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Thermal Comfort during daily prayer times in an Air-Conditioned Mosque in Malaysia

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Abstract

This study evaluated the thermal environment in an air-conditioned mosque in Malaysia during the various daily prayer times. The objectives of the study includes determining the clo values, the neutral operative temperature, comfort temperature, and assessing the reliability of the PMV model predictions in determining thermal comfort in these situations. A field study was conducted in November 2012 and April 2013 during *Subuh*, *Zohor*, *Asar*, *Maghrib* and *Isyak* prayer times. Results show that PMV model predictions and AMV were found to be 25.88 °C and 30.44 °C, respectively. The difference of 4.56 °C between PMV and AMV indicates that thermal comfort under these conditions cannot co-relate well with ASHRAE Standard-55. A new range of thermal comfort temperature between 26.99 °C to 31.41 °C was derived. Overall observations found that worshippers' thermal comfort in the hot and humid climate such as Malaysia favours the adaptive approach.

Key words: Mosque, prayer times, Predicted Mean Vote, Actual Mean Vote, Adaptive approach

1. Introduction

With the rapid growth of mosque building and its functions in the Muslim community in Malaysia, a provision for thermal comfort of worshippers is a prime concern. Inappropriate thermal comfort in mosque buildings leads to unsuitable thermal environment for the worshippers and the functions held inside. It has become common practice that mosques in Malaysia are installed with air-conditioning (A/C) systems to provide cooling and better thermal comfort to the worshippers. However, there is a lack of information on the actual indoor climatic as well as thermal comfort conditions in Malaysian mosques so far. The increasing trend of A/C use in Malaysian mosque buildings is apparently increasing electricity consumptions in the daily mosque operations.

In order to evaluate the thermal comfort in an A/C building, Predicted Mean Vote (PMV) and Predicted Percent Dissatisfied (PPD) are the common thermal comfort indices that have been used worldwide. The international standard such as ASHRAE Standard-55, (2013) and ISO 7730, (2005) have defined the approach to thermal comfort evaluation in terms of PMV and PPD. Many studies have been conducted to investigate the indoor thermal comfort in buildings using the PMV and PPD approach such as:- Orasa & Oliveira, (2011) on office, Al-ajmi, (2010) ; Al-homoud et al., (2009) on mosque, Kwok & Chun, (2003) on school, Azizpour et al., (2013) on hospital and others. On the other hand, evaluation of thermal comfort using the adaptive model also has been introduced. This approach has been particularly promoted by Nicol and Humphreys whereby they have found strong correlation

between indoor and outdoor conditions with occupants adaptation behaviour (Nicol, 2004 ; Nicol & Humphreys, 2002).

1.1 Malaysian Climate and Mosque Religious Practices

Malaysia is located within the Latitude and Longitude of 1º - 7º North and 100º - 119º East, respectively. The daily ambient air temperature is about 24 ºC to 38 ºC, whilst relative humidity ranges between 70 % to 90 % through the year, with relatively low air movements. These climatic conditions basically result in a high thermal environment in building indoor spaces.

Malaysia has a majority of Muslim population, whose religious practices such as daily prayers, preaching and citation of the Al-Quran are held in the main prayer hall (MPH) of mosque buildings.

The communal daily prayer is performed five times a day (*Subuh, Zohor, Asar, Maghrib* and *Isyak* prayers) starting from early morning until night time with duration of about thirty minutes to an hour each to complete. Each of the prayers will be performed in a group, led by an *Imam* with the worshippers standing, bowing, prostrating or sitting behind the *Imam* aligned in *safs*. Table 1 summarises the meanings of terminologies used in this study.

Table 1: Religious terminologies

Malay	**Arabic**	**English**
Subuh	*Fajr*	Dawn
Zohor	*Zohar*	Early afternoon
Asar	*Asr*	Late afternoon
Maghrib	*Maghrib*	Sunset
Isyak	*Isha*	Night
Terawikh	*Tarawikh*	Special Ramadhan night prayer after *Isyak*
Imam	*Imam*	Person leading a prayer
Baris	*Safs*	Rows
Aurat	*Aura'*	Parts of human body forbidden to be exposed to view: Male – between the navel and the knee Female- the whole body except for the face and palms
Qariah	*Qaryah*	Community living nearby/neighbourhood sharing the mosque
Mehrab	*Mihrab*	A niche in the wall of a mosque that indicates the direction of Mecca
Mimbar	*Minber*	A pulpit in the mosque where the imam stands to deliver sermons
Qiblat	*Qibla'*	Prayer direction to the holy city of Mecca

This study aims to evaluate the thermal environment in an A/C mosque during the various daily prayer times. The objectives of the study include (i) Determining the clo-values of worshippers during prayer times, (ii) Determining the neutral operative temperature and comfort temperature from worshippers' thermal responses; and (iii) Assessing the reliability of the PMV model predictions in determining thermal comfort in A/C mosque building.

2. Field study

Thermal comfort is evaluated in MPH of one air conditioned mosque building (Mosque A/C) for daily prayer mode. The selected Mosque A/C is located at Latitude 5.5170 °North and Longitude 100.2600 °East, Kepala Batas Penang Malaysia. Overall, a total number of 44 mosque buildings are located around Kepala Batas town, Penang Malaysia. Whilst it is

impossible to cover all mosque building types, the following criteria have been considered for the choice of mosque for this study:

- Construction of not more than 10 years old
- Of reasonable size (<1000 worshippers')
- Modern design and using modern construction materials
- Building with dome
- Using mechanical system such as air conditioning

Measurement data were recorded on 25-27 November 2012 and 14-16 April 2013 representing the local cooler and the hotter seasons, respectively. Worshippers' thermal comfort and sensations were evaluated and observed during the daily prayer time modes of *Subuh, Zohor, Asar, Maghrib* and *Isyak.* These involved collection of environmental indoor measurement and questionnaires among worshippers'. Outdoor thermal environmental data from nearby Butterworth weather station of the Meteorological Department of Malaysia were obtained for the measurement dates.

2.1 Mosque building as a case study

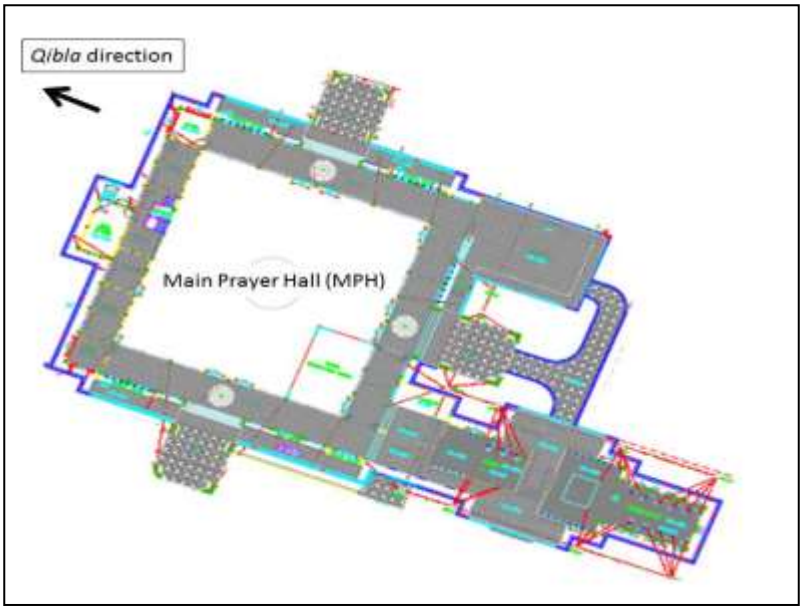
The selected sample of Mosque A/C (known as *Masjid AT-Taqwa*) is one of the *qariah* (community) mosques (Figure 1). The mosque was built in year 2004 and was constructed based on a square plan. The total built-up area of the MPH is 640.1 m^2 and the wall height is 6 metres. The West-facing wall is oriented towards the direction of holy city, Mecca and contains the *mehrab* where the *Imam* is located during prayers. Adjacent to the *mihrab* is the *mimbar*, located at the right side and elevated 1.5 metres above the floor, where the *Imam* delivers the Friday sermon (*Khutba*). The walls facing Northward and Southward are built with two sliding doors for entrance and six windows on each side. The wall facing Eastward, is built with four sliding doors for entrance and also with three windows on each side. The door dimension is 1.83m x 2.2m each. Windows have a frame dimension of 2.2m x 1.6m and built in with four sliding leaves. All the windows are installed for ventilation purposes. The mosque has a roof that is constructed together with one big dome, located at the center of the MPH. The MPH can be occupied by approximately 800 worshippers' at any one time. The floor area is finished with carpet that has a built-in pattern for the *safs*, parallel to the *qibla* wall (Westward). The distance between each *saf* is about 1.06 metres. The mosque had been installed with 12 units of split air-conditioning system (capacity is approximately 32 horse power) and supported by 15 units of wall fans. All the appliances are wall-mounted to distribute cooled air into the MPH area (Figure 1). The control temperature of the air-conditioning units were set at 21 °C and indoor fans were running at maximum speed. During the operation of the mechanicals system, all windows were fully closed with occasional opening of the doors.

a) Building view from West

b) View of *Mehrab* and *Mimbar*

c) Internal view of South-facing wall

d) View of wall-mounted A/C unit and fans



e) Main prayer hall (MPH) layout plan

Figure 1 Plan of Mosque A/C
Note: a) Building view from West, b) View of *Mehrab* and *Mimbar*, c) internal view of South-facing wall, d) View of wall-mounted A/C unit and fans, and e) MPH layout plan

2.2 Questionnaire survey

The survey questionnaire consists of three sections: (a) demographic background, (b) clothing, (c) current thermal comfort. The questionnaire was developed and adopted from previous study (Al-ajmi, 2010) where worshipper can feel free to evaluate their thermal environment in MPH of Mosque A/C. In addition, the clothes types was also obtained from the survey and cloth value (clo) was estimated based on clothes assemblies references in ISO 7730 (2005). ASHRAE seven point thermal sensation scale (+3 to -3) was included in questionnaire, to assess the Actual Mean Vote (AMV) or Thermal Sensation Vote (TSV) reflecting the qualitative thermal sensation of worshippers. To compare the results of the survey (AMV) with those of the PMV model predictions, statistical methods were carried out using SPSS software version 20.0 (SPSS, 2012). The control point is based on ASHRAE acceptable thermal environment for general comfort where PPD <10% or (-0.5 < PMV < +0.5) ASHRAE Standard-55, (2013).

2.3 Objective measurement

Measurements of indoor microclimatic conditions were made with a portable meteorological climatic assembly known as `Multi Station Thermal Comfort Real Time Monitoring System' (MSTCRTMS). The MSTCRTMS station includes sensors for the measurement of dry-bulb air temperature (T_a ; °C), globe temperature (T_g ; °C) wind speed/air velocity (V; m/s) and relative humidity (RH ; %). Air velocity, air temperature and relative humidity were measured using function probe of KIMO CTV100-ANA300. Globe temperature was measured using a globe thermometer. All measurements were connected to ADAM View Software Version 4.30.004, the thermal data logging system. The equipment set-up have been tested and calibrated before starting the measurements. The MSTCRTMS station was installed at a height of 1.1 m above from floor level and located at fixed position in main prayer hall (between *saf* 6 & 7). The height level proposed by ASHRAE Standard-55, (2013) for light activity-standing/sitting, is almost suitable condition to worshippers during performance of the daily prayers. The metabolic rate value used in this study was estimated to be 1.3 met as recommended by previous research (Al-ajmi, 2010), for near sedentary physical activity. PMV and PPD values were determined using software CBE Thermal comfort tools for ASHRAE Standard-55 (Hoyt et al., 2012).

3. Results

3.1 Demographic information

Table 2 shows the worshippers' demographic information which included the worshippers' categories and ages. The number of respondents was 396 people and all of them were male. They included 6.3 % from mosque officers, 41.8 % from *qariah* (close community) and 51.9 % from others (non *qariah* members, visitors and travellers). Their ages range from 18-30 (22.73 %), 31-40 (10.61 %), 41-50 (42.42 %), 51-60 (21.21 %) to over 61 (3.03 %).

Figure 2 illustrates the MPH of Mosque A/C, the MSTCRTMS position, the worshippers' with their attires during performance of their prayer and the evaluation of thermal comfort among worshippers'. Physical data for daily prayers was recorded starting at 2.30 am and lasting till 10.30 pm, synchronized with Malaysian standard time.

Table 2: Demographic information

Mosque A/C	Daily prayers (n=6 days)					Mean
	Subuh	Zohor	Asar	Maghrib	Isyak	all
Sample size	66	66	66	66	66	%
Worshipper						
Mosque officers	6	2	9	0	3	6.30
Qariah members	31	22	27	31	27	41.80
Others	29	42	30	35	36	51.90
Age						
18-30	16	10	16	19	15	22.73
31-40	9	17	10	15	7	10.61
41-50	16	22	19	24	28	42.42
51-60	17	13	16	6	14	21.21
61 above	8	4	5	2	2	3.03

a) Thermal comfort station in MPH

b) Daily prayer mode

c) Questionnaires

Figure 2: Measurement activities at Mosque A/C on 25-27 November 2012 and 14-16 April 2013

3.2 Clo value

Table 3 shows the common clothes worn by the worshippers' during performance of daily prayers at Mosque A/C including the clo values. The most common clothes indicated is traditional Malay long sleeves shirt paired with *kain sarung* (59.1 %) during *Subuh* prayer, while 43.9 % and 40.9 % during *Maghrib* and *Isyak* prayers. At noon (*Zohor* prayer), most of the respondents were working employees and they wore the normal working attire of long sleeve shirts paired with normal trousers. Thus, during *Zohor* prayer, 24.2 % of respondents wore these clothes compared to traditional Malay clothes (19.7 %). The highest clo values indicated as in Table 4 is during *Zohor* prayer (0.581), followed by *Subuh* prayer (0.536), *Maghrib* prayer (0.516), *Isyak* prayer (0.512) and *Asar* prayer (0.495). This clo value was then used for PMV calculation.

Figure 3 shows that there is no correlation ($R^2 = 0.005$) between worshippers' clothing and Operative Temperature when they attended Mosque A/C. There are several factors involved regarding this situation. Firstly, the climatic condition which is hot and humid throughout the year, and secondly, the requirement of Muslim's attire when performing the prayer. In Islam, there is no limitation to the type of attire when visiting the Mosque for performing the prayers except that it must cover the basic *aurat* (men: from knee to navel; women: the whole body except the face and the two palms) and be clean from dirt. Thirdly, due to the strategic location of the mosque (close proximity to houses), the Malay traditional attire such as traditional Malay long sleeves shirt paired with *kain sarung* were the most common attire worn by the worshippers especially for *Subuh*, *Maghrib* and *Isyak* prayers. The same situation was reported by Al-ajmi et al., (2006) in Arab counties where it was found that the worshippers wore customary attire during prayers at the mosque.

Table 3: Common clothes wearing by worshippers' during daily prayer

Type of clothes	Clothes percentages				
	Subuh	***Zohor***	***Asar***	***Maghrib***	***Isyak***
Traditional Malaysia long sleeves shirt with trousers	9.1	18.2	27.3	27.3	25.8
Traditional Malaysia long sleeves shirt with *kain sarung*	59.1	19.7	31.8	43.9	40.9
Traditional Malaysia long sleeves shirt with normal trousers	9.1	3	7.6	3	13.6
Traditional Malaysia long sleeves shirt, with jeans	1.5	0	0	0	0
Normal shirt with kain *sarung*	3	16.7	4.6	4.6	1.5
Normal shirt with normal slack	0	0	3	1.5	0
Normal shirt with jeans	0	0	1.5	0	1.5
Arabic clothes (*Jubah*) with *kain sarung*	15.2	1.5	3	9.1	6.1
Arabic clothes (*Jubah*) with normal trousers	3	3	1.5	0	6.1
Arabic clothes (*Jubah*) with athletic sweat pants	0	4.5	1.5	4.5	0
Long sleeves shirt with normal trousers	0	24.2	13.6	3	1.5
Long sleeves shirt with jeans	0	6.1	1.5	0	0
Long sleeves shirt with *kain sarung*	0	3	3	3	3

Table 4: Clo value by worshippers' during daily prayer

Clo-value	*Subuh*	*Zohor*	*Asar*	*Maghrib*	*Isyak*
Mean	0.536	0.581	0.495	0.516	0.512
S.D	0.147	0.191	0.100	0.139	0.128
Min	0.420	0.420	0.420	0.420	0.420
Max	0.860	0.890	0.890	0.890	0.860

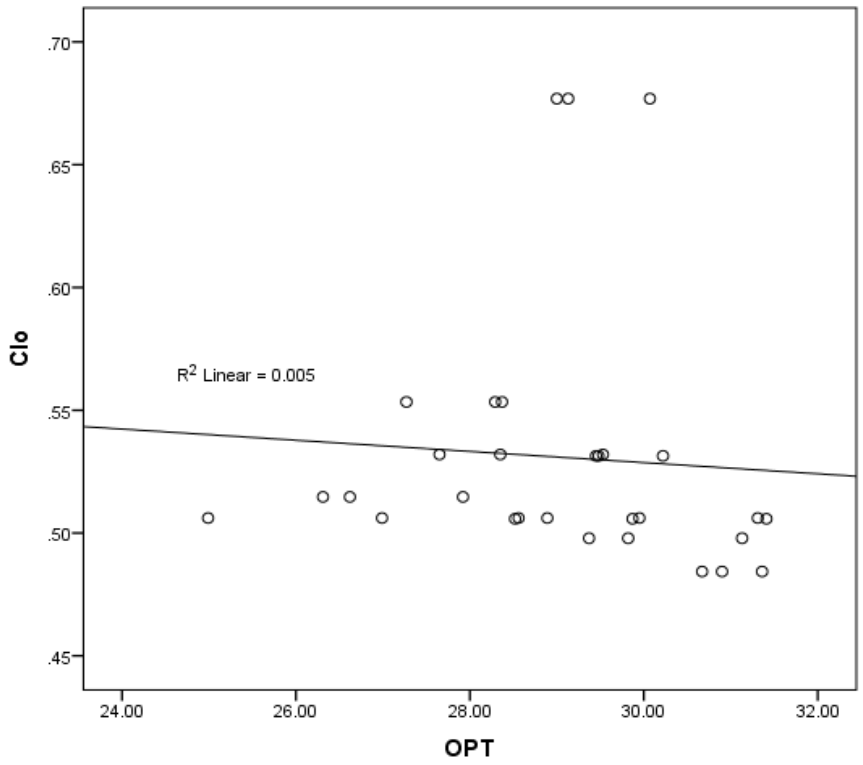


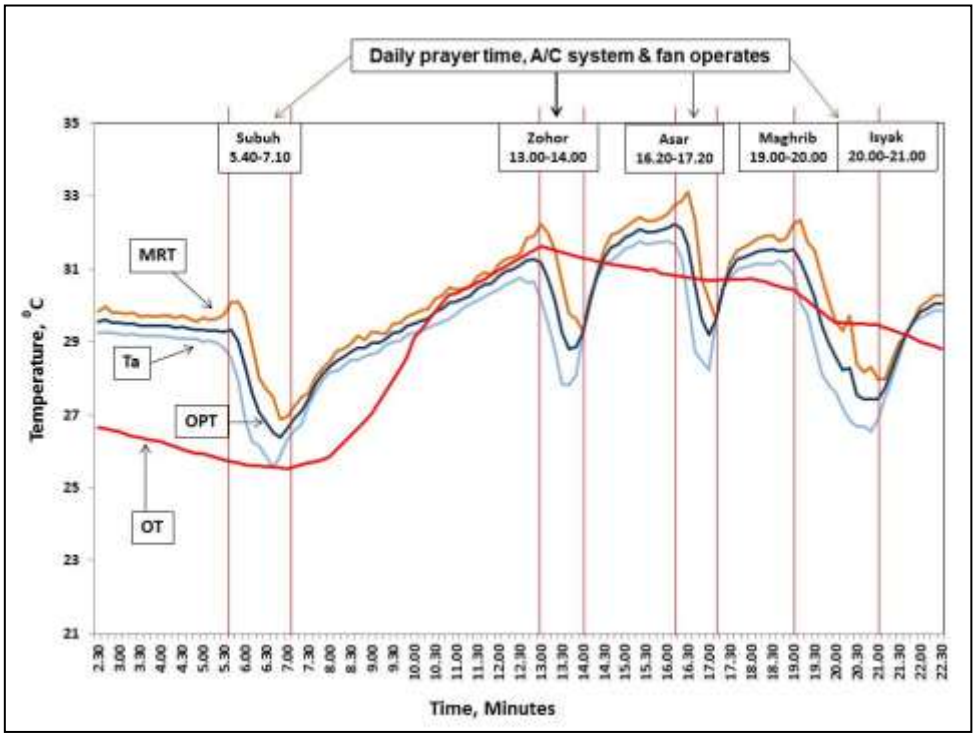
Figure 3: Clo value and relation to Operative Temperature (OPT)

3.3 Indoor climatic conditions

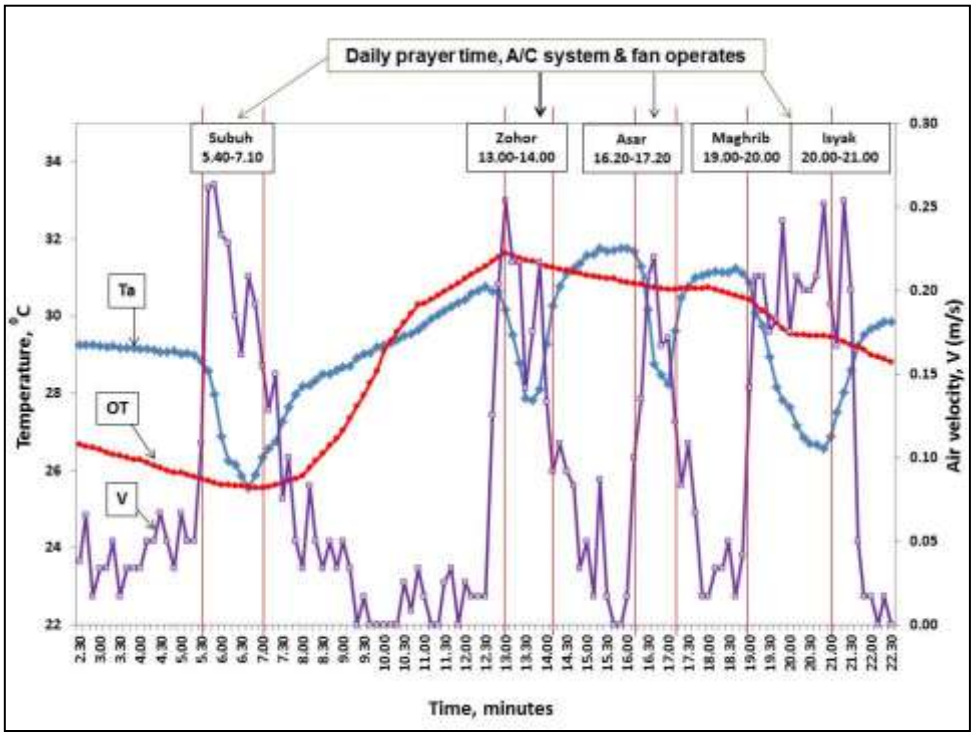
Figure 4 shows the daily pattern of the average indoor climatic conditions in Mosque A/C starting from 2.30 am till 10.30 pm daily. The observed periods were *Subuh, Zohor, Asar, Maghrib* and *Isyak* prayers. It is observed that indoor ambient temperature (Ta) and air velocity movement (V) in MPH have unique patterns when the air conditioning system and fans were operated. Ta was generally reduced meanwhile the air flow increased during these prayer times. The same observation can be made for relative humidity (RH) where small percentage was reduced in all daily prayer times. After worshippers completed each prayer mode, the air conditioning system and fans were switched off. Thus, the indoor Ta and RH increased again slightly and the air flow decreased.

Mean Radiant Temperature (MRT) and Operative Temperature (OPT) were having higher values in early morning period of 2.30 -5.30 am, and subsequently at 7.10-13.00pm, 14.30-16.10 pm, 17.30 -18.50 pm and 21.10-22.30 pm. One explanation is that during these times all openings were closed and all fans and A/C system were not operating, resulting in warmer

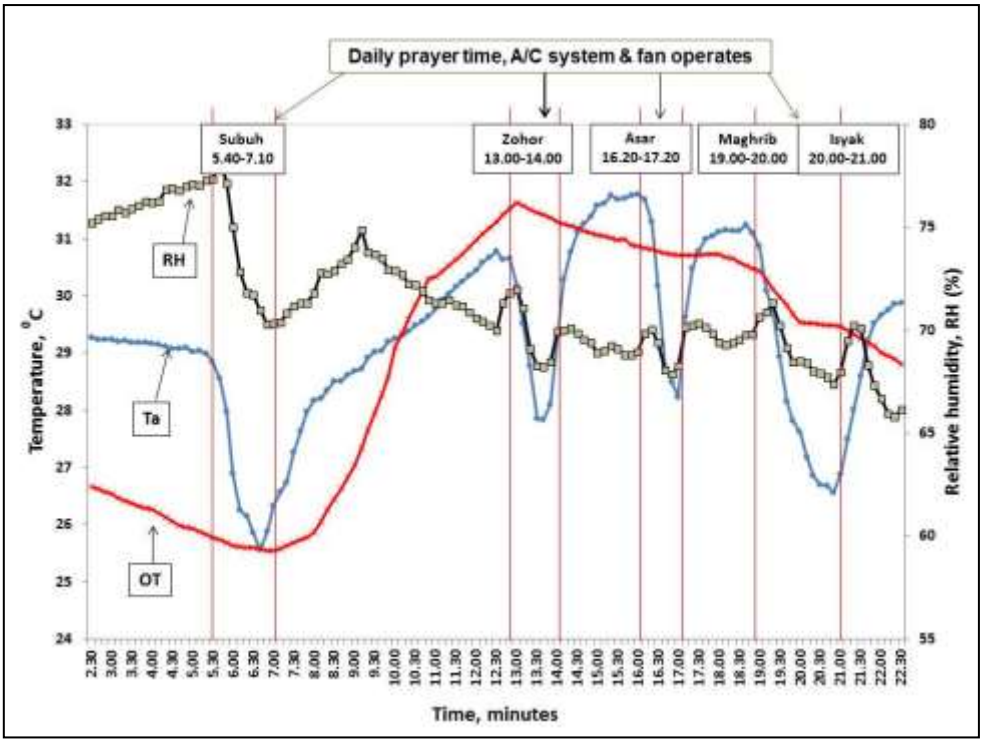
indoor conditions and surfaces. When prayer time starts, the MRT and OPT decreased slightly due to the cooling process produced from the operation of A/C systems and fans.



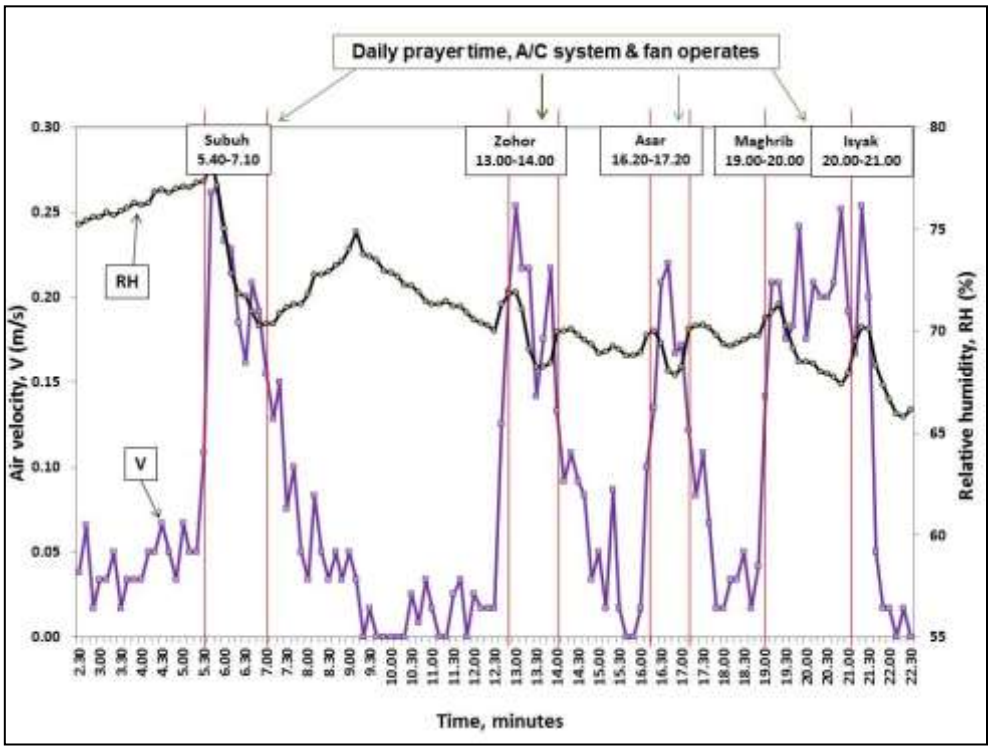
a) Indoor Temperature (Ta), Mean Radiant (MRT) and Operative Temperature (OPT)



b) Indoor Temperature (Ta) VS Air velocity (V)



c) Indoor Temperature (Ta) VS Relative Humidity (RH)

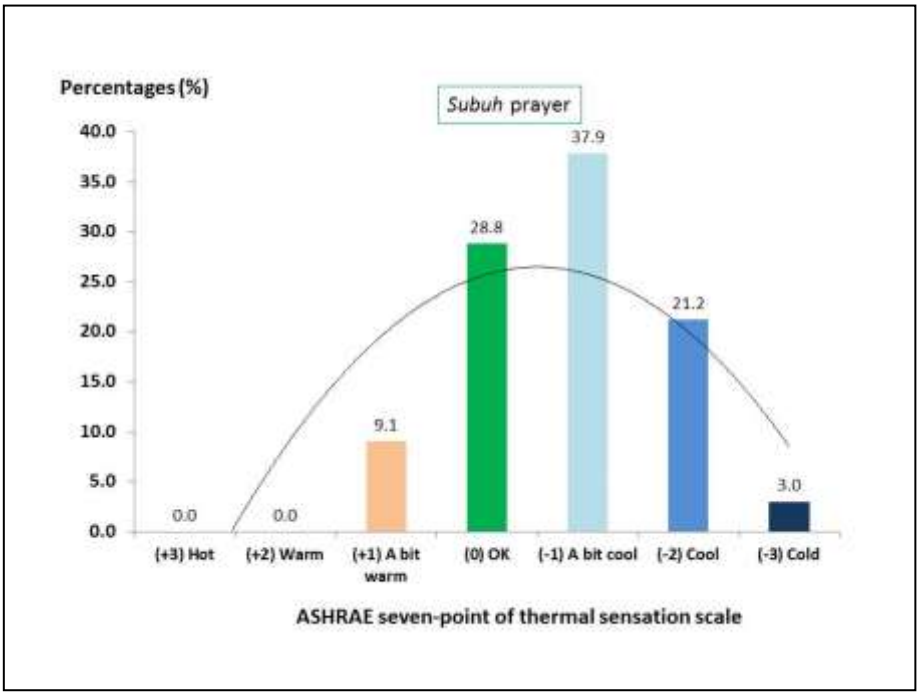


d) Air velocity (V) VS Relative Humidity (RH)

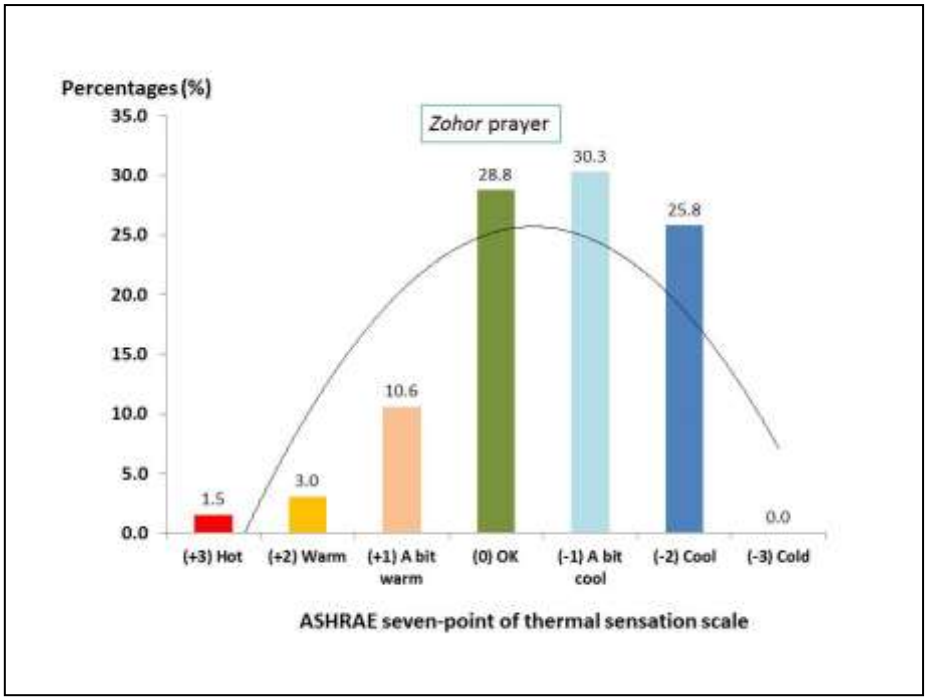
Figure 4: Indoor climates in Mosque A/C
Note: Ta = Indoor Temperature; MRT =Mean Radiant Temperature; OPT= Operative Temperature; OT = Outdoor Temperature; V=Air Velocity; RH= Relative Humidity

3.4 Worshippers' thermal sensation

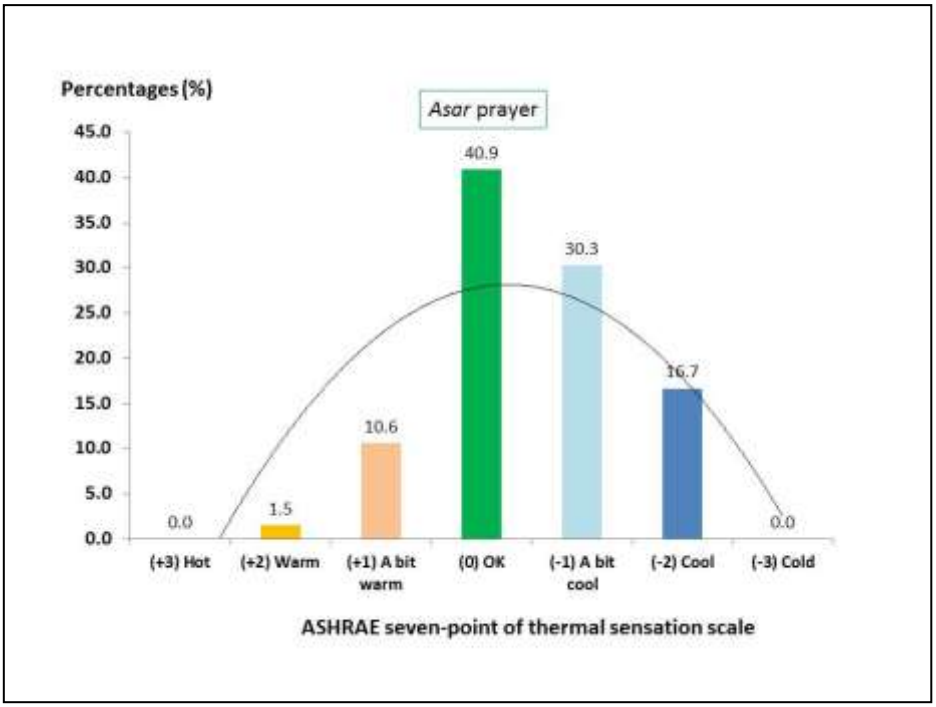
Figure 5 shows the result of thermal response based on ASHRAE seven-point thermal sensation scale (ASHRAE Standard-55, 2013). Most of the votes for *Subuh, Zohor* and *Maghrib* prayer times indicate cool thermal sensations, which reflects that the worshippers felt cool with their environment instead of normal. Only *Asar* and *Isyak* prayers contain a normal curve distribution which indicates that worshippers felt normal with the thermal environment. At observation times, OPT temperature range were from 26.38-29.33 °C (*Subuh*), 28.81-31.20 °C (*Zohor*), 29.2-32.1 °C (*Asar*), 28.6-31.5 °C (*Maghrib*), 27.4-28.6 °C (*Isyak*), respectively. There is a variance of vote for Isyak prayer where the OPT temperature was slightly low but the vote was normal when compared to *Maghrib* prayer. The explanation to this is the length of stay in MPH by worshippers' who remained in the MPH after completing their *Maghrib* prayer. During this times, they had a short religious lecture which was delivered by the *Imam*. Sometimes, they would continue praying individually or quietly recite Al-Quran until the *Isyak* prayer time. This practice was common and therefore resulted in a longer period of stay in the mosque (say 2 hrs.) for these worshippers. Even though the indoor OPT temperature was slightly higher, the thermal sensation votes shows that the majority of worshippers accepted their thermal environment (Figure 5). One possible explanation is due to the longer staying period in the mosque (2 hrs.) resulting in body adjustment and adaptation behaviour among worshippers. The prior exposure to the external hot and humid conditions gave the benefits to worshippers to prepare and try to tolerate the cooler indoor conditions. The same situation was reported by Kwok & Chun, (2003) in school buildings where past experience or knowing the indoor thermal condition will give the student the chance to prepare themselves before being exposed to the conditions.



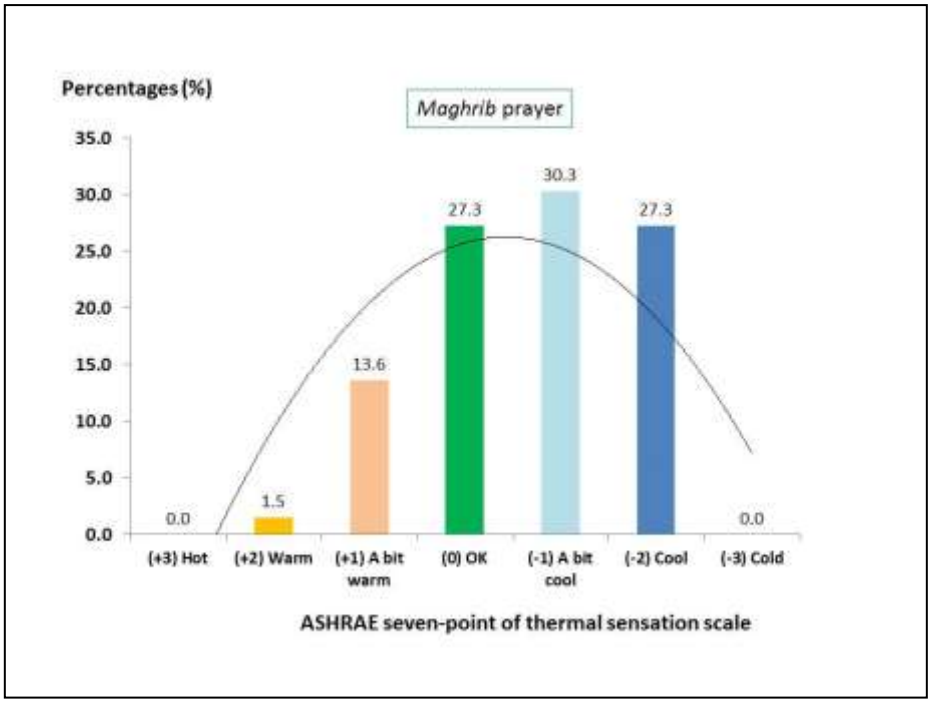
a) *Subuh* prayer



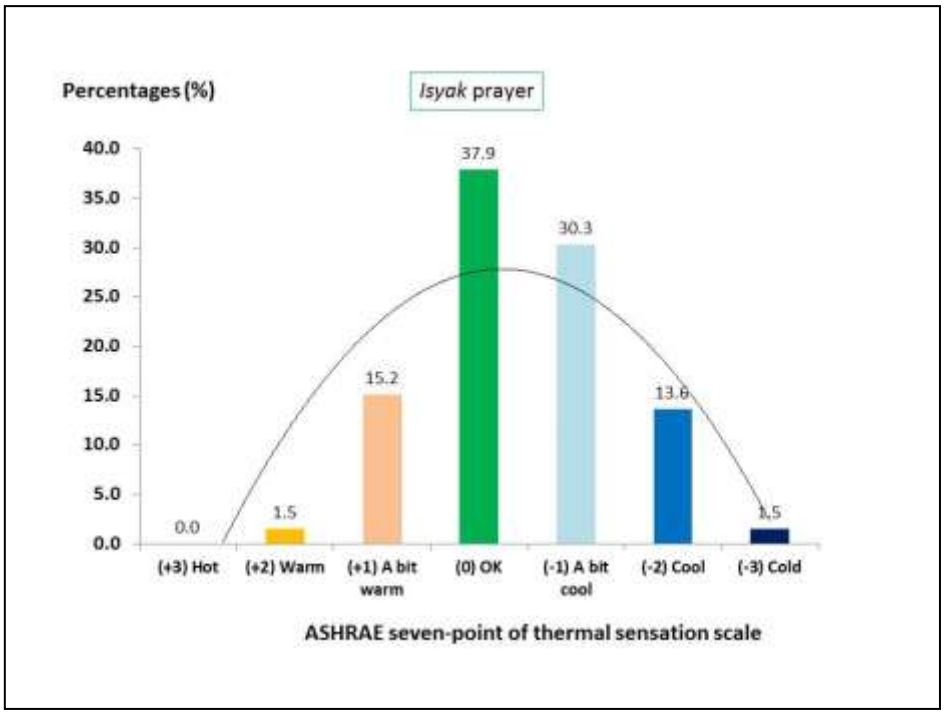
b) *Zohor* prayer



c) *Asar* prayer



d) *Maghrib* prayer



e) *Isyak* prayer

Figure 5: Thermal response based on ASHRAE seven-point thermal sensation scale
Note: a) *Subuh* prayer, b) *Zohor* prayer, c) *Asar* prayer, d) *Maghrib* prayer, and e) *Isyak* prayer

Thermal preference of worshippers when exposed to the indoor thermal environment was evaluated. Worshippers were asked if they preferred to change the thermal environment they were experiencing (Table 5). The results show that more than half of worshippers preferred to change their thermal environment to cool during prayer times except for *Subuh* prayer which garnered only 48.5 %. Similar result was reported by Azizpour et al., (2013) in Malaysia case where most of the respondents preferred to change their thermal environment to cool. Observation of mean OPT temperatures show that worshippers were exposed to higher OPT temperatures during the prayer times. This differs from the finding by Azizpour et al., (2013) study where the mean OPT temperature was lower. One possible explanation might be that Mosque A/C operates the air condition on intermittent basis (i.e. only during prayer times), whereas in Azizpour's case the buildings which offer medical services were operating the air-conditioning system round-the-clock. Furthermore, Mosque A/C operates the air condition for a very large volume of air space in a very short period, and not in a fully-closed situation.

Table 5: Comparison of thermal preference votes

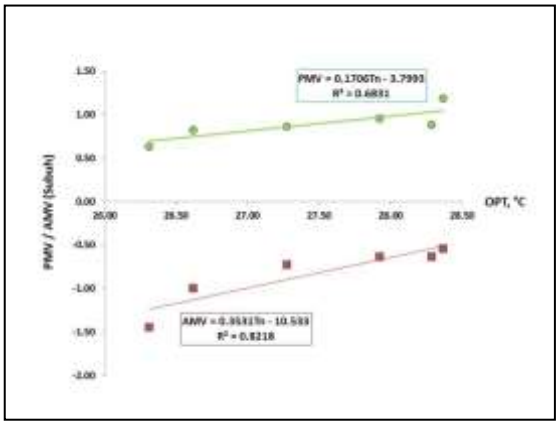
Researchers	**% to be cool**	**% to be warm**	**OPT, °C**
Kwok & Chun, (2003**)**	8.7	8.7	24.10
Al-ajmi & Loveday, (2010)	11	22	23.71
Al-ajmi, (2010)	19.5	11.6	23.98
Azizpour et al., (2013)	52.1	21.1	25.24
This Study-Daily prayers			
Subuh	48.5	1.5	27.46
Zohor	66.7	1.5	29.75
Asar	65.2	4.5	30.45
Maghrib	65.2	1.5	29.83
Isyak	56.7	4.5	27.93

3.5 PMV model predictions and actual mean vote (AMV)

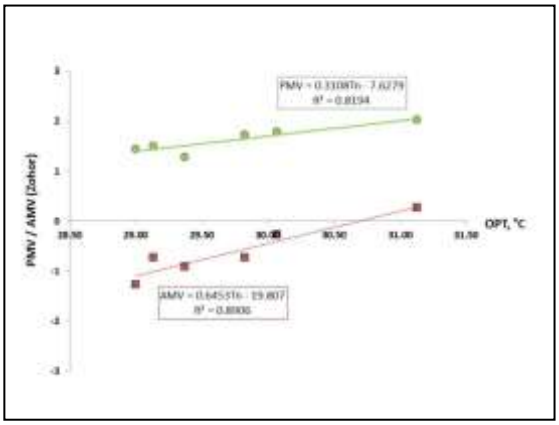
In ideal case, the Actual Mean Vote (AMV) should relate equally to Predicted Mean Vote (PMV). AMV and PMV for all daily prayers have been investigated and plotted in linear regression graph as in Figure 6. The graphs represent the values of AMV and PMV as a function of Neutral Operative Temperature (Tn) for all prayer times. One dot represents the mean vote of 11 respondents in each daily prayer for duration of 6 days. Result shows that most of the dots are located below the zero line, thus the line slope of actual AMV and PMV is much lower than the theoretical. Moreover, to find out whether worshippers' who perform their daily prayer in Mosque A/C are satisfied with the level of indoor thermal conditions, the neutral operative temperature (Tn) is a key indicator. The linear regression analysis was then applied to determine the values of Tn Temperature for all prayer times. The outcome from the graph, the linear regression equations are listed below;

PMV = 0.1706Tn – 3.799;	AMV = 0.3531Tn – 10.533	-*Subuh* prayer
PMV = 0.3108Tn – 7.628;	AMV = 0.6453Tn – 19.807	-*Zohor* prayer
PMV = 0.2892Tn – 7.00;	AMV = 0.5179Tn – 16.271	-*Asar* prayer
PMV = 0.4046Tn – 10.494;	AMV = 0.6520Tn – 20.131	-*Maghrib* prayer
PMV = 0.2889Tn – 7.146;	AMV = 0.2975Tn – 8.689	-*Isyak* prayer

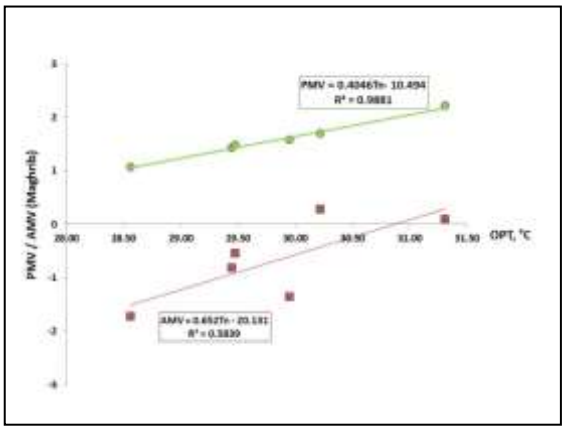
The gradient of the regression number indicates how sensitive the worshippers' were with their thermal environment for both predicted value and actual thermal response by subjective evaluation. The linear regression equation was then derived to zero for PMV and AMV in order to get the Tn temperature.



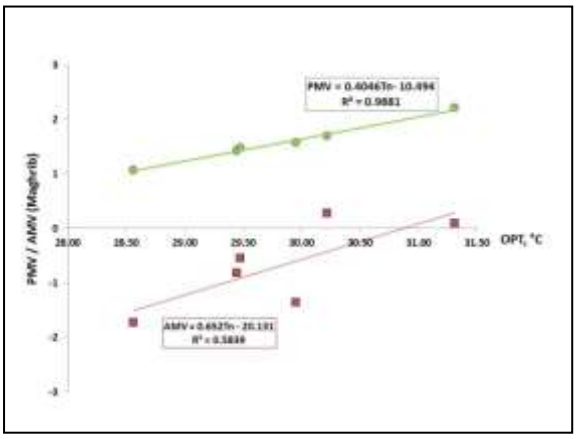
a) *Subuh* prayer



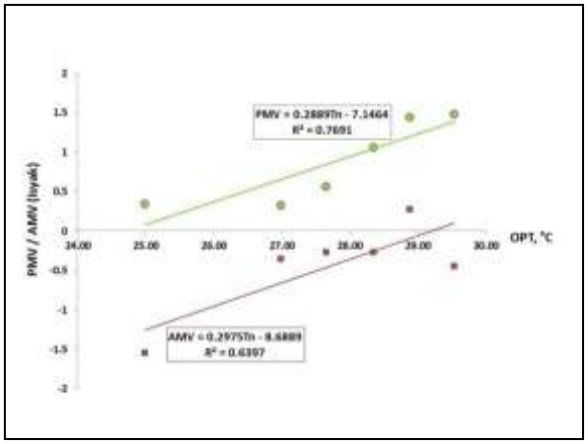
b) *Zohor* prayer



c) *Asar* prayer



d) *Maghrib* prayer



e) *Isyak* prayer

Figure 6: PMV, AMV and relation to Operative Temperature (OPT)

Table 6 shows the OT, OPT, PMV and AMV which were obtained from the regression equation methods. It clearly shows that PMV values underestimated the whole thermal conditions of the prayer times compared to AMV. The discrepancies range between the lowest of 4.47 °C (*Isyak* prayer) and the highest of 7.56 °C (*Subuh* prayer) where the variables factor such as clothes value, metabolism rate, air speed, relative humidity and mean radiant temperature (MRT) are involved in PMV prediction model. Meanwhile, observation of the relationship between OPT-AMV in daily prayer times shows there is a small amount of discrepancies. When the OPT was low (*Subuh* prayer: 27.46 °C), the AMV was slightly higher. Thus, the thermal sensation vote has discrepancy of 2.37 °C. In contrast, when the OPT was higher (*Zohor* and *Asar* prayer times), the discrepancy is only 0.94 °C and 0.97 °C, respectively. It is also noted that AMV values are also closer to OT values except for *Subuh* prayer time. This trend reflects a scenario akin to adaptive concept, but which needs further investigations.

Table 6: OT, OPT, PMV and AMV for daily prayer

Prayer time	**OT (°C)**	**OPT (°C)**	**PMV (°C)**	**AMV (°C)**	**PMV-AMV diff (°C)**	**OPT-AMV diff (°C)**
Subuh	26.61	27.46	22.27	29.83	-7.56	-2.37
Zohor	31.46	29.75	24.86	30.69	-5.83	-0.94
Asar	31.46	30.45	24.20	31.42	-7.21	-0.97
Maghrib	29.98	29.83	25.94	30.88	-4.94	-1.05
Isyak	29.50	27.93	24.74	29.21	-4.47	-1.28

3.6 Overall comfort temperature

The overall comfort temperature in Mosque A/C is determined based on the thermal acceptability of indoor environment as indicated in the ASHRAE Standard-55 (2013). This relates to the ASHRAE seven-point thermal sensation scale where the values must be within the limit of 80 % (± 1 of PMV) or 90 % (± 0.5 of PMV). Both limits are applicable due to personal behaviours, but the most widely accepted practice refer to respondents who vote inside the limit of (± 0.5) which represents the thermal comfort in the particular space. Thus, Figure 7 shows the deviation of PMV and AMV values at the limit of 90 % (± 0.5 of PMV) and the relationship to overall comfort temperature. The linear regression equation is then derived to zero (0) for PMV and AMV in order to get the overall Tn temperature. The overall Tn temperatures for PMV and AMV are thus determined to be 25.88 °C and 30.44 °C, respectively.

Table 7 shows the comparison of PMV and AMV values in several research works within hot climates. For Mosque A/C the difference is 4.56 °C. This significant difference may be due to the fact that the air-conditioning system used for such a large scale space is inappropriate and ineffective due to the short period of operation.

Ultimately, the comfort temperature was determined by applying deviation of PMV and AMV at the limit (± 0.5) of thermal sensation response: Thus, an operative temperature was found to be in the range of 26.99 °C to 31.41 °C, respectively which represent the overall comfort temperature in Mosque A/C during the daily prayer modes (Figure 8).

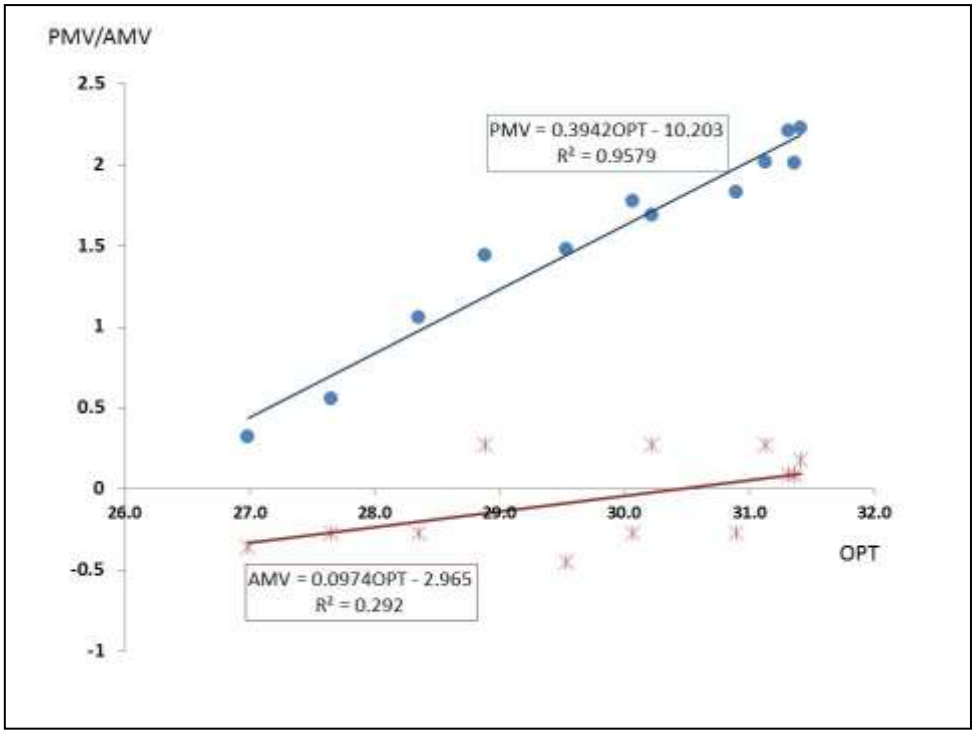


Figure 7: Deviation of PMV and AMV at the limit of (± 0.5) and relationship to overall comfort temperature

Table 7: Comparison PMV model predictions and AMV in this case study and other studies

Buildings, countries	**PMV** (°C)	**AMV** (°C)	**Diff.** (°C)	**Researchers**
Housing, Kuwait	23.3	25.2	-1.90	Al-ajmi & Loveday, 2010
Hospital, Malaysia	24.49	26.46	-1.97	Azizpour et al., 2013
A/C Mosque, Kuwait	23.3	26.1	-2.80	Al-ajmi, 2010
Mosque A/C, daily prayer	25.88	30.44	-4.56	**This study**

Indoor climate of Mosque A/C was compared to the ASHRAE Standard-55, (2013) comfort zone. Observation of the daily pattern of OPT temperature shows that thermal comfort specified by ASHRAE Standard-55 was hardly achieved in Mosque A/C building during the daily prayer times (Figure 9). Only during *Subuh* prayer it almost reached to the upper limit of the ASHRAE comfort zone. Based on the findings and nature of current building operation, new comfort temperature for worshippers' in Mosque A/C building is recommended by shifting about 3.99 °C to 4.91 °C from the lower and upper limits of the thermal comfort boundary in the Standard.

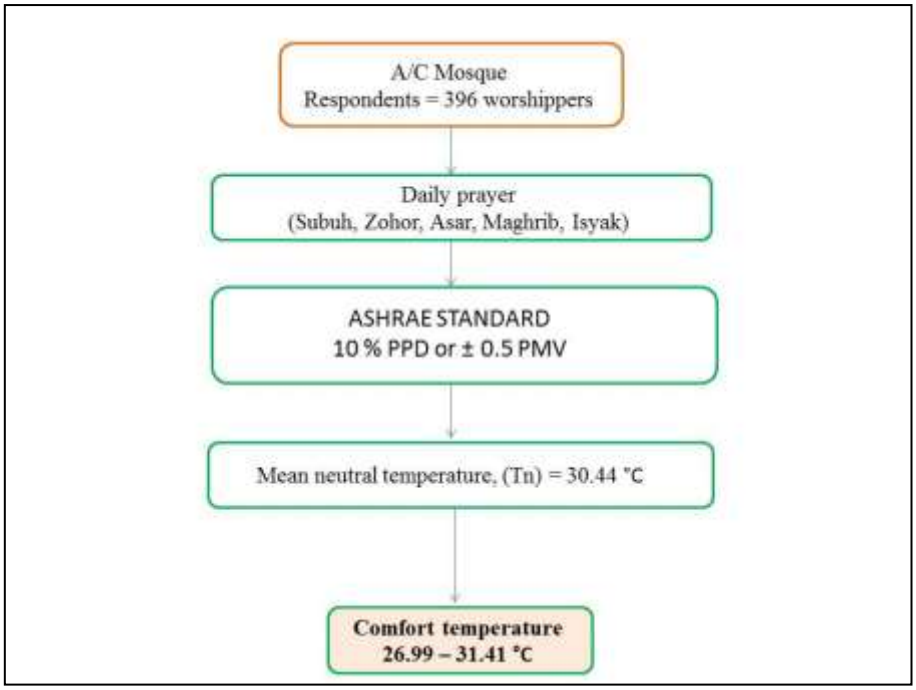


Figure 8: Overall comfort temperature

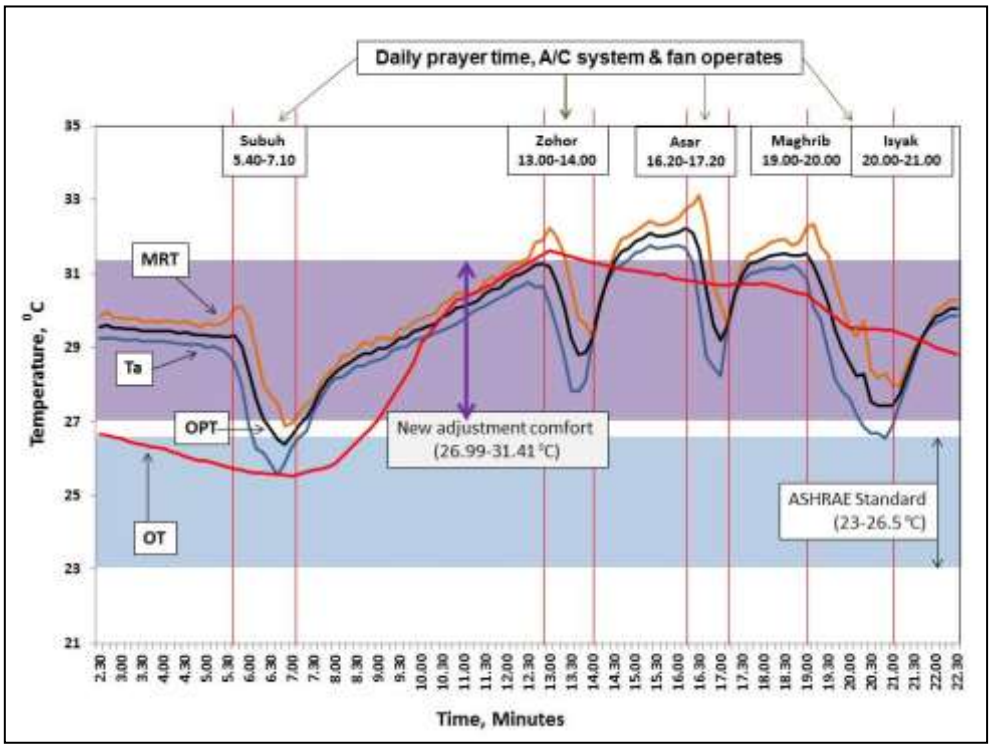


Figure 9: Indoor climates compared to comfort zone from ASHRAE Standard
Note: Ta =Indoor Temperature; MRT =Mean Radiant Temperature; OPT= Operative Temperature; OT = Outdoor Temperature

4. Energy Cost for Mosque A/C

The function of the air-conditioning system is to address the heat load of buildings with cooling and to produce comfort to occupants. Saidur, (2009) in his report mentioned that Malaysian buildings consumed 57 % of the energy in operating the air conditioning system, which is higher than Indonesia (51 %), Saudi Arabia (50 %), Spain (52 %) and USA (48 %). This is a big percentage of expenditure to be allocated for operation of air conditioning system and to meet the comfort demand. However, the nature of activities in a mosque building differs from that of an office building.

Figure 10 shows the electricity cost for Mosque A/C for the year 2012. The average cost per month of electricity consumption is RM 2,983.00. Without delving into fine details, it can be seen that the cost for November is marginally less than that for April, reflecting the seasonal climatic variation. The highest usage in September coincides with the *Ramadhan* fasting month, during which intensive activities take place in a mosque such as breaking the fast, the special night prayers of *terawikh* (pre-midnight) and *qiamullail* (after midnight) as well as *iktiqaf* (contemplation in MPH) besides the five daily prayers. The month preceding *Ramadhan* , known as *Syaaban*, coincides with August. This is the time when activities in the mosque start to pick up pace in anticipation of Ramadhan with more worshippers' attending the daily prayers and other religious gatherings. October coincides with *Syawal* during which the *Eidil Fitr* is celebrated (locally known as *Hari Raya Puasa*) whereby families will spend more time visiting each other. During this time the activities in mosques normally subside before picking up again.

Figure 11 shows the annually monthly mean OT thermal environmental data from nearby Butterworth weather station of the Meteorological Department of Malaysia for the past ten years (2003-2012). It clearly shows the month of April and May have highest OT, whilst October and November have the lowest monthly OT. It is to be noted that almost all operational costs of a *qariah* mosque is born by the local community through contributions and occasional fund-raising activities. The community elects a mosque committee to manage its affairs.

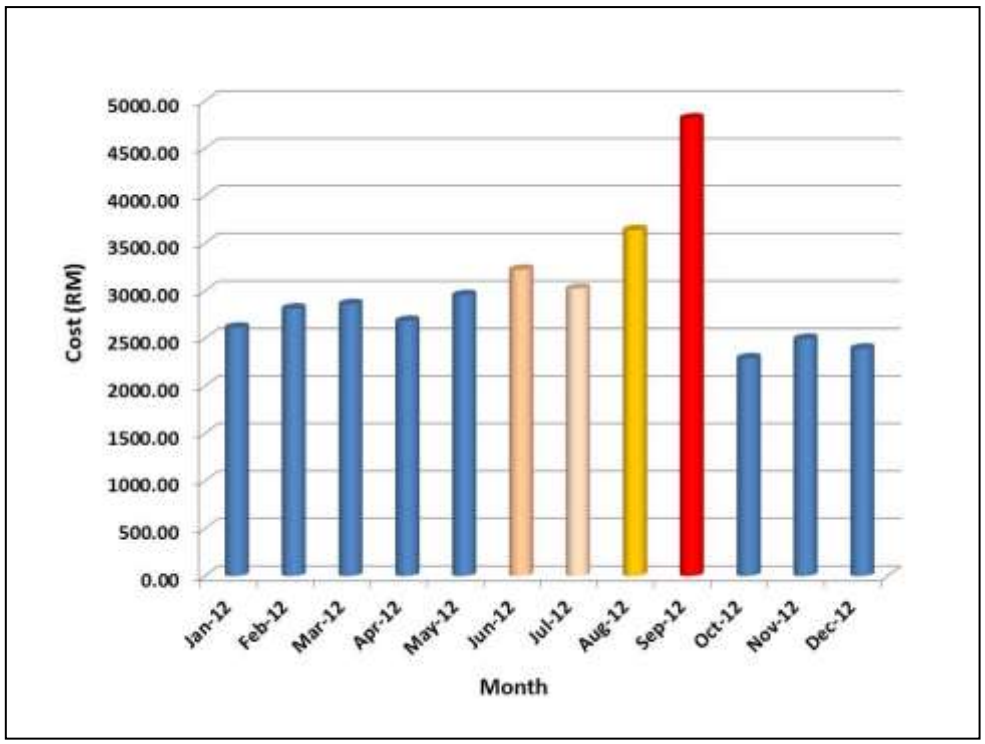


Figure 10: Electricity cost of Mosque A/C for January-December 2012

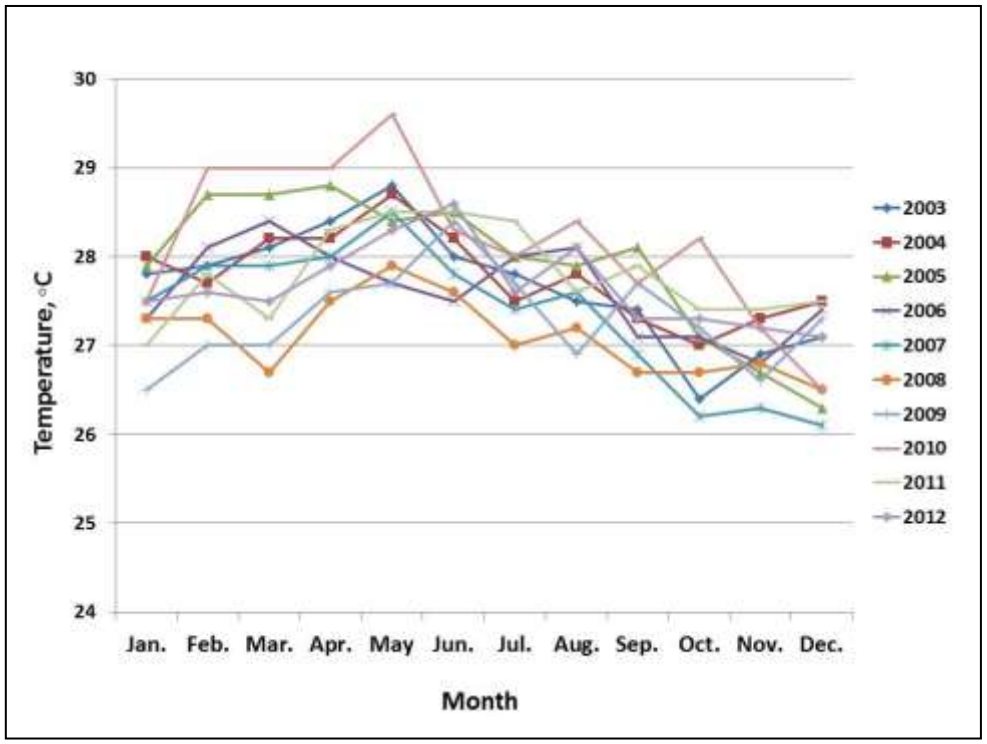


Figure 11: Annual monthly mean Outdoor Temperature (OT) for duration 2003-2012

5. Conclusions and recommendations

The findings can be summarized as follows:

- The most common clothes worn by the worshippers' during daily prayer times in Mosque A/C are traditional Malay long sleeve shirt paired with *kain sarung*. In addition, worshippers from nearby offices wear their normal working attire of long sleeve shirt paired with normal trousers.
- Based on the ASHRAE seven-point thermal sensation scale, it is indicated that the distribution of votes for *Subuh, Zohor* and *Maghrib* prayers tends toward cool condition but *Asar* and *Isyak* prayers have a normal distribution of votes.
- Worshippers' preference for cooler conditions in most of the prayers times.
- The underestimation of thermal conditions using the PMV model compared to the actual thermal sensation (AMV) shows that worshippers' behaviour with past experience of higher climatic conditions has a preference to adapt with the internal thermal environment that they are exposed to either lower or equal to the outdoor temperature.
- The results indicate that thermal environment in Mosque A/C could hardly achieve the comfort zone as proposed in ASHRAE Standard-55, (2013). This implies that thermal comfort conditions in Malaysian mosques of similar design and operation to Mosque A/C cannot co-relate well with the ASHRAE- standard.
- The recommended new comfort temperature for Mosque A/C is 3.99 °C to 4.91 °C from lower and upper limits of the ASHRAE thermal comfort boundaries.
- The outdoor thermal environment is reflected in the use pattern of electricity in Mosque A/C, with drastic increases due to seasonal religious activities related to the fasting month of *Ramadhan*.

It is recommended that further studies be done to investigate the most appropriate and economical method to provided thermal comfort conditions in Malaysian mosque buildings, given the nature and frequency of religious activities involved as well as the design of the indoor spaces.

6. Acknowledgements

We gratefully acknowledge the cooperation of officers of Masjid At-Taqwa, Kepala Batas Penang Malaysia, with special mention to mosque Committee Members, Tuan Haji Ir. Ahmad Zakiyuddin (The Chairman), Tuan Haji Abdul Rahman (The Honorary Secretary) and worshippers for their continuous support and participation during the field study.

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