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The Study of Air Temperature When the Sun Path Direction to Ka'abah: with a Case Study of Al-Malik Khalid Mosque, Malaysia

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ABSTRACT

A field study on air temperature was carried out in the main prayer hall of Al-Malik Khalid mosque, Penang, Malaysia. The main purpose of this study is to investigate and observe the indoor air temperature conditions during the occurrence of the sun path towards qibla direction on 16th July 2010. The scope of the study covers the main prayer hall under the pyramid roof. A quantitative method was used in the analysis by using thermo hygro anemometer instrument to measure the indoor and outdoor air temperature. The temperature was measured hourly, during daylight hours from 7am to 7pm in July 2010 from 15th to 17th. The result obtained shows that the mosque has the correct and accurate orientation to the qibla. In addition, there are no significant difference between the day of 16th July where the sun was perpendicular over the Ka'abah and one day after and before. The average difference between indoor and outdoor is about 0.46°C to 1.71°C.

1. Introduction

Mosque is defined as a place for congregating prayers. The importance of mosque is that it is the most sacred places by the Muslim believers. The thermal comfort inside the mosque is therefore one of the basic requirements to ensure the comfort to the worshipers performing

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their prayers in tranquility and reverence.

Thermal comfort is defined as "*that condition of mind that expresses satisfaction with the thermal environment*" (ASHRAE, 1992). According to Wang and Wong (2007) comfort sensation of people who live in tropical or temperate climate is different than those in cold climate. However, this decision was based on the results of previous studies in the UK, India, Iraq and Singapore. It is printed out that temperature above 30°C is not considered uncomfortable in some cases. As argued by Hussein and Rahman (2009) based on the respondents survey in the tropical regions in Malaysia that the people have a higher heat tolerance as they accepted the thermal condition which exceeded the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard.

(Al-ajmi, 2010) noted that to control the thermal sense, it is possible to the residents and building officers to adjust their dress according to the level of thermal stress in the surrounding environment, where this feature is limited for the prayers inside the mosque. Nicol and Humphreys (2002) highlighted the principle of adaptive approach to thermal comfort as "*If a change occurs such as to produce discomfort, people react in ways, which tend to restore their comfort."* They reported that in case of no possibility to adjust cloth or activity and air movement cannot be used, the comfort zone may be as narrow as ±2°C. However, in the case of these adaptive opportunities are available and adequate, such as mechanical ventilation (fans), the comfort range may be considerably wider (Wang and Wong, 2007).

There is not much literature for investigation the indoor thermal condition in the mosques in Malaysia. However, a study can be mentioned are taking account on thermal comfort requirements for Friday prayer in the mosque by Saeed (1996) during the hot season in Riyadh indicated that most people are feeling comfortable, while a few prefer cooler conditions. Another study was conducted by Soegijanto and Yohana (2004) by measuring air temperature, relative humidity and air velocity as well as by conducting simulation using Energy Plus software. They concluded that thermal condition inside the building was still within the comfort zone with slightly warm condition. A field study on energy use and thermal comfort conditions in three air conditioning mosques in hot-humid climates been carried out by Al-Homoud et al (2009) who evaluated the thermal comfort according to ASHRAE thermal comfort standard from 20°C to 24°C during winter season while from 23°C to 26.5°C during summer season. However, the study concluded that there are relatively high-energy uses for some mosques, which are not necessarily translated into better thermal comfort conditions. A field study on thermal comfort in the mosque in Indonesia was carried out by Samad et al (2006) in two main prayer hall, in the first floor and second floor. The results were compared by the standard of Indonesia published by LPMB institution, Department of Public Work. The condition in the first floor categorized as not Comfort area (above 27.1°C), while in the second floor categorized as warm comfort area (between 25.8°C - 27.1°C).

A study has been conducted in Malaysia by Abdul Rahman (1995) on the indoor comfort temperature. He concluded that the thermal comfort for tropical region ranges from 25.5 - 28°C. A field study had been conducted on the thermal comfort in Singapore. The study reported that the thermo-neutrality operative temperature was 28.5°C (Leow, 1988). Wong and Khoo (2003) conducted the field study in Singapore on classroom temperature, the study reported that classroom with mechanical ventilation such as fans, the natural temperature recorded was 28.8°C and the desirable temperatures range from 27.1 to 29.3°C implying that the ASHRAE Standard 55 is not appropriate in the free-ventilated buildings in the tropical climate. A field studies on thermal comfort were conducted in Thailand by Busch (1990) and in Singapore by Dear et al (1991) in office building. Both studies concluded that the natural temperature for natural ventilation building was 28.5°C. Hussein and Rahman (2009) had carried out a field study on the environmental conditions and occupant comfort level in Malaysia, where the natural temperature of 28.4°C with comfort level ranges from 26.0ºC to 30.7ºC was obtained by regression analysis of temperature sensation votes (TSV) on operative temperature. The finding was compatible with the finding of the study conducted by Wong and Khoo (2003) for classroom comfort level in Singapore, Busch (1990) for office comfort level in Thailand and Dear *et al* (1991) in Singapore.

2. Building Description

A Mosque which was chosen for this study is Al-Malik Khalid mosque, located in Universiti Sains Malaysia, Penang. The design took a form of a pyramid where the roof carried by four pairs of ribs (beams) as the main roof structure, with upper windows making as stack effect (Figure1).

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The main prayer hall for study has rectangular in shape, with 1:1.3 (the long axis 1.3 facing to qibla) with a total area approximately 14,040 sq. ft.. However, 7612 sq. ft. are with lower ceiling height about 9 ft. (2. 75m) in the corner and rear of the hall, while in the middle of the hall the roof start rises up from 13.5 ft. (4. 1m) to 42.75 ft. (13.1 m) in the center of the hall (Figures 2 and 3). A large area of the glass window openings are on it is four side walls.

Figure 1: Pyramid form of Al-Malik Khalid Mosque

Figure 2: Form of the indoor ceiling with upper windows

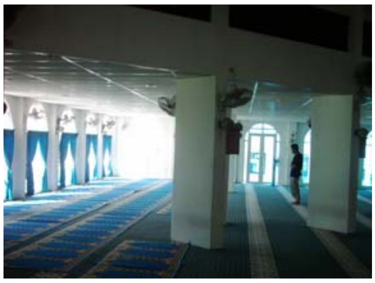

Figure 3: Lower ceiling area with window openings

3. The Climate of Penang Island

Penang Island located between latitude of N5°7′ to N5°35′ and longitudes of E100°9′ to E100°32′ (Weng, 1991). The prevailing climate in the island is uniformly high temperature and humidity. According to Dale (1964), Penang island is one of the sunniest parts of Malaysia. According to Weng (1991), sunshine is abundant usually from 8 am to 5 pm with periods in between overcast and cloudy sky, with an average at least 6 hours. The mean daily temperature seldom drops below 26.0°C. However, the temperature in general ranges from about 24°C to 34°C. Relative humidity is ranging from near saturation at the early morning to 50% at mid-day, the average around 80%, with high rainfall about 2000mm (reach 3000mm in the highlands), the monthly rainfall is between 250mm to 500mm. Penang Island is sheltered from the wind due to the location between Peninsular Malaysia and Sumatra Island. Most of the days have wind speed between 1 to 5 m/s. The calms period where the wind speed not exceeds 0.2m/s is relatively high (18.9%). However, the wind direction frequencies are from the North, north-east and south-east (Weng, 1991).

4. Sky Conditions

Sky condition is defined as a description of the appearance of the sky (OFCM, 2005). It is very important to refer and classify the data of the outdoor and indoor conditions to the sky condition. Some authors classified the sky conditions into three categories, namely clear sky (0 Oktas), partly cloudy or intermediate sky (between 1 - 7 Oktas) and cloudy or overcast sky (8 Oktas) (Danny and Joseph, 2001). However, 15 standard sky conditions which probably include all skies conditions found in nature, this standard adopted by The International Commission on Illumination (CIE) (ISO, 2004). Moreover, the 15 CIE Standard Skies contain five clear sky, five intermediate sky and five overcast sky conditions (Li et al., 2010). According to (IESNA) Illuminating Engineering Society of North America (IESNA, 2000) to assess the sky condition normally estimate the amount of cloud cover at the sky which estimated in tenths. The amount of clouds covers the sky is expressed on a scale from 0.0 for clear sky to 1.0 for overcast sky as shown on Table 1.

Table 1: Classification of sky condition (IESNA, 2000).

Clear	Partly cloudy	Overcast
0.0 to 0.3	0.4 to 0.7	0.8 to 1.0

Due to the location of Malaysia under the influence of tropical climate, it has its own uniqueness of the sky condition. The sky in Malaysia is mostly classified as intermediate sky, the average coverage of the sky with the clouds of 6 to 7 Oktas (Zain-Ahmed, 2000 ; Shahriar and Mohit, 2006). A study has been conducted in East Malaysia (Kota Kinabalu, Sabah) by Djamila *et al* (2011) on the sky condition mentioned that from 70% - 90% of the sky ratio cover with the cloud, another study conducted in West Malaysia (Shah Alam, Selangor) by Zain Ahmed et al (2002) classified the sky condition as intermediate 85.6% of the time and 14.0% overcast.

5. Limitation of the Study

It should be noted that all the measurements that were taken from the field was under the intermediate sky condition (6 to 7 Oktas) which considered as the prevailing sky condition in Malaysia. As mentioned by Ahmed (2000) the sky condition in Malaysia is sorted as intermediate or average, whereby the sky clouds 85.7% of the time and the rest 14.0% as overcast. Due to the period of raining condition from 2pm to 7pm on the first day (15 July 2010) clearly affect the data collection as shown in Figure 4, so the data within this period cannot be counted. There is an air-conditioning unit installed in the mihrab which cannot be counted due to the short-period running, when the imam and people performing prayer. It

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should be noted that the study was not proposed to carry out the thermal comfort evaluation in the mosques. Rather to give an idea about temperature conditions as related to the comfort zone.

6. Qibla Direction

The qibla can be defined as the direction toward the Ka'abah, but the question which must be answered what is the exact direction? Knowing the direction of the qibla is important and necessary in the Muslim communities, where prayers and the direction depend upon it. However, there are many ways to determine the direction of qibla such as mathematic calculation and the compass. But the most basic and easiest method without any doubt is the direction of the shadow on either 28th of May or 16th of July. However, according to King (1993) the sun is exactly over Mecca twice a year on 28th of May and 16th of July, at the middle of the day (noontime). Morban (2009) reported that the exact time where the sun is perpendicular to the Ka'abah on 28th May is at noon 12:17:52 p.m., and 16th July at noon 12:26:40 p.m. on local time of Saudi Arabia. This time corresponds to 09:17:52 am and 09:26:40 am Greenwich, Main Time (GMT) respectively. So you just need to calculate the time difference between the place where you want to determine the qibla and the time at Saudi Arabia or at Greenwich, Main Time. This method only works in places that receive sunlight at the time when the sun was over the Ka'abah in Mecca which an estimated half of the world, so it will be possible to determine the qibla just by observing the direction of the shadow or the direction of the sun at that time. Figure 5, shows a picture taken inside the mosque on 16th July at 5:26 pm (Malaysia local time), when the sun was perpendicular over the Ka'abah. The picture shows that the vertical window frame is perpendicular to the prayer rows. Figure 8 shows the sun-path diagram for Penang during all the year. The path of the sun on 16 July is highlighted as well as the position at 5.26pm. It is also shown (figure 8) the façades exposed to the solar radiation. The East and North-East façades receive direct solar radiation from early morning until 12pm, while the West façade receive direct solar radiation from 1pm until sunset.

7. Methodology

The measurements were conducted in July 2010 from 15th (Thursday) to 17th (Saturday) for continuously three days. The reason for selected these days is due to the position of the sun on the sky as mentioned above. Measurements were carried out indoor and outdoor of the mosque at high 90 cm from the ground level. This height is supposed to be reasonable for sitting condition when reading the holy Qur'an and prayers. Five indoor points were selected for investigation at the prayer hall, and one point selected outdoor about 12 m in front of the mosque (Figure6).

The measurable factor is air temperature (°C), which can evaluate the thermal environment and consequently the comfort condition inside the mosque. These measurable factors were measured hourly, indoor and outdoor during daylight hours from 7am to 7pm for three days continuously at all points with about10 minutes interval time. No measurement was conducted at night from 8pm to 6am. The device used to measure air temperature is EXTECH 45160 3in1 Thermo Hygro Anemometer (Figurer7). ASHREA has defined 7 point scale to quantifying people's thermal sensation, as shows in Table 2.

Table 2: Scale of thermal sensation (ASHRAE, 1992).

-3	-2	-1	0	+1	+2	+3
Cold	Cool	Slightly cool	Natural	Slightly warm	Warm	Hot

The range of thermal sensation (value temperature in table 2) of these points is made depend on respondents vote, which is different according to their own physiological, psychological and behavioral adaptations. Because of this fact, according to Singh et al (2010) it has been found that at the same temperature; different respondents have the different thermal sensation, or at different temperatures have the same thermal sensation. The temperature values corresponding to -1 and +1 sensations are always ±3°C – 3.5°C of neutral temperature. From this study it can conclude the temperature scale for 7 points as follows in Table 3. Other scale consists of 6 points by Hassan and Ramli (2010) is as shown in Table 4 which refers to the study from Hussein and Rahman (2009) and Abdul Rahman (1995).

Table 3: The scale of measurement for temperature (Singh et al., 2010).

Scale	-3	-2	-1	0	+1	+2	+3
Description	Cold	Cool	Slightly cool	Natural	Slightly warm	Warm	Hot
Range of Temperature	<19°C	19-22.4°C	22.5-25.6°C	25.7-27.5°C	27.6-30°C	30.1-33.5°C	>33.5°C

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Table 4: The scale of measurement for temperature (Hassan and Ramli, 2010).

Scale	0	1	2	3	4	5
Description Range of Temp.	Cold <16°C	Cool 16–25.5°C	Comfort 25.5–28°C	Warm 28–32°C	Hot 32-40°C	Extremely hot >40°C

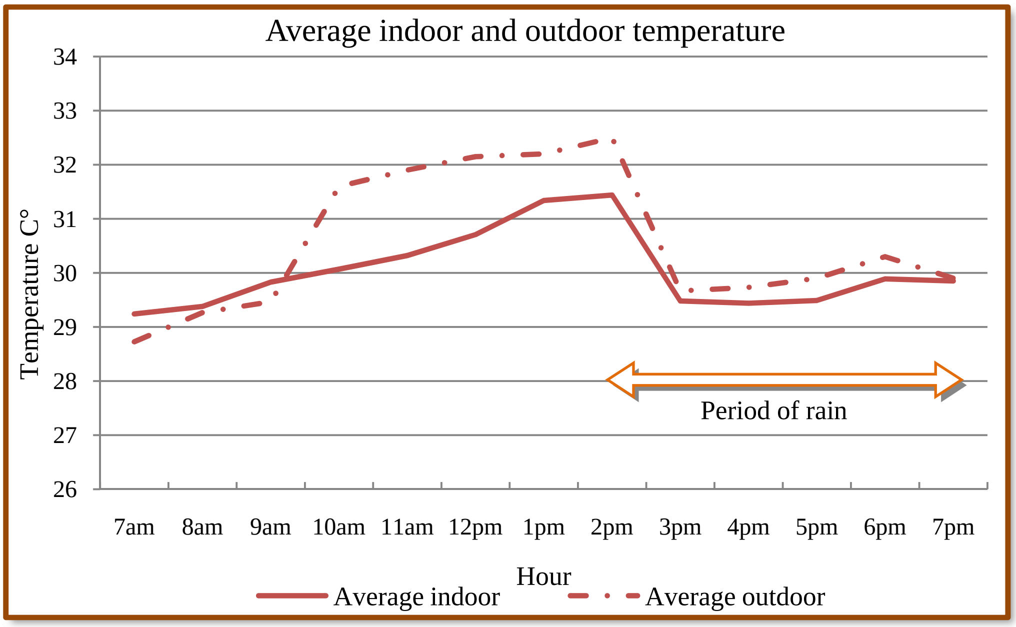

Figure 4: Average indoor air temperature (Orange line), and average outdoor air temperature (Dash dot line) on 15 July 2010.

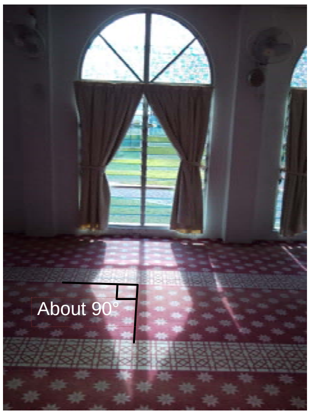

Figure 5: Picture taken in side mosque on 16th July at 5:26pm (Malaysia local time).

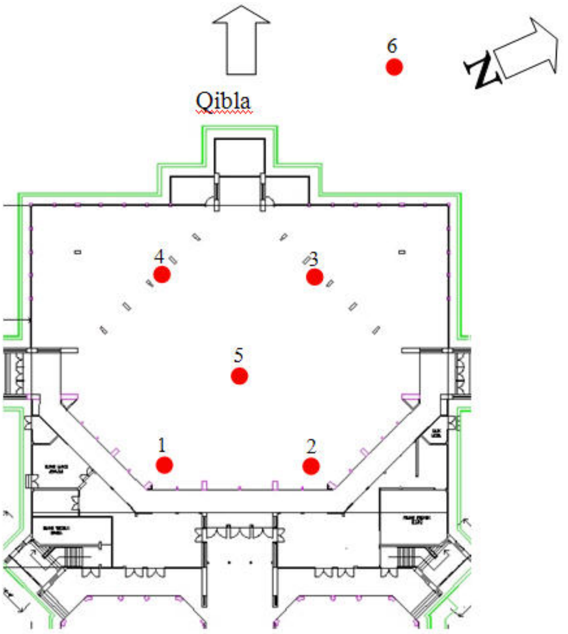

Figure 6: The plan of Al-Malik Khalid mosque, shows the selected five indoor location and outdoor location.

Figure 7: EXTECH 45160 3in1 Thermo Hygro Anemometer.

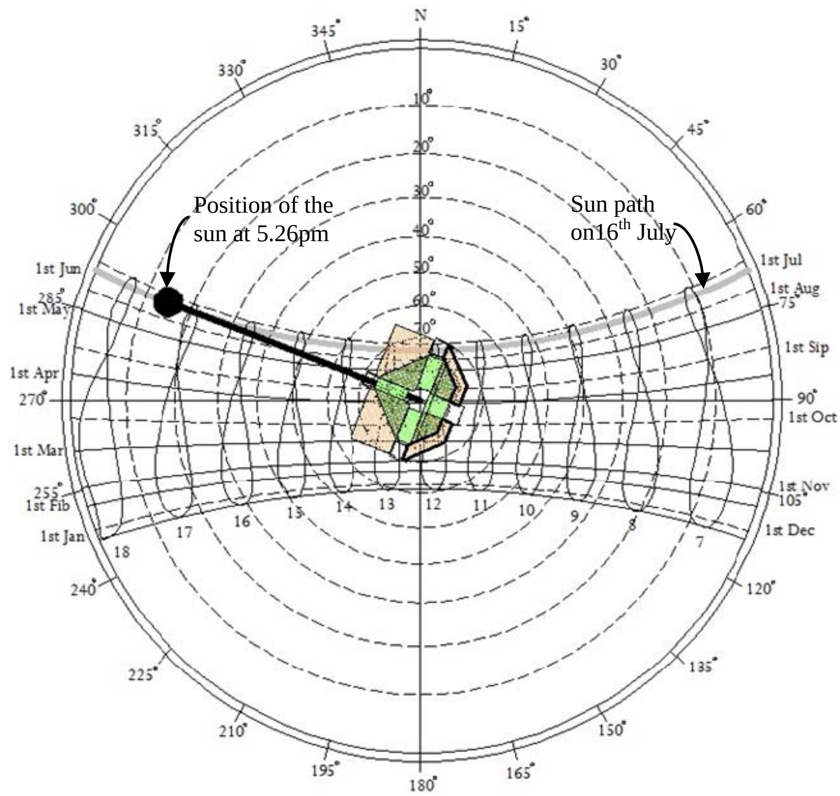

Figure 8: Sun bath diagram of Al-Malik Khalid Mosque throughout the year, shows the position of the sun at 5.26pm on the day of 16 July. Source**:** Suntool Software

8. Result and Analysis

The air temperatures taken from the survey for indoor and outdoor temperature are shown in the line chart graphs to indicate the results. The X-axis represents either specific points been selected indoor or the hours when the air temperature data was taken from indoor and outdoor, while the Y-axis represents the degree of air temperature in degree Celsius (°C), (Figures 9 to 14).

From the analysis of indoor air temperature (Figure 9-A,B,C,D), it was observed very small difference among the points. However, from the average, the warmest point was at No 4, No 3 then No1, No2 and No5. This difference is due to position of the point in the mosque (near or far from the windows and walls) and the pyramid shape of the roof lead to different surface exposure to the solar radiation (different sun angle) thus different heat gain for a different indoor point position.

The graphs in Figure 10 shows that the average indoor air temperature for all points are lower than the average outdoor air temperature from 10am to 6pm, the average of air temperature difference is about 0.46°C to 1.71°C, While the transformation begins at about 7 pm until 9am where the indoor air temperature is higher than outdoor air temperature with an average range from 0.05°C to 0.68°C (within the period of data collection) because of no direct solar radiation.

The lowest outdoor air temperature recorded at 7am 27.83°C while the highest recorded at 3pm 33.15°C, in contrast to the lowest indoor air temperature recorded at 8am 28.00°C while the highest recorded at 4pm 32.85°C.

All indoor and outdoor air temperature at point 1,2,3,4,5 and 6 (Figures 11-15 and Table 5) recorded higher than 28.5°C except six degrees recorded indoor at 7am and 8am, and three degrees outdoor at 7am and 8am, so both indoor and outdoor can be considered under discomfort level (above 28.5°C) during the day time. However, within the period of data collection, if we agree with the range of thermal comfort determined in the literature ranging from 26°C – 30.7°C, the indoor air temperature approaches from comfort level from 7am to 12pm, while outdoor from 7am to 10am. The night time is supposedly under 28°C by referring to these results of the day time temperature as no solar radiation.

The indoor air temperature becomes within the discomfort level after 12pm, where the air temperature mostly recorded between 30.7°C to 32.85°C. While the outdoor air temperature becomes within the discomfort level after 10am, where the air temperature mostly recorded between 30.73°C to 33.15°C. As a result, the use of natural air ventilation (passive design) and mechanical fan operation (active design) are necessary. Comparison was carried out between the indoor air temperatures for each point on 16 July (when the sun path toward qibla) with the average of the same point and the average of outdoor air temperature (Figure 11 to 15). It can be noted that there are no significant different between the day of 16 July and one day after and before, that is due to no significant different occurs in the sun-path within three days.

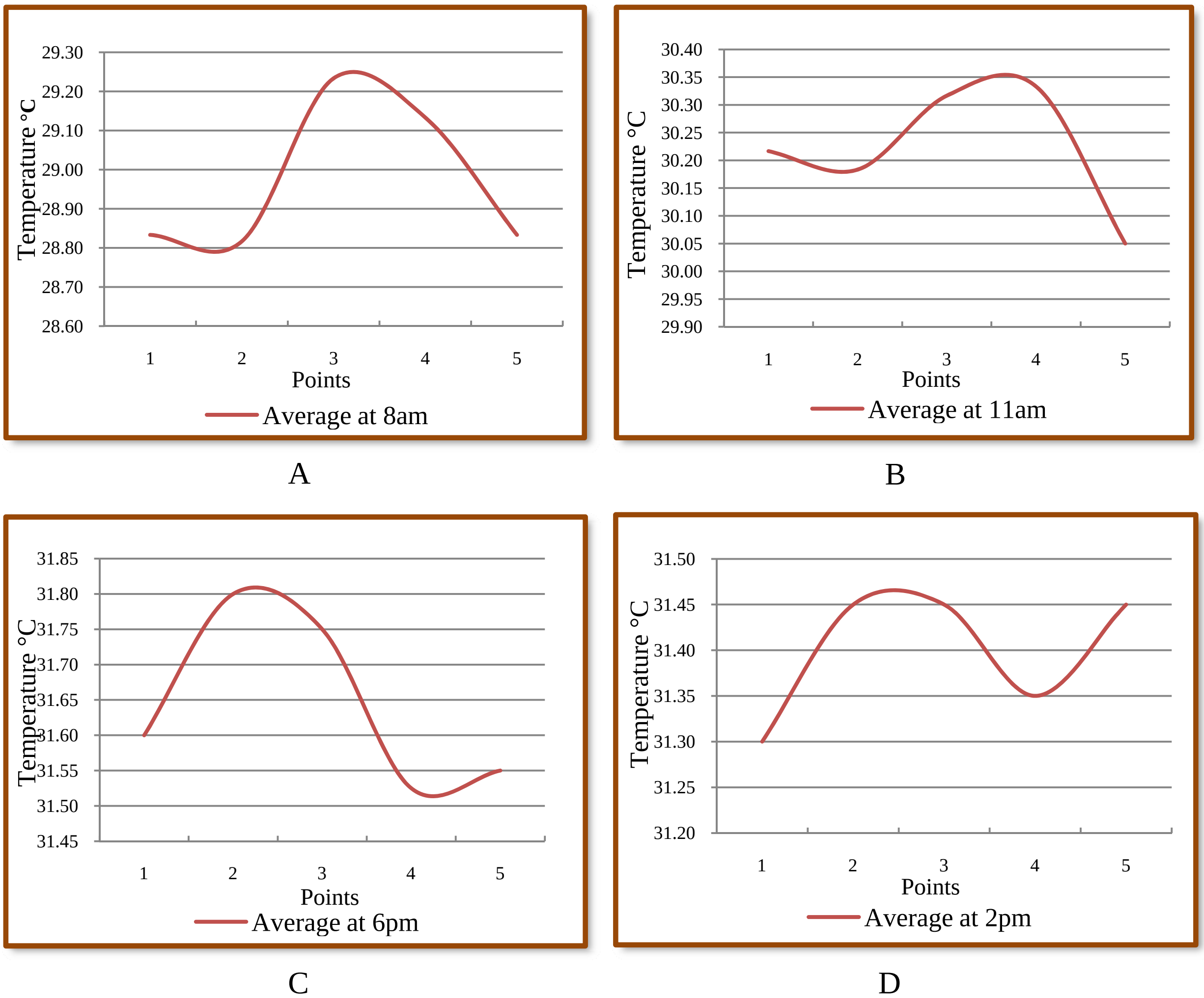

Figure 9-A,B,C,D: Average indoor air temperature for all points at different time in order to clarify the different among the points.

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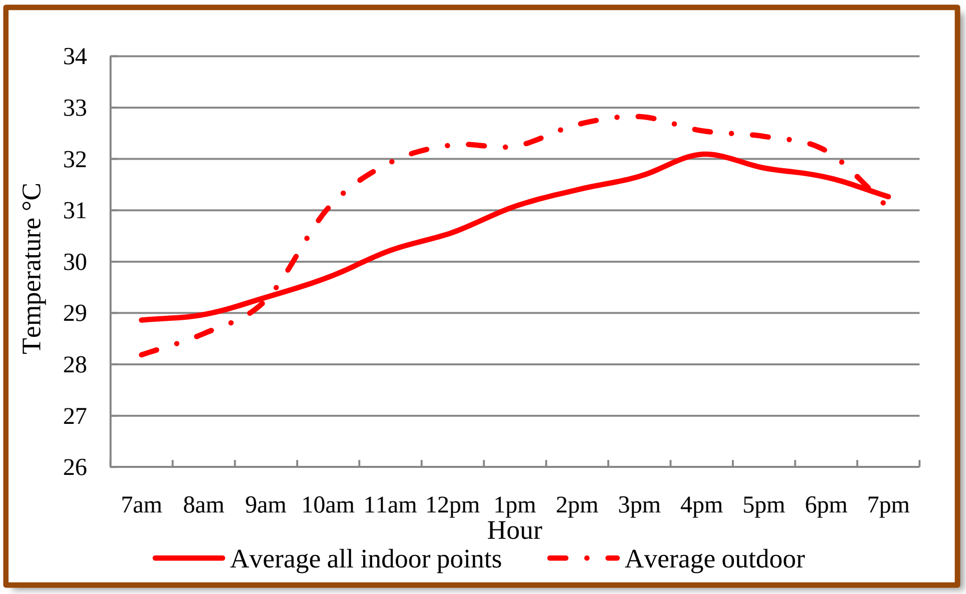

Figure 10: Average indoor air temperature for all points (red line), and average outdoor air temperature (Dash Dot line).

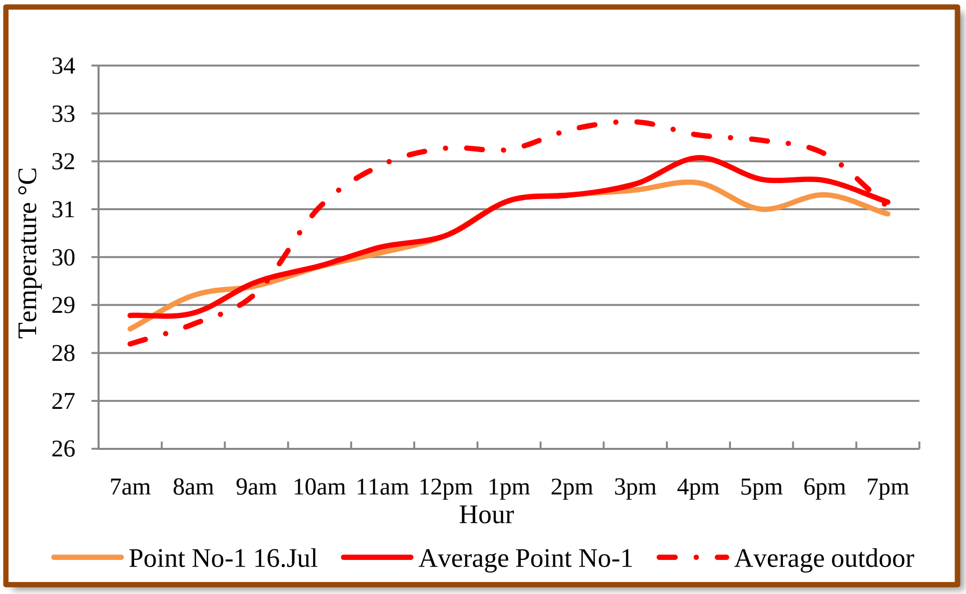

Figure 11: Average indoor air temperature for point 1 (Red line), indoor air temperature point 1 on 16 July 2010 (Orange line) and average outdoor air temperature (Dash Dot line)

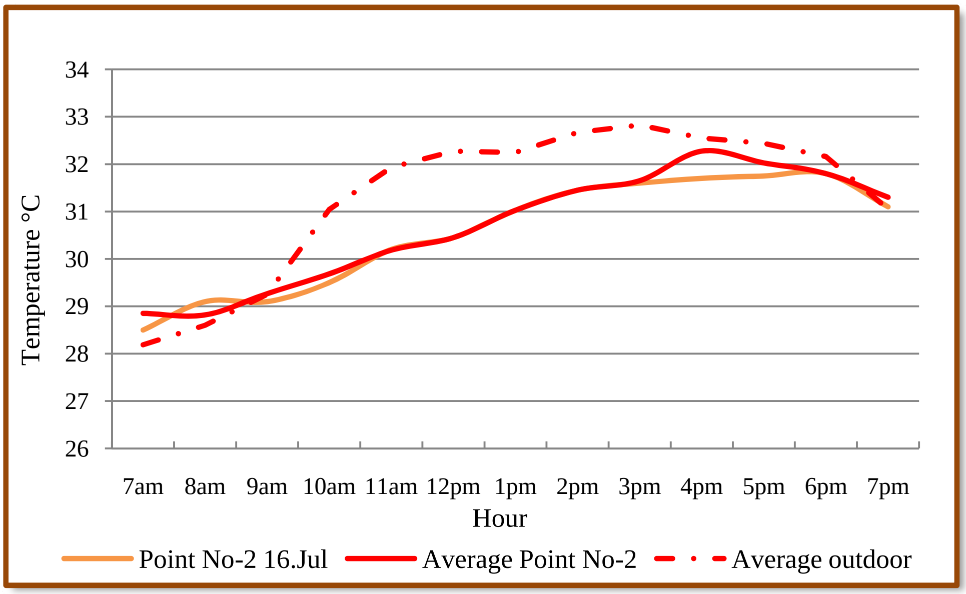

Figure 12: Average indoor air temperature for point 2 (Red line), indoor air temperature point 2 on 16 July 2010 (Orange line) and average outdoor air temperature (Dash Dot line).

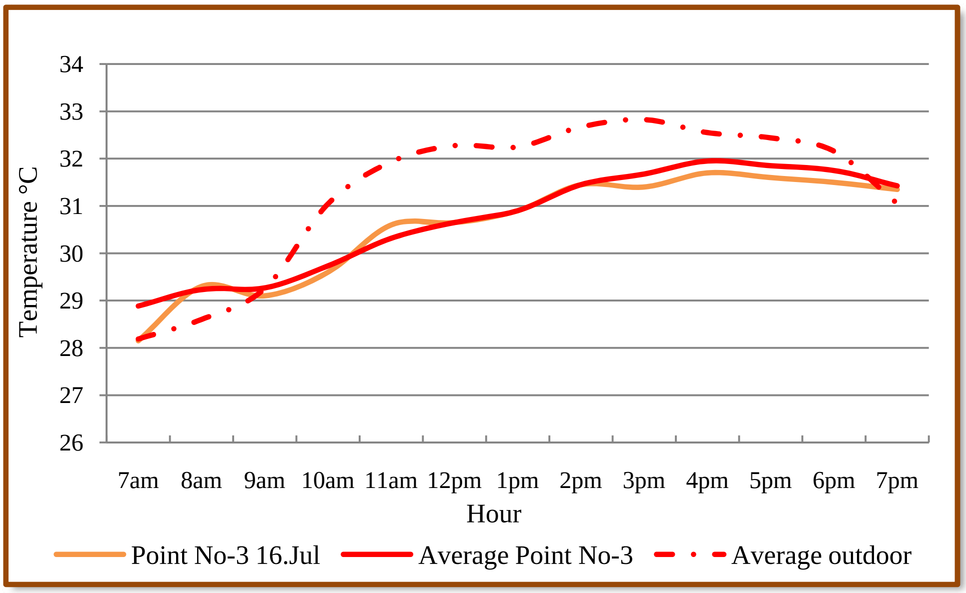

Figure 13: Average indoor air temperature for point 3 (Red line), indoor air temperature point 3 on 16 July 2010 (Orange line) and average outdoor air temperature (Dash Dot line).

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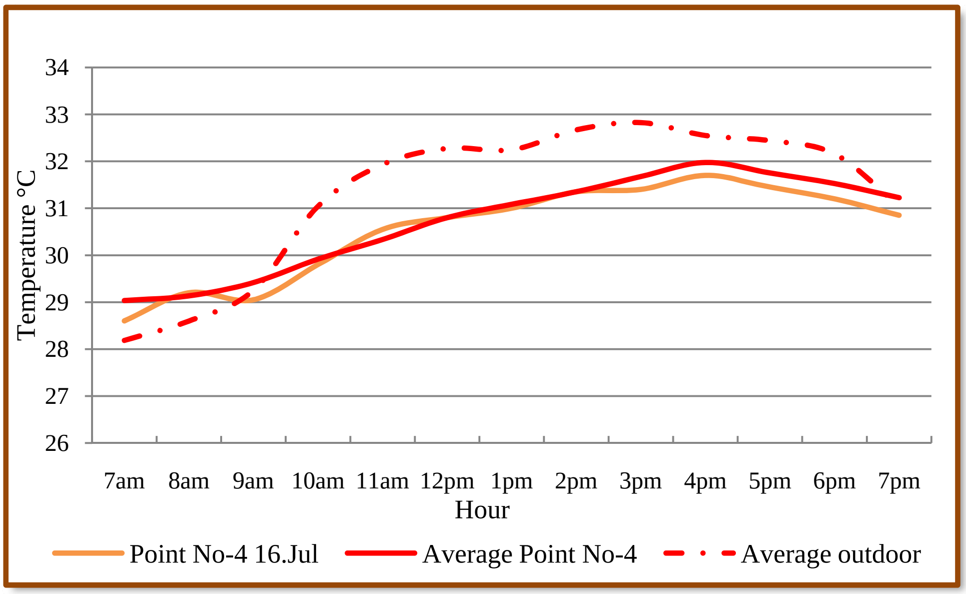

Figure 14: Average indoor air temperature for point 4 (Red line), indoor air temperature point 4 on 16 July 2010 (Orange line) and average outdoor air temperature (Dash Dot line).

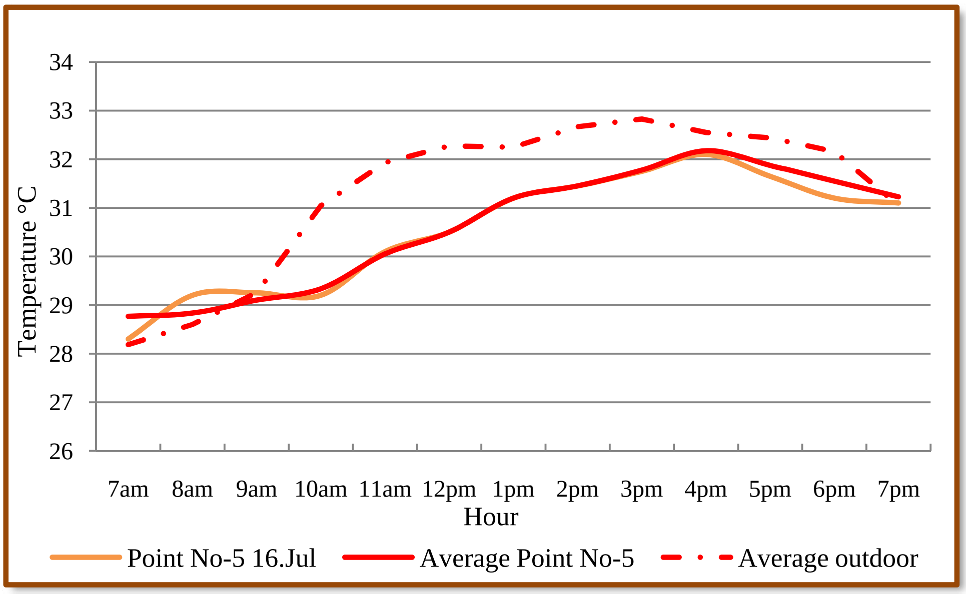

Figure 15: Average indoor air temperature for point 5 (Red line), indoor air temperature point 5 on 16 July 2010 (Orange line) and average outdoor air temperature (Dash Dot line).

Table 5: Indoor and outdoor air temperature in Celsius.

Day	Hour	Indoor Point 1	Indoor Point 2	Indoor Point 3	Indoor Point 4	Indoor Point 5	Outdoor
Day 1 Thursday 15/7/2010	7am	29	29.1	29.5	29.6	29.8	28.73
	8am	29.3	28.9	29	29.25	28.5	29.27
	9am	30.35	30.3	30.05	30.2	30.4	29.47
	10am	29.5	29.9	30.2	30.2	29.7	31.60
	11am	30.35	30.35	30	30.2	29.95	31.90
	12pm	30.5	30.7	30.7	31.1	30.55	32.15
	1pm	31.5	31.5	31.1	30.95	31.4	31.70
	2pm	31	31.4	31.8	31.4	31.6	32.50
	3pm	29.55	29.7	29.2	29.35	29.6	29.67
	4pm	29.1	29.3	29.7	29.8	29.3	29.73
	5pm	29.55	29.45	29.7	29.3	29.45	29.90
	6pm	29.85	29.8	30.05	29.8	29.95	30.30
	7pm	29.85	29.9	29.6	30	29.9	29.9
Day 2 Friday 16/7/2010	7am	28.5	28.5	28.15	28.6	28.3	28
	8am	29.2	29.1	29.3	29.2	29.2	28.5
	9am	29.4	29.1	29.1	29.05	29.25	28.7
	10am	29.8	29.5	29.6	29.8	29.2	30.73
	11am	30.1	30.2	31.6	31.55	30.1	31.7
	12pm	30.45	30.45	30.65	30.8	30.5	32.2
	1pm	31.18	31.03	30.9	31	31.2	32.5
	2pm	31.3	31.45	31.45	31.35	31.45	32.67
	3pm	30.5	30.65	31.4	31.4	30.45	33.15
	4pm	31.55	31.7	31.7	31.7	32.1	32.5
	5pm	31.4	31.75	31.9	31.85	31.8	32.68
	6pm	31.3	31.8	31.5	31.2	31.2	32.87
	7pm	30.9	31.1	31.35	30.85	31.1	31.6
Day 3 Saturday 17/7/2010	7am	28.85	28.95	29	28.9	29	27.83
	8am	28	28.45	28.7	28.4	28.1	28.03
	9am	29.05	29.3	28.65	29	28.55	29.60
	10am	29.3	29.65	29.4	29.75	29.1	30.80
	11am	30.2	30	29.9	29.95	30.1	32.20
	12pm	30.4	30.2	30.6	30.5	30.45	32.48
	1pm	30.85	30.55	30.7	31.05	31	32.54
	2pm	31.6	31.5	31.1	31.3	31.3	32.83
	3pm	31.65	31.7	31.95	31.95	31.8	32.50
	4pm	32.6	32.85	32.2	32.25	32.25	32.60
	5pm	32.25	32.32	32.1	32.05	32.8	32.2
	6pm	31.9	31.8	32	31.85	31.9	31.45
	7pm	31.4	31.5	31.5	31.6	31.35	30.50

9. Discussion

From the observation of sun penetration into the mosque, it is clearly indicated that the mosque has the correct and accurate orientation to the qibla. The analysis of temperature found that the average difference between indoor and outdoor is about 0.46°C to 1.71°C, this small difference is due to the large area of the window and large amount of natural ventilation

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between indoor and outdoor. From the temperature recording, it is also observed that the maximum of outdoor temperature and indoor temperature has a time difference of 1 - 2 hours. This time lag different is due to the large area of window and doors in the prayer hall with roof cover, which lead to a large amount of natural ventilation. Within the period of date collection from 7am to 12pm the temperature considered as an acceptable thermal condition.

From the analysis of indoor air temperature, it was found a very small difference between the points. However, point N1 record lowest reading after 12pm it is due to the position of the point in the south side of the mosque and the walls and roof surfaces near this point is not exposed directly to solar radiation. Point No 2 records high temperature reading after 12pm until 6pm due to the exposed of the walls and roof surfaces near this point to solar radiation from the early morning until the afternoon, where these positions gained heat and then reradiate heat to the indoor afternoon. Point No3 and No4 record high reading from 7am to 12pm due to near from the window having direct heat gain from the wall in the frontal side and roof surfaces which receive the solar radiation from noon until sunset. Point No5 record low temperature reading from 7am to 11am then starts rise-up from 12pm to 4pm, and then cool-down from 4pm to 7pm. These phenomena are due to the high of the roof over this point (highest roof height) and due to the sun angle where the roof surface receives a large amount of heat over this point at noon. Consolidate the warm air ventilated at the upper roof space.

10. Conclusion

It can be concluded from this study that the mosque oriented towards the qibla correctly and accurately. No significant difference between the day of 16 July where the sun was perpendicular over the Ka'abah and the other two days. Due to the small different in air temperature between indoor and outdoor and short time lag, it becomes more important to study the mosque envelope to determine the most significant solution to protecting the indoor environment from outdoor climatic factors, especially to induce the wind speed level such as air cross ventilation and stack effect to the indoor area, and the use of efficient active mechanical operation, as well as the use of shading devises on frontal façade to prevent the entering of low angle solar radiation.

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