A Delta OHM HD 32.3 data logger version 0.1.5.31 is designed for analysis of moderate environments through PMV index and PPD index.

FIGURE 3. Photo of Penang State Mosque

TABLE 1. Air conditioning system and data nameplate

Items	Capacity	Number
Air cooled chiller	100 RT	3 nos
Refrigerant	R22	45 kg /100 RT
Power supply	3P, 415V, 50Hz	1
Air handling unit	25,200 CFM	AHU-1
	19,200 CFM	AHU-2
	24,000 CFM	AHU-3
	30,000 CFM	AHU-4
	18,000 CFM	AHU-5
Air distributions	Duct GI with diffusers	–
Operation	6.5 hrs	Daily prayer
	11.5 hrs	Friday prayer

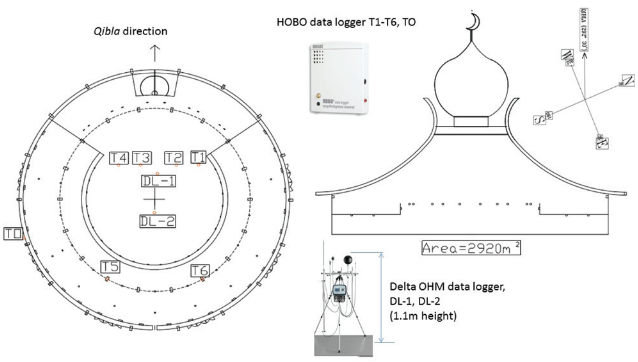


FIGURE 4. Location of instruments at main prayer hall (Graphic view)

The instrument is provided with three inputs for probes with SICRAM module (probes have an electric circuit to communicate with the instrument). The basic detected measurements, using probes HP3217.2 (combined probe for temperature Pt100 and relative humidity-capacitive RH sensor), TP3276.2 (Ø50 mm globe thermometer with temperature Pt100 sensor) and AP3203.2 (omnidirectional hotwire, airspeed 0-5 m/s) probes can determine and measures the air speed, V_a (m/s), globe temperature-T_g (°C), ambient temperature-T_a (°C) and relative humidity-RH (%). The accuracy of the probes HP3217.2 (temperature class 1/3 DIN; RH ± 2.5%), TP3276.2 (class 1/3 DIN) and AP3203.2 (± 0.05 to 0.15 m/s). In addition, direct measurement can be directly obtained mean radiant temperature (MRT), PMV/PPD index. On the other hand, another set of instrument consists of 6 units of portable HOBO data logger version 3.7.11 (Figure 4 and 5) was located straight and same line at the front side, T1 to T4 (4 units) and back side of the mosque, T5 to T6 (2 units). HOBO data logger version 3.7.11 is designed to measure the indoor environment such as temperature (°C) and relative humidity-RH (%) with 12 bits resolution measurements. The accuracy of the probe's temperature at ± 0.35°C from 0° to 50°C and ± 2.5% from 10% to 90% RH. The reason for putting the straight and same line is to measure the changes in temperature from the wall side up to the center of the main prayer hall. This is because the cool supply air was drawn from diffusers located at sidewalls of the mosque. All the instruments were installed at 1.1 m height above the floor as suggested by Al-Ajmi (2010). This is an ideal measurement height at moderate activity such as prayer position and the movement. At the same time, outdoor temperature also being recorded using 1 unit HOBO data logger, which was installed at pillar side of the outdoor wall. All instantaneous data from HOBO instruments are captured automatically at 5 minutes interval and directly save in the HOBO ware memory disc. All data then was downloaded to a laptop for further analysis. To analysis, the thermal comfort, operative temperature (OPT) is what humans experience thermally in a space. OPT is the combined effect of the mean radiant temperature and indoor air temperature. The mathematically OPT can be determined as below (Mc Quiston, Parker & Splitler 2005):

$$OPT = \frac{MRT + T_a}{2} \quad (1)$$

Where: OPT = Operative temperature
MRT = Mean radiant temperature, K
T_a = Indoor dry bulb temperature, K

RESULTS AND DISCUSSIONS

A summary of the indoor thermal performance in the Penang State Mosque that has been observed and measured is stated in Table 2. The air temperature and relative humidity of average indoor ambient were 25.0°C and 64.4%, with standard deviation (std. dev.) of 1.03 and 1.39, respectively. Whilst, the average wind velocity (air movement) in the main

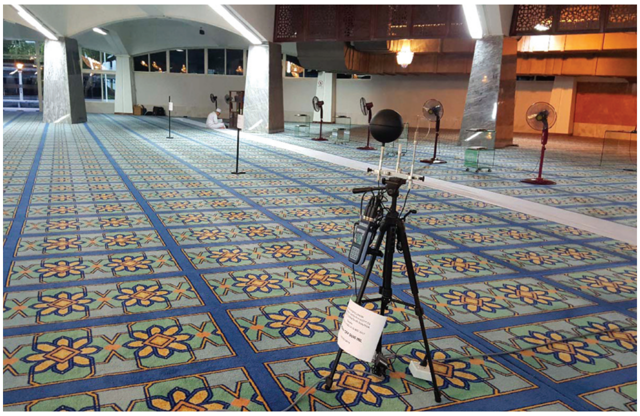


FIGURE 5. Deployment of measuring instruments at main prayer hall

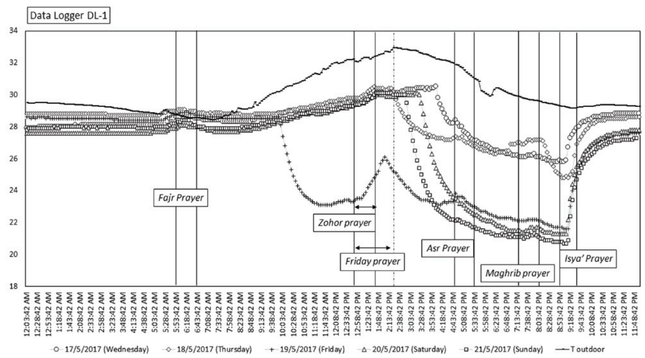
prayer hall was in between 0.07 to 0.76 m/s, with the mean value of 0.66 m/s and std. dev. of 0.11. The OPT obtained by calculations varied in between 23.8 to 26.9°C, with the mean value of 25.0°C, and std. dev. of 0.74, respectively. Table 2 also indicated statistical summaries of thermal environments and thermal indices of all prayers, where PMV ranging from +0.05 to +0.86 with the mean of 0.36 and std. dev. of 0.21. Meanwhile, PPD was an average of 17.0.

Figure 6 shows the indoor temperature that has been measured for 24 hours at the main prayer hall, starting from 17th – 21st May 2017. The temperature T1-T6 and T0 were measured with Hobo data logger version 3.7.11. Meanwhile, temperature DL-1 and DL-2 were measured with Delta OHM HD 32.3 data logger version 0.1.5.31. The first observation found that main prayer hall has a different temperature profile during weekday, weekend and Friday prayer. The graph shows that the air conditioning system was started operation (ON) and shutoff (OFF) at a different time (inconsistent). This result was in contrast to the interview session with the mosque officer, where the officer stated that the air conditioning system was fixed from 3.00 PM to 9.30 PM. The different operation condition will lead to the variability of operation time, produced different a thermal environment profile as well as daily energy consumption. On the other hand, during Friday prayer, the air conditioning system started (ON) earlier, which is at 10.00 AM in the morning that cause indoor temperature decreased in between 21.4-25.4°C but slightly increased at 1.00 PM. This is because the main hall for the prayer to be conducted was fully occupied with worshippers and therefore heat gain from worshippers were contributed heat load inside the mosque. After Friday prayer ended, the temperatures started to cool down again until *Isya'* prayer ended.

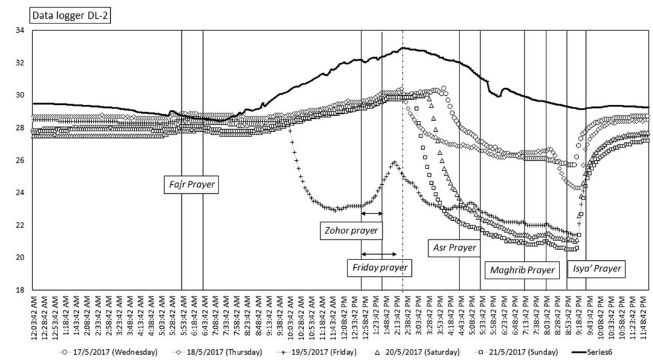
Second observation found that the mosque officers operate the air conditioning system with the aim to supply good thermal environment during *Asr* prayer, *Maghrib* prayer and *Isya'* prayer. *Fajr* prayer and *Zohor* prayer was not covered by the air conditioning system due to the assumption that thermal environment was still acceptable by the worshippers at that time (from interview session). Only mechanical ventilation such as stand fan was used to moderate the air ventilation. It was found that outdoor temperature starts slightly higher from 11.00 AM onwards (Figure 6) which reflected the comfort condition at *Zohor* prayer. The temperature effect at *Zohor* prayer is still tolerated (adaptive comfort) due to thermal sensation which need more investigated.

TABLE 2. Overall indoor thermal performance, air conditioning ON period

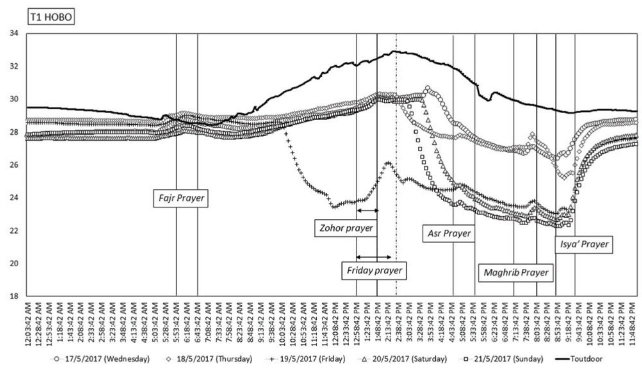
Climatic	Average	Min	Max	Std. Dev.
Indoor temperature (°C)	25.0	22.5	27.3	1.03
Relative humidity (%)	64.4	58.1	66.8	1.39
Wind velocity (m/s)	0.66	0.07	0.76	0.11
Operative temperature (°C)	25.0	23.8	26.9	0.74
PMV	0.36	0.05	0.86	0.21
PPD	17.0	10.32	29.8	4.42



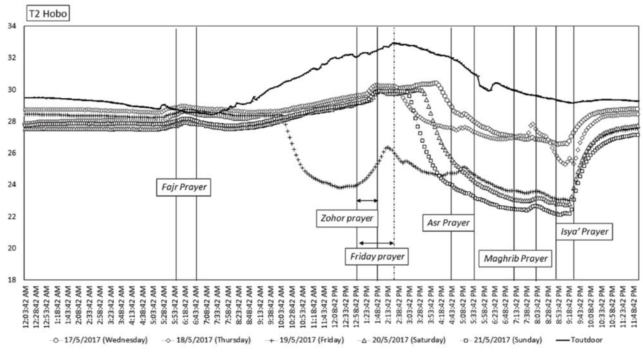
(a) Data Logger DL-1



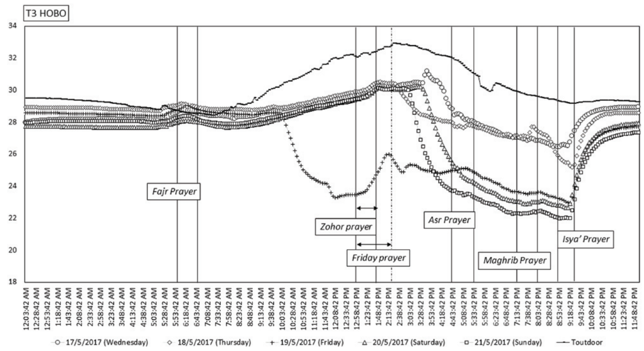
(b) Data Logger DL-2



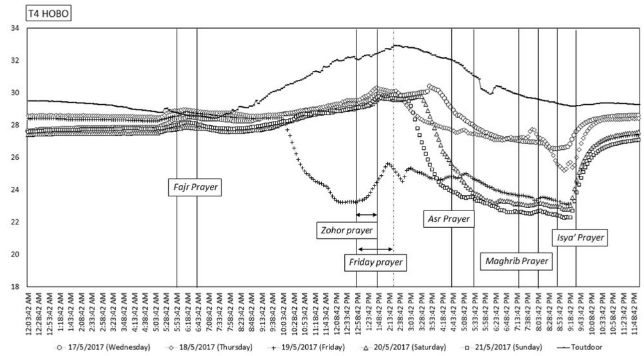
(c) T1 -Hobo



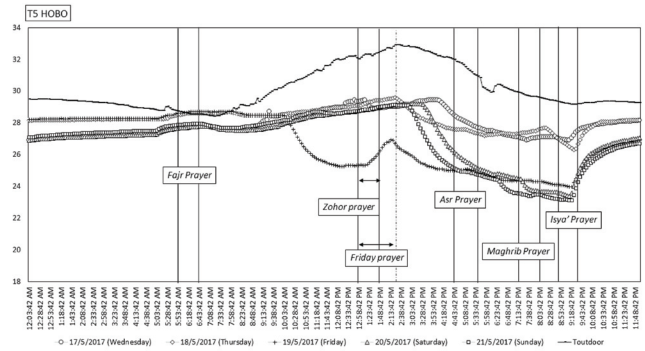
(d) T2- Hobo



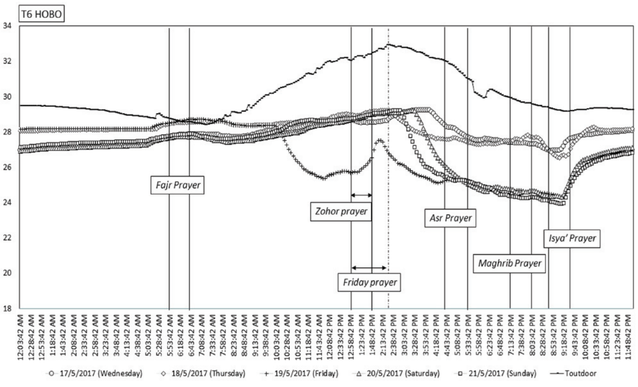
(e) T3- Hobo



(f) T4 - Hobo



(g) T5 - Hobo



(h) T6 - Hobo

FIGURE 6. Measured indoor temperature profile for 24 hours at main prayer hall, 17th - 21st May 2017; (a) Data logger DL-1, (b) Data logger DL-2, (c) T1 Hobo data logger, (d) T2 Hobo data logger, (e) T3 Hobo data logger, (f) T4 Hobo data logger, (g) T5 Hobo data logger, (h) T6 Hobo data logger

Note: DL-1 & DL-2 are measured by Delta OHM HD 32.3 data logger version 0.1.5.31. T1, T1, T3, T4, T5, T6 are measured by Hobo data logger version 3.7.11

Third observation found that mosque officers have continuously operates the air conditioning system from *Asr* prayer to *Maghrib* prayer and *Isya'* prayer which is about at 6.5 hours non-stop. The mosque has an intermittent occupancy period at intermittent time based on prayer time. Observation shows that average of peak occupancy was found at range from 30 minutes until 60 minutes in each prayers time. Hence, the air conditioning system was found operated even though no occupancy or minimum occupancy in main prayer hall especially after *Asr* prayer to *Maghrib* prayer time. It was found that approximately about 1.5-2 hours losses in cooling due to no occupancy. In addition, air conditioning system also supply cooling to the entire space of the main prayer hall even only a part of the mosque was used to perform the prayers activities. One of the reasons believed that mosque officer was lacked knowledge, not properly trained and has no technical background about the air conditioning system operation and standard. This condition wastes the energy, efficiency and as well as operating cost because the system covers all area of the mosque even when there is no occupancy or only certain part of the space is being occupied. To overcome this type of operation, thermal zoning strategies should be implemented at large mosque because only small part of the mosque is being used. This strategy was also been suggested by Budaiwi & Abdou (2013).

The wind velocity and OPT were compared in Figure 7. A good wind velocity generated from stand-fans operation for both *Fajr* and *Zohor* prayer without using air conditioning system. During *Fajr* prayer, ambient temperature was observed slightly cool compared to *Zohor* prayer. OPT temperature, on the other hand, began to rise and cause the main prayer hall to be warmer. When air conditioning is in operation, the wind velocity was observed slightly higher but in contrast with OPT which is slightly lower. Wind velocity and movement is an important factor to determine the cosiness in certain area. From the condition of wind velocity at main prayer hall (0.62 m/s), this condition already at the comfort level and it is theoretically achieved as indicated by Nicol (2004).

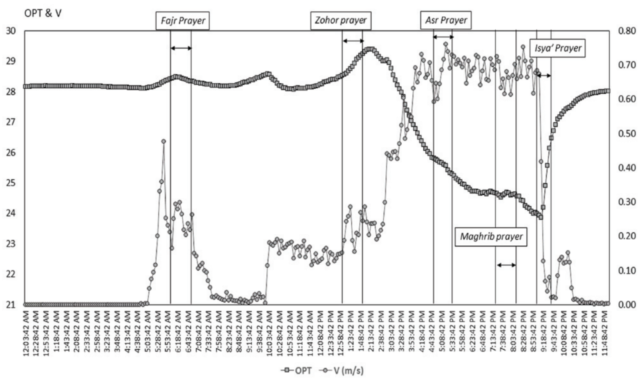


FIGURE 7. Measured Operative temperature (OPT) and wind profile, (V_a) 24 hrs at main prayer hall, 17th – 18th & 20th – 21st May 2017

Operative temperature (OPT) and humidity combination are shown in Figure 8 comparing the mosque indoor climate. The good indicator for humidity is ranging from 50% – 60% (ASHRAE Standard 55, 2013). Hence, the humidity was recorded in between 58% to 66% , which is an acceptable indicator of good mosque indoor air climate. Malaysia people had a high preference for humid condition based on their natural experience and adaptation (Makaremi et al. 2013).

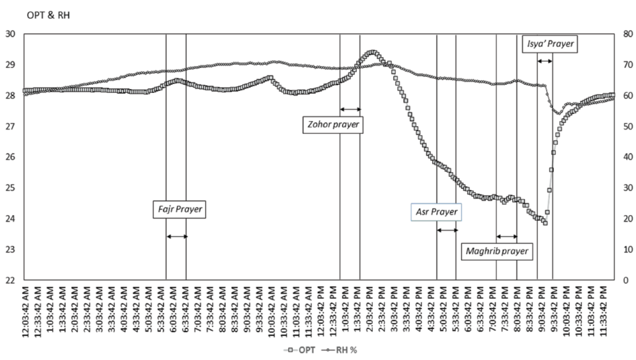


FIGURE 8. Measured Operative temperature (OPT) and relative Humidity (RH-%) 24 hrs at main prayer hall, 17th – 18th & 20th – 21st May 2017

The minimum temperature distributions recorded at all instruments in main prayer hall during air conditioning operation are presented in Figure 9. The recorded temperatures give an overall view that the mosque indoor climate has achieved the thermal preference level which also in line with comfort zone for building such as office, hospital, school and etc. Based on Hussin et al. (2015), the new comfort temperature range in air-conditioned mosque is from 27°C to 31°C. Therefore, temperature in the Penang State mosque can be adjusted up to 27°C as worshipper has accepted the thermal preference level as indicated by Hussin et al.

(2015). A simulation study to adjust the temperature has been conducted by Kiattiporn et al. (2008) in similar climatic has proved this statement. However, more comprehensive case study work is needed to prove this statement especially in a large scale of air-conditioned mosques.

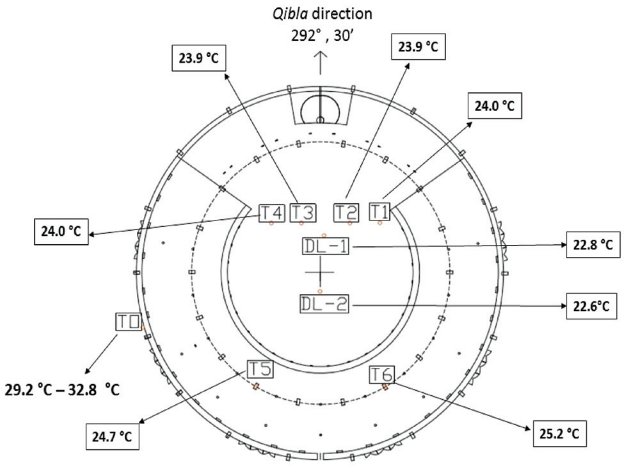


FIGURE 9. Minimum temperature distributions at location from 3.30 PM-9.30 PM, 17th - 21st May 2017

To analyze the strength of the relationship between OPT and PMV, a scatter diagram is plotted between the two, refer Figure 10. The linear regression equation from the PMV instrumental data are found as;

$$PMV = 0.265\ OPT - 6.22,\ (R^2\ = 0.82) \quad (2)$$

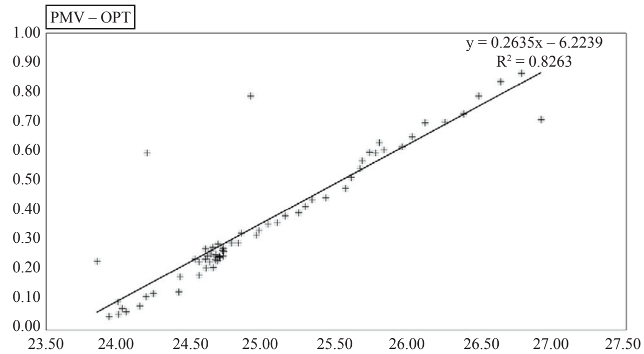


FIGURE 10. Correlation between PMV and OPT at Penang State mosque (–0.5 , +0.5 of ASHRAE Standard 55, 2013)

The correlation was statistically significant where majority of the dot values are falls between neutral and slightly warm scale. It is observed that when the PMV is equal to 0, the neutral OPT for PMV is 23.6°C. This condition was similar findings with Al-Ajmi (2010) but 2.3°C lower than Hussin et al. (2015) at mosque building which were 23.3°C and 25.9°C, respectively. In overall, predicted thermal sensation is found 72% achieved their PMV indices and within the comfort zone range (-0.5, +0.5). It should be noted that a comprehensive thermal comfort analysis of mosques is not intended as part of this paper, but rather to obtain a fair idea about thermal performance and conditions as related to the current HVAC operation strategies. Hence, this result indicated that thermal environment condition at Penang State Mosque are neutral as worshippers are experience in high outdoor temperature at their local climate.

CONCLUSION

It is possible to use objective measurements to predict occupant perceived thermal environment in air-conditioned mosque building. Some conditions need be considered, such as occupant staying period, building operation time and as well as air conditioning ON/OFF schedule and operation procedure. The finding has demonstrated that indoor temperatures achieved during the hours of the air conditioning system operation and fell within those recommended by the ASHRAE 55 Standard. By increasing the indoor temperature setting up to 5°C higher, thermal comfort can still be negotiated and accepted by the occupants. Sectional air conditioning zones also has an advantage which cooled only the floor areas that are used for praying. Most of the mosque officers are lacking of knowledge about the air conditioning system operation. Properly trained the mosque officers can increased the technical knowledge and handling procedure. By applying the operation strategy, mosque management can save the energy consumption as well as maintain thermal comfort. In overall, predicted thermal sensation is found 72% achieved their PMV indices and within the comfort zone range (-0.5, +0.5). Hence, thermal environment condition at the Penang State Mosque are neutral as worshippers are experience in high outdoor temperature at their local climate.

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