Jurnal Kejuruteraan 35(3) 2023: 647-655
https://doi.org/10.17576/jkukm-2023-35(3)-12

Assessment of Indoor Thermal Condition on Traditional Vernacular Masjid: A Case Study on Masjid Kampung Laut, Malaysia

Nur Athirah binti Khalit*, Zuraini binti Denan, Aliyah Nur Zafirah binti Sanusi & Norwina binti Mohd Nawawi

Kulliyyah of Architecture and Environmental Design, International Islamic University Malaysia, Malaysia

**Corresponding author: athirah.khalit@gmail.com*

Received 5 August 2022, Received in revised form 2 November 2022
Accepted 3 December 2022, Available online 30 May 2023

ABSTRACT

Traditional vernacular architectures in Malaysia include public buildings such as a masjid were designed with the tropical climate in mind and have proven to be an excellent example of providing indoor thermal comfort to the occupants. It is a naturally ventilated building being greatly influenced by the building designs. In traditional vernacular architecture, the roof is the main building enclosure that contributes to the total heat gain. Hence, the research aims to assess the indoor thermal condition of Masjid Kampung Laut, Kelantan, the first traditional vernacular masjid in Malaysia. Data were collected using the method of field measurement to evaluate the indoor comfort level of the masjid, in terms of indoor air temperature, air velocity, and relative humidity. The results demonstrate that the average indoor air temperature is acceptable and Masjid Kampung Laut responded favorably to the local climate. However, it is believed that with an increase of 0.4m/s to 1.2m/s of air movement, will further enhance indoor thermal comfort. Therefore, the findings can guide further thermal comfort prediction studies for other naturally ventilated buildings. Several other potential passive design strategies for roof design are proposed in this study to achieve acceptable indoor thermal comfort conditions for the masjid in Malaysia.

Keywords: traditional vernacular masjid, field measurement, indoor thermal comfort

INTRODUCTION

Traditional vernacular buildings are referred to as heritage buildings that record our history and culture. It is a historic retreat that essentially conveys modern society's cultural and artistic heritage. Traditional vernacular *masjid* in Malaysia was generally built in response to the local culture, climate, and environment. They have unique design and architecture and at the same time have a high value of art and technology. Therefore, this precious national asset should be preserved and its existence recorded.

The studies of traditional vernacular *masjids* have been conducted ever since the people recognize their impact on the history of one's civilization. Among the scope of studies are building history, building typology, building layout and space planning, building style, building structures and construction (Hassan, Syafik, & Nawawi, 2017), the indoor environment, energy performance, and many more.

Geographically, Malaysia is located on the Equator between latitude 1° - 7°N and longitude 100° - 119°E, exposing Malaysia to an average of 4000-5000Wh/m² in monthly solar radiation and an average of 4 to 8 hours of daily sunlight. Malaysia experiences high humidity, high temperature, and uniform diurnal pattern (Jamaludin, Mohammed, Khamidi, & Wahab, 2015) throughout the year. Buildings in tropical regions like Malaysia will typically endure a hot and humid climate all year round with uniform temperature and high humidity. According to the Malaysian Meteorological Department, the daytime minimum and maximum temperature ranges are 23°C to 27°C and 30°C to 34°C respectively. The relative humidity recorded was in the ranges of 52% to 91%. Meanwhile, according to MS1525:2007 and the Department of Standard Malaysia (DOSM), the recommended range for Malaysian indoor air temperature is 23°C to 26°C, and the relative humidity range is 55% to 70% respectively.

Therefore, indoor thermal comfort is a critical element and an important issue for the building industry in Malaysia. In hot and humid climate countries, mechanical ventilation such as air conditioning has become one of the most preferred solutions to maintain the desired indoor comfort level (Hussin & Salleh 2013).

CURRENT *MASJID* ISSUE

Masjids are categorized by their unique combination of functional and operational requirements and are considered as spiritually important buildings in Malaysia and other Islamic countries. It is a place for Muslims to gather and perform their congregational prayers and communal religious activities. Therefore, its indoor thermal comfort is a vital requirement to ensure tranquil comfort for the worshippers when performing their activities especially in traditional vernacular *masjids* that use natural ventilation as their method of cooling. However, current *masjids* were often reportedly had poor indoor thermal performance (Azmi & Ibrahim 2020), (Noman, Kamsah, & Kamar 2016), (Budaiwi & Al-homoud 2013) that reduces the comfort of its users leading toward thermal discomfort.

Presently, the trend is in providing mechanical air conditioning systems by using high volume low-speed (HVLS) fans in the main prayer halls of many current *masjids*. This indicates that *masjid's* indoor environment is not thermally comfortable and it is a less sustainable practice. As identified by (Afgani, Denny, Puad, Mahmud, & Basri 2015), most *masjids* and *suraus* in Malaysia use fans and air conditioning systems. Out of the total registered *masjids* and *suraus* in each state, 71% in Johor, 67% in Terengganu, and 80% in Selangor use fans and air conditioning systems. These can be due to the high indoor air temperature in the main prayer hall caused by constant exposure to solar radiation throughout the year. In line with that, several researches investigate how to improve indoor thermal comfort, especially in public buildings (Liping & Hien 2007; Rahim & Marasabessy 2019; Roslan et al. 2015; Wong, Jianxiu Wen, Tong, Tan, & Kardinal Jusuf 2018).

The indoor thermal comfort of traditional vernacular buildings is crucial as it affects the people's activities inside the building. So, it is necessary to evaluate the present environmental performance of traditional vernacular *masjid* through parameters that respond directly to the current condition (Fatimah & Yusoff, 2020). The development and changes of the surrounding built environment and current climatic conditions will influence climatic elements such as wind and air temperature, thus affecting indoor thermal performance. Therefore, this study aims to investigate the indoor thermal comfort of traditional vernacular *masjid* due to its significant and unique functions, especially for the surrounding Muslim community. It also analyzes and evaluates influencing factors towards the indoor thermal performance of *masjid* in a tropical environment. The findings from this study justify passive design strategies applied in many traditional vernacular buildings that respond favorably to the local climate and environment. Moreover, the intention is to improve indoor thermal comfort through the enhancement of building design.

MASJID KAMPUNG LAUT

Masjid Kampung Laut (Figure 1) was selected for this study because it is the oldest *masjid* in Malaysia that still stands, functional and intact in its original building design condition, which is made of timber. It is very unique due to its history, location, building layout, construction materials, and importantly its tiered pyramidal roof design. The architecture style and design of Masjid Kampung Laut strongly resembles traditional Malay architecture (Nordin & Misni 2018) that applied sustainable and passive design strategies (Hassan et al. 2017). Furthermore, it is similarly constructed according to traditional Malay houses that used local materials which are 'Chengal' and 'Merbau' hardwood for structure, floor and wall construction, and 'Singhorra' as the roof tiles.

FIGURE. 1 Image of Masjid Kampung Laut at Nilam Puri

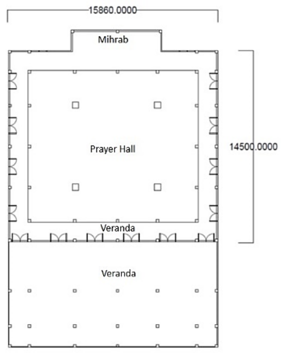

FIGURE. 2 Floor plan of Masjid Kampung Laut.

Masjid Kampung Laut is situated in Nilam Puri, Kelantan 14 km from Kota Bharu. The original location of Masjid Kampung Laut was in Kampung Laut, 18km away from its present site. The relocation took place in 1967 due to a great flood that hit Kelantan (Hassan 2011). Masjid Kampung Laut has a slightly rectangular layout (16m x 15m) (Figure 2) with a total height of 9600mm from floor to tip of the roof. It has three pyramidal roof tiers that create two segments in between the roof. These segments were designed with openings in between that allow for roof stack effects. The *masjid* has an average of 23.3% total openings inclusive of doors and windows on each side of the main prayer walls that help to promote cross ventilation. Meanwhile, the roof openings at the first stack have an average of 96% of the total roof segment wall. With a total area of 240 m², its full capacity at the main prayer hall is for 230 persons based on the standard guideline from MS 2577:2014.

Masjid Kampung Laut's design is classified as a traditional vernacular style (Hassan 2010; Nasir, Teh, & Yuan 2011) that considers four significant factors in its architectural style: local climate, local building material, existing craftsmanship, and subcultural background (Asif, Utaberta, & Sarram 2019). Many scholars have identified that the traditional vernacular *masjid* design is responsive to the tropical climate. This responsive building, also known as 'passive buildings', has a closer relationship with its surroundings to achieve a comfortable internal environment with minimal resources used. The attributes are; building location and orientation, building envelope/ shape, volume/ floor to floor height, natural lighting, natural ventilation, and landscaping.

TABLE 1. Scholars research concerning Masjid Kampung Laut, Kelantan.

	Building's Attributes	Descriptions	Resources	Significance to thermal comfort
1	Building layout	Symmetrical with square or rectangular plan	(Shah, Arbi, & Inangda, 2014)	Spaces flow into one another freely with few boundaries or obstructions.
2	Building envelope and fenestration	Walls with openings	(Nazli Che Din, Nurul Amira Abd Jalil, Yahaya Ahmad, Rosniza Othman, 2013)	Promote cross ventilation
		Wide openings	(Nasir et al. 2011)	Induce prevailing wind
3	Structural details	On stilt design	(Dr. A. Ghafar Ahmad. (1999)., 1999)	Promote cross ventilation
4		Tiered pyramidal roof design	(Azizul Azli Ahmad, 2013),(Hassan, 2010, 2011; Surat, Utaberta, & Tahir, 2010)	Gaps between roofs create a stack effect and allow cross ventilation
5	Building materials	Timber		Low thermal capacity

The design of Masjid Kampung Laut uses a passive design approach, similar to traditional Malay houses. On stilts design elevates the building from the ground, thus allowing air movement beneath the building and subsequently cooling the building (Figure 3). Previously, the actual height of the elevated floor was about 2.3 m above ground when the building was at its original site, however, today the floor level is about 1m above the ground surface. Moreover, full-length window design also allows cross ventilation to occur at an appropriate body height as the wind velocity increases in parallel with the latitude. These windows and openings are protected by large roof overhangs that offer protection from heavy rain and reduce glare. The orientation of the *masjid* faces the qiblah direction at 292° (North-West orientation) hence, this orientation minimizes the total area exposed to direct solar radiation.

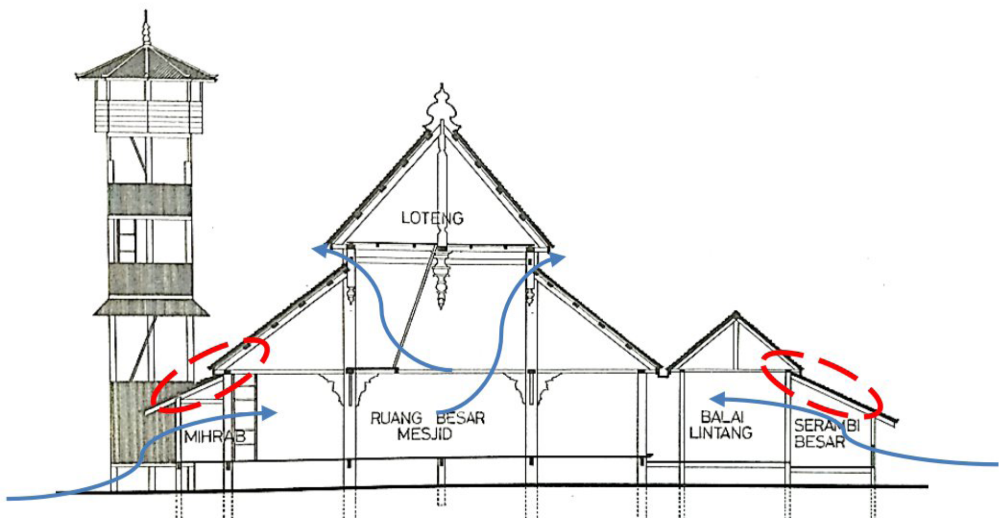

FIGURE. 3 Section of Masjid Kampung Laut shows the cross-ventilation, stack effects, and overhang roofs.

Furthermore, as the *masjid* is located near a river, the surrounding water element creates an airy and breezy area. The evaporation and heat absorption of water helps to cool the surrounding area. Water bodies and greeneries can also aid space cooling. As of now, Masjid Kampung Laut was relocated back to its original 1800 site to relive the initial ideas of the building orientation and surrounding context. The materials are timber, specifically 'Cengal' for the wall and structural members, and 'Rumbia' for the roof. The building materials are extremely strong in carrying the load, have heat latency, porosity and can provide thermal comforts to the occupants.

RESEARCH METHODOLOGY

The research method used in this study is field measurement. The purpose of field measurement is to observe and record the existing dry bulb temperature, relative humidity, and air velocity. In the preliminary study, only these three parameters were focused on. This is because air temperature and relative humidity values are essential to determine the thermal comfort level based on Olgyay's bioclimatic chart, while air velocity also has a significant effect on indoor thermal comfort. The research requires a bioclimatic chart that indicates the highest allowable range for humidity. Olgyay Bioclimatic Chart gives a 90% permissible humidity range (Bughio, Schuetze, & Mahar 2020). Based on Olyay's research, the following bioclimatic chart assembles individual factors and shows the correlation between various climatic elements in the context of the comfort zone. Olgyay's chart has a constant comfort range from 20°C to 30°C (Al-Azri, Zurigat & Al-Rawahi 2013). The level of comfort applies indoor spaces with an indoor level of clothing. Since Olgyay's chart only considers the outdoor conditions excluding the indoor physiological considerations, this chart is only relevant for a hot and humid climate like Malaysia where there are minimal fluctuations between indoor and outdoor temperatures (Al-Azri et al. 2013). Therefore, this research considered three parameters for bioclimatic analysis which are; air temperature, relative humidity, and air velocity.

FIELD MEASUREMENT

The field measurement was conducted at Masjid Kampung Laut for three days from 9th July to 11th July 2019 from 8 am to 8 pm. Based on the data from Meteorological Department, the highest temperature in Malaysia is from April to July. As this is a preliminary study, the measurement was executed for a short duration only.

OUTDOOR MEASUREMENT

Outdoor weather measurements were based on data from Malaysia Meteorology Department. The nearest station is Station Kota Bharu at the latitude of 6° 10' N, longitude 102° 18' E, and is 4.4m above sea level. Meanwhile, Meteologix Data hourly recorded external dry bulb temperature, relative humidity, and wind speed at the height of 5.0 m above the sea level for Kota Bharu station.

INDOOR MEASUREMENT

To measure the indoor thermal performance of Masjid Kampung Laut, the study used two (2) instruments; Hot Wire Anemometer and Kestrel Pocket Weather 4000 (FIGURE. 4).

(a) (b)

FIGURE. 4 Field Instrument (a) Hot Wire Anemometer (b) Kestrel Pocket Weather 4000.

Both instruments measure indoor dry bulb temperature, mean radiant temperature, relative humidity, and air velocity consequently on the stated dates. Both instruments were set up in the center of the main prayer hall since it is the farthest spot from any point of openings and at the height of 1.2 meters from the floor level (Figure 5), well within the average height of humans. However, Hot Wire Anemometer measurement was manually recorded every hour at the same point. As for Kestrel Pocket Weather, the accuracy for the air velocity measurement was ±0.6m/s, while for the air temperature, the accuracy was ±1°C and the accuracy for relative humidity was ±3%.

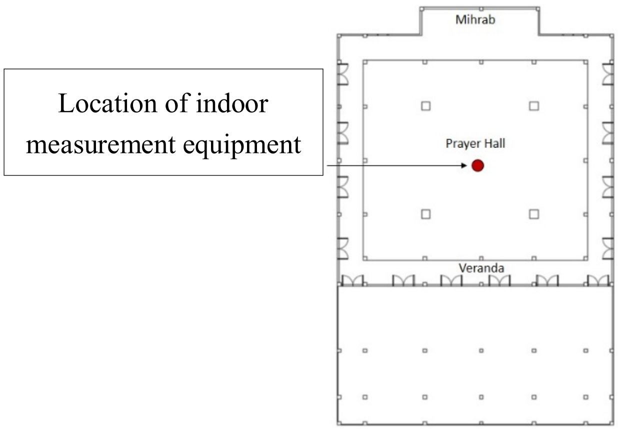

FIGURE. 5 The location of the measuring equipment.

RESULT AND DISCUSSION

OUTDOOR PERFORMANCE

The measured outdoor data on air temperature, relative humidity, and air velocity were shown in (FIGURE. 6). Within the measured dates, the lowest outdoor dry bulb temperature was recorded on 9th July at 8 pm and 10th July at 8 am which was 24°C while the highest was on 9th July at 2 pm at 34.4°C, meanwhile, the average outdoor temperature was 27.9°C. Overall, mornings and nights have low outdoor dry bulb temperatures and in parallel to that, relative humidity was also high during that time. The maximum outdoor relative humidity was recorded on 9th July at 8 pm and 10th July at 8 am which were 92% and 91% early in the morning and at night time while the minimum was 67% in the evening. This high percentage of relative humidity at night-time is common for equatorial countries and it decreases gradually with the increment of air temperature during the daytime. The recorded average outdoor humidity was 75.2%. In summary, the minimum and maximum outdoor air temperature and relative humidity during the measurement period are closely identified with the range of air temperature. On the other hand, the maximum recorded outdoor wind speed was 4.7m/s while the minimum was 0m/s. The average recorded air speed was 2.6m/s since the weather station was located nearby the sea, higher air velocity is expected.

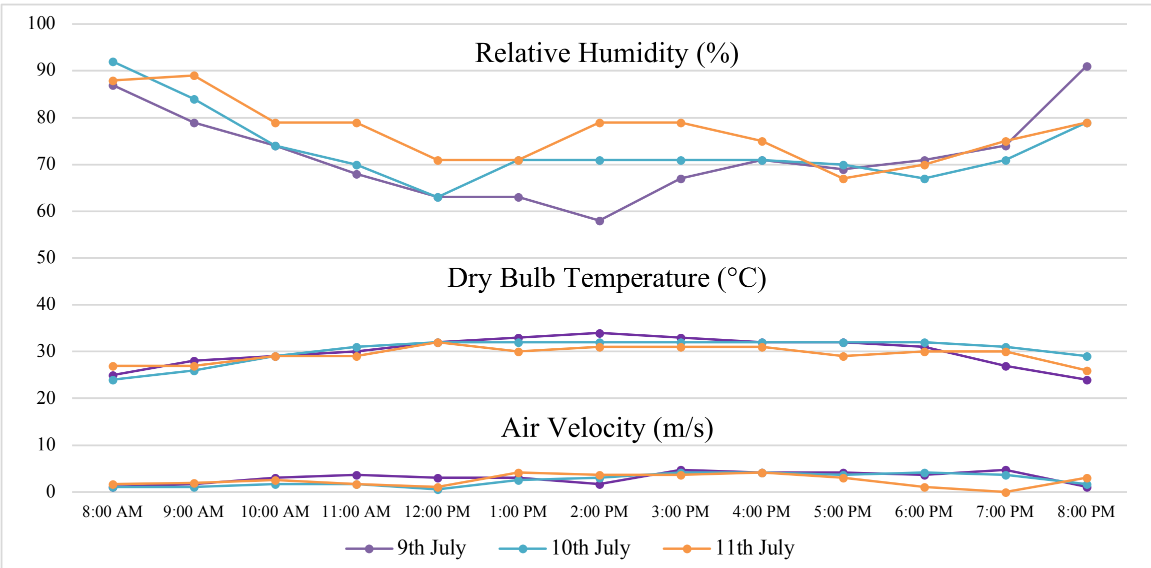

FIGURE. 6 Outdoor relative humidity, dry bulb temperature, and air velocity data for Kota Bharu recorded by Meteologix Data.

INDOOR PERFORMANCE

The comparisons between measured indoor and outdoor data for dry bulb temperature, relative humidity, and air velocity were demonstrated in (Figure 7, 8, and 9).

Comparing both instruments, there were inconsistencies in the recorded air temperature on 9th and 10th July. However, on 11th July, similar indoor air temperatures were recorded by both instruments. The results show that Hot Wire Anemometer recorded higher temperatures than Kestrel Weather Data may be due to the manual process of recording data for the Hot Wire Anemometer. It also shows that most of the readings for indoor dry bulb temperature were higher than outside air temperature with differences in the range of 0°C - 4°C.

Likewise, for outdoor temperature, the lowest average indoor dry bulb temperature was during early morning and night time. The lowest temperature was recorded on 11th July at 9 am, at 27°C while, the highest was during the afternoon of 10th July at 3 pm, which was 34.9°C. The difference between the lowest and highest average indoor air temperatures had indicated that there was some heat absorption and storage by the building materials before it was transferred to the inside of the mosque. These heat absorption and storage had caused the increase in indoor air temperature from morning to evening, although the average outdoor air temperature decreased.

Generally, mornings and nights have low outdoor dry bulb temperature and in parallel to that, relative humidity also was high during that time. The maximum outdoor relative humidity was recorded on 11th July at 9 am which was 90.9% during early morning while the minimum point was the evening of 9th July at 4 pm, which was 52.2%. This high percentage of relative humidity in the early morning and night time is common in equatorial countries and it decreases gradually with the increment in daytime air temperature.

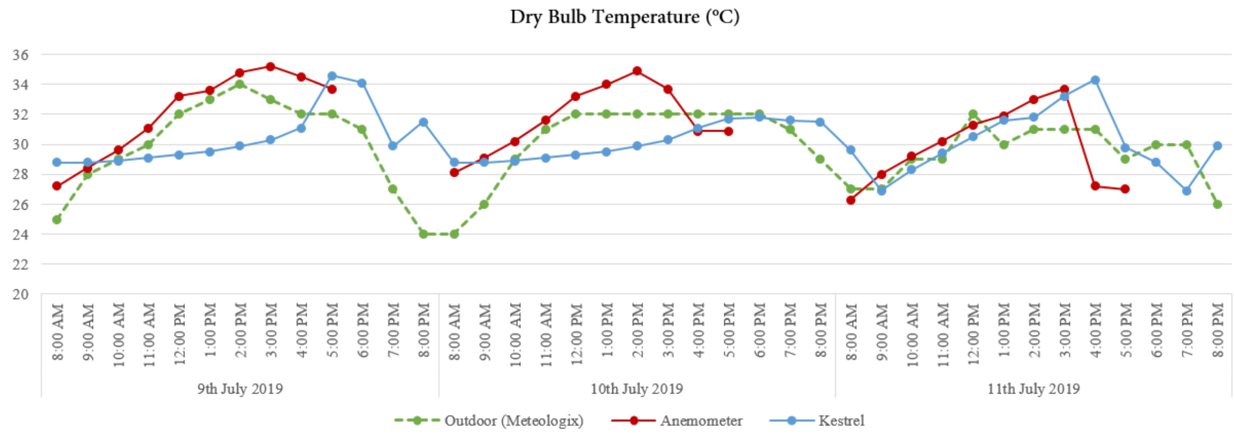

FIGURE. 7 Comparison of indoor and outdoor dry bulb temperature.

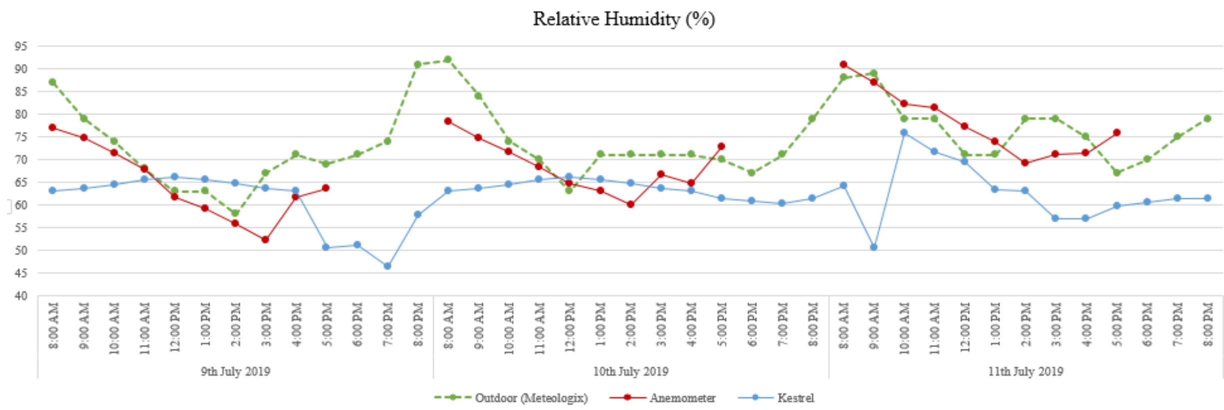

FIGURE. 8 Comparison of indoor and outdoor relative humidity.

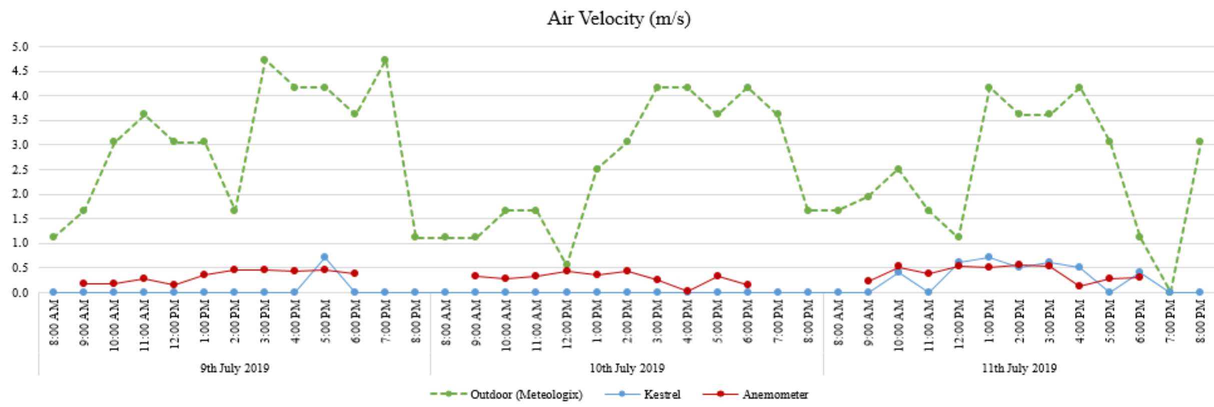

FIGURE. 9 Comparison of indoor and outdoor air velocity.

The results show that outdoor wind is stronger in velocity compared to indoor air. This may be due to the elevation of the weather station which is 5.0 m above sea level while the position of field instruments is around 2.2 m above ground level. Furthermore, the weather station is located nearby the sea so higher wind speed is expected. Therefore, the building's elevation will receive increased air movement speed and indirectly will influence the result of indoor air velocity. On the other hand, the maximum recorded indoor air velocity was 0.7m/s while the minimum was 0m/s.

Meanwhile, for the average indoor air velocity, the values were below 0.1 m/s. These indoor air velocity values might be higher if the indoor measuring equipment is placed in areas where direct cross ventilation occurs. The simple layout plan of Masjid Kampung Laut, and the presence of many openings at the sides and front of the main prayer hall allow natural cross ventilation to occur.

OLGYAY'S BIOCLIMATIC CHART

Data related to dry bulb temperature and relative humidity from the on-site measurement tools are plotted in the chart for analysis. From the analysis using Olgyay's Bioclimatic Chart of Hot Wire Anemometer, it was observed that the dry bulb temperature and relative humidity ranges stay outside the comfort zone for the case study (Figure 10). To achieve comfort, natural ventilation and dehumidification are very essential. It was noted that from 30 readings, 10 readings were in the comfort range with the assistance of air velocity and another 20 readings were in the discomfort range. However, with an increase of 0.4m/s air movement, 2 readings will achieve comfort, 14 readings will achieve comfort if the air movement increased to 1.0m/s and another 4 readings will achieve comfort if the air movement increased to 1.2m/s.

Meanwhile, analysis from Kestrel Pocket Weather 4000 showed that 3 readings from dry bulb temperature and relative humidity ranges stayed inside the line of comfort range while the other 36 readings stayed outside the comfort zone for the case study (Figure 11). It was noted that from 39 readings, 26 readings were in comfort range with the assistance of air velocity and another 13 readings were in discomfort range. However, with an increase of 0.4m/s of air movement, these 13 readings will achieve comfort.

Both charts above indicate that bioclimatic design techniques can improve comfort in Masjid Kampung Laut by increasing air velocity. As air velocity increases, the comfort zone will expand upward to cover a larger extent and the interior will be comfortable because ambient air speed affects the user's thermal comfort. As the indoor air velocity increases, the water on the body surface evaporates more and the person starts to feel colder. Furthermore, it also helps reduce the available still air mass around the person by dispersion therefore, the chilling effect will increase.

Based on studies done by (Fatimah & Yusoff, 2020; Yusoff & Ja'afar, 2019), thermal comfort for naturally ventilated buildings reflects that in a hot and humid climate, people can tolerate higher air temperature, where they still feel neutral at 33°C. This value is slightly lower than the highest indoor dry bulb temperature recorded by both types of equipment in Masjid Kampung Laut, which was 34.8°C. The temperature differences are still in the range of between 1°C to 3°C therefore, it is still acceptable for the users (Profile, 2012) indicating that the indoor environment of Masjid Kampung Laut can provide thermally comfortable conditions to users.

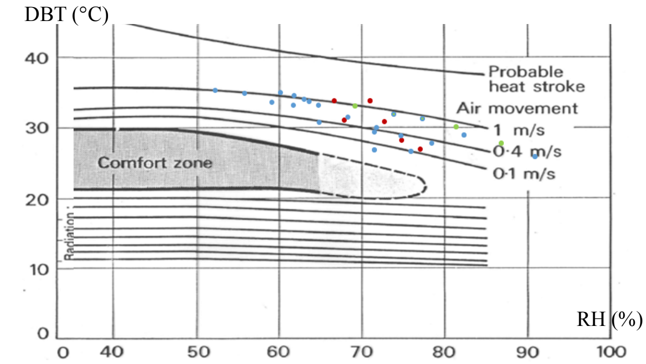

FIGURE. 10 Olgyay's bioclimatic chart for Hot Wire Anemometer readings.

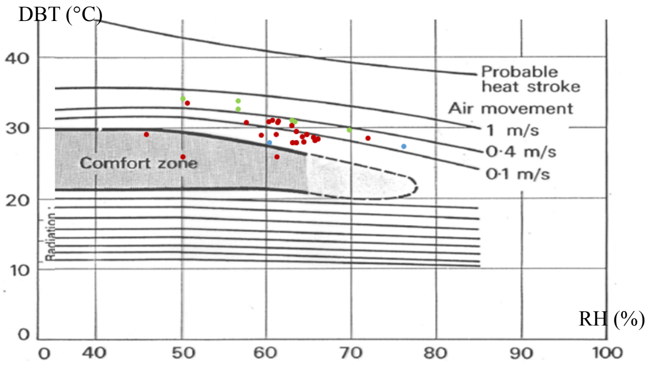

FIGURE. 11 Olgyay's bioclimatic chart for KESTREL readings.

Thermal comfort conditions at the main prayer hall of Masjid Kampung Laut are also influenced by the architectural character of the *masjid.* As mentioned earlier, the verandas and roof overhangs help to reduce direct solar radiation penetration into the main prayer hall. In addition, the wide openings at the main prayer hall and roof openings help induce the prevailing wind inside the main prayer hall. The thermal comfort of Masjid Kampung Laut may be further enhanced by the increased indoor air velocity. The design of tiered pyramidal roof portrayed in traditional vernacular *masjid* promotes stack effect and passive design strategies such as roof openings (Wahab, Ismail & Kadir 2016), roof overhangs, roof pitch, and roof volume. Hence, it is suggested that future research examine the potential of increasing the indoor air velocity at Masjid Kampung Laut through its roof design.

CONCLUSION

In a hot and humid or tropical climate, high temperature and high levels of humidity should be taken into consideration; unlike in a warm climate, where high temperature is the only problem to be tackled. The study shows that the architectural character of Masjid Kampung Laut can provide indoor thermal comfort to the users. The *masjid* has architectural characteristics and designs that responded favorably to Malaysia's hot and humid climate, such as a sitting on stilts design, a simple layout plan with wide openings and verandas, a tiered roof design that allows for roof openings at the roof segments, large roof overhangs, and the choice of building materials. However, this aspect needs to be investigated further in the future. The evolution of modern *masjid* design nowadays has led to the intervention of many active measures in achieving indoor thermal comfort such as using mechanical ventilation. Nevertheless, there are still many valuable architectural characteristics to be learned from our traditional vernacular *masjid* in the aspects of passive design strategies for effective natural ventilation. This study is a preliminary investigation of a traditional vernacular *masjid's* indoor environmental condition and thermal comfort.

ACKNOWLEDGEMENT

The authors would like to thank International Islamic University Malaysia, Malaysia for supporting this research.

DECLARATION OF COMPETING INTEREST

None

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