JOURNAL OF ISLAMIC ARCHITECTURE
P-ISSN: 2086-2636 E-ISSN: 2356-4644
Journal Home Page: http://ejournal.uin-malang.ac.id/index.php/JIA

AN APPRAISAL OF INDOOR THERMAL COMFORT IN A NATURALLY-VENTILATED MODIFIED OLD MOSQUE IN BANDA ACEH, INDONESIA

| Received July 22nd, 2022 | Accepted January 31st, 2023 | Available online June 20th, 2023|
| DOI http://dx.doi.org/10.18860/jia.v7i3.17131 |

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ABSTRACT

A traditional mosque is a form of conformity between the design and the climate. The warm humid climate in Indonesia characterizes the environment, which is quite challenging to work with. The traditional mosque, with the uniqueness of the roof design, allows the application of a natural ventilation system that can work effectively in circulating air to reduce the effect of heat in the room. However, the application of the design has rarely been found in modern mosques due to the widespread use of the dome. This study appraised Tgk Dianjong Mosque, one of the old mosques in Banda Aceh, Indonesia. The old mosque was modified by replacing the roof material and ventilation. This study aims to appraise the indoor thermal comfort of the mosque considering the application of natural ventilation. The method used in this research is descriptive quantitative, with research data collected through physical measurements, i.e., air temperature, relative humidity, and air velocity. The collected data were analyzed using the CET (Corrected Effective Temperature) index and assessed based on SNI 03-6572-2001. Multiple linear regression analysis was conducted to determine how much wind speed influences the thermal condition of the mosque. The study was conducted for two days, with the selected time being in the morning, afternoon, and evening to obtain more varied data. This study performs that the renovation of replacing the roof ventilation with fixed glass would contribute to the lack of airspeed throughout the mosque. The old material of the roof, i.e., leaf grass, was displaced with a metal roof, creating a highly effective temperature and hence indicated as uncomfortable.

KEYWORDS:
Traditional Mosque; Thermal Comfort; Effective Temperature

INTRODUCTION

The mosque as a Muslim worship building has several main elements: *haram*, *mihrab*, pulpit, porch, and *wudhu'* area. Among the five elements, the *haram* or prayer room is the most vital element in the mosque because it is a place of worship, da'wah, and other religious activities [1]. Moreover, the prayer room requires comfortable and quiet conditions due to its function.

Based on research on comfort at several Jami Mosques in the city of Solo, the most common problems found in mosques are caused by natural ventilation [2]. It is assumed to occur due to the high temperature in the room and the lack of air movement. The solution to these problems can be solved through the effective use of openings. Previous studies [3] have shown that the best air temperature occurs when the windows are partially open due to the high wind movement in the room and minimizing exposure to solar radiation in buildings. These results indicate that the two factors, namely, wind speed and solar radiation, greatly influence the effectiveness of the aperture.

Priya & Kaja [4] stated that wind movement is the only way to achieve physiological comfort at high temperatures because it affects evaporative and convective heat loss from humans. It is in accordance with research conducted by Syamsiyah & Izzati [5], which shows that the most comfortable thermal conditions are obtained during the Asr prayer, namely when there is a difference in air temperature which makes the wind move faster than other prayer times.

In addition, the surrounding environmental conditions also affect the thermal comfort of the mosque. It is in accordance with previous research [6], which stated that the large courtyard around the mosque cannot provide smooth airflow and comfortable temperatures due to the use of paving blocks and the dense surrounding environment filled with buildings to form a temperature air 25°C-35°C and wind speed 0.1-1.0 m/s.

The design characteristics of mosques in Indonesia initially developed with a character without a dome. It can be seen in most of the ancient mosques in

Indonesia, such as the Great Mosque of Demak on Java Island and the Tuha Indrapuri Mosque in Aceh. Both have a similar roof shape, namely a roof overlapping (without a dome). Sutjipto Wirjosuparto [7] concluded that the mosque model with this form was adapted from a traditional Javanese building called the pavilion and is known to originate from a part of the Hindu temple in India which is square and built terraced above the ground.

The roof design of this type of mosque is assumed to be able to adapt to humid tropical climate conditions. It is due to using a multistory roof with gaps that can function as openings for natural ventilation and a medium for entering natural light into the prayer area [1]. Furthermore, this gap creates a stack effect air ventilation system, which occurs when warm air escapes through the window openings on the roof and is replaced with cold air from outside [8].

However, this design has been very rarely used in the design of modern mosques. Instead, most mosques have applied a roof structure not integrated with the top opening. As a result, hot air tends to be trapped, so the stack effect natural ventilation system cannot occur.

In the case of Banda Aceh City, most mosques have used dome elements on their roof structures, such as the Baiturrahman Grand Mosque, Al Makmur Great Mosque, Baiturrahim Mosque, Harun Geuchik Leumik Mosque, and others. It is reinforced by previous research [9], which stated that the typology of mosques in Banda Aceh City is characterized by using domes. The rise of the use of the dome occurs due to the many assumptions which state that the dome is a symbol of the mosque [1]. However, this assumption is considered inaccurate because if traced based on history, the dome is not the original element of the mosque [10].

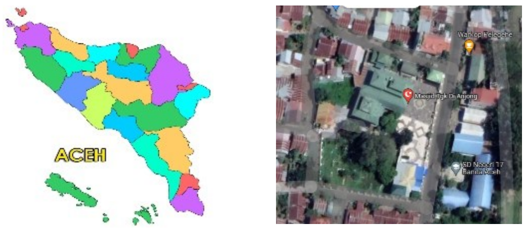
Based on these problems, the author intends to study the conditions related to thermal comfort in old mosques in Banda Aceh City. The selected case study is Tgk. Dianjong Mosque has a typology of shapes that can apply a stack effect natural ventilation system. The absence of a dome and the presence of a top opening in the roof structure would induce airflow. However, Tgk. Dianjong Mosque has been renovated using fixed-type openings made of glass at the roof. This type of opening only works naturally as a medium to enter light into the building yet neglects the airflow out of the buildings [11].

This study was conducted with the aim of (1) measuring the level of thermal comfort at the Tgk Dianjong Mosque and (2) knowing the effect of wind speed on the thermal conditions within the Tgk. Dianjong Mosque.

METHODS

This research uses a descriptive quantitative method. Research topics are explained using appropriate theory and measurement data. The research variables to be measured consisted of independent variables (air temperature, wind speed, and relative humidity) and dependent variables (effective temperature).

Figure 1. shows the location of the object of research, namely the Tgk Dianjong Mosque, located in Peulanggahan Village, Kuta Raja District, Banda Aceh City.



a b

Figure 1. Research Location (a) Map of Aceh Province [source: GoogleMaps] (b) Map of Tgk Dianjong Mosque [source: Google Maps]

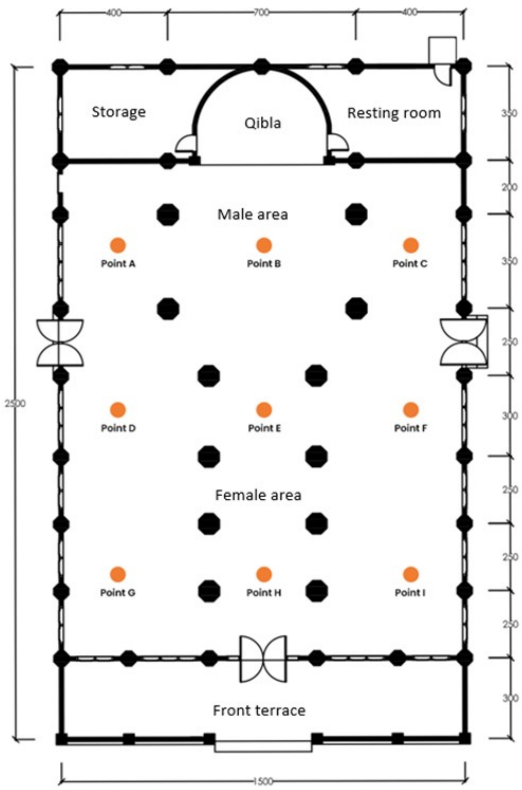


Figure 2. Floorplan of the mosque and the measurement point

The data was collected on the 10th and 17th of October, 2021, in the morning, afternoon, and evening. Figure 2 shows the depiction of measurement points in the prayer area, which consists of 9 measurement points. The data analysis technique used in this research is a descriptive statistical analysis technique and multiple linear regression analysis between the independent and dependent variables. The level of thermal comfort is assessed using SNI-03-6572-2001, based on the ET (Corrected Effective Temperature) thermal comfort index.

DISCUSSION

OBJECT OVERVIEW

Tgk. Dianjong Mosque is located in Peulanggahan Village, Kuta Raja District, Banda Aceh City (Figure 1). This mosque is one of the historical mosques in Banda Aceh. Built for the first time in 1769, this mosque uses wood construction and consists of three floors.

Figure 3. The Transformation of Tgk. Dianjong Mosque from the past to the current time [12]

Referring to history, the old mosque has the same roof material, i.e., such as sago leaf, as the traditional house. Although rebuilt in a slowly changing form over time, the mosque underwent significant changes after the tsunami [12]. The most visible change is the use of more modern materials (the use of brick and reinforced concrete). An illustration regarding the shape transformation of the Tgk Dianjong Mosque is shown in Figure 3.

The mosque area is attached to the Islamic scholar's cemetery. The ground floor area of the mosque is ±375 m2 (not including the cemetery and *wudhu'* area).

Figure 4. The condition of the indoor and outdoor of the Tgk. Dianjong Mosque [author]

Figure 4 shows the indoor and outdoor conditions of the mosque. It can be seen that this mosque is oriented Southeast – Northwest (following the Qibla direction), and openings are found on all sides. The material used for the walls is reinforced concrete, the roof covering is zinc, and most openings use window blinds made of wood.

Figure 5. Description of the condition of the types opening [author]

The spatial arrangement of the mosque is non-hypostyle (typical of mosques in Southeast Asia). Figure 5 shows the ground floor plan of the mosque in the shape of a square, with the prayer areas for men and women only separated by curtains. Each building wall has openings in the form of doors, windows, and ventilation holes for natural ventilation. Natural lighting is obtained through the fixed window opening in the void area in the middle of the room. Most of the openings are of the casement side-hung type. Fixed window-type openings are only found in the void area.

THERMAL COMFORT CONDITIONS AT THE TGK DIANJONG MOSQUE

The assessment of the level of thermal comfort is carried out by SNI-03-6572-2001, which uses an effective temperature index as a quantity in determining thermal comfort. The Indonesian National Standard (SNI-03-6572-2001) states that the thermal comfort limit in Indonesia is from a temperature of 20.5 °C ET – 27.1 °C ET [13].

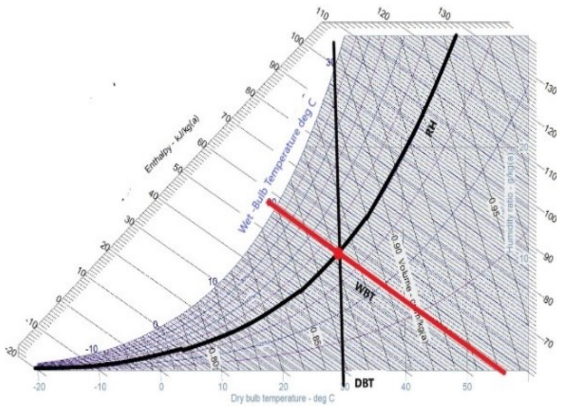


Figure 6. The trace of DBT and RH on the Psychometric diagram to get the WBT (Wet Bulb Temperature)

The effective temperature value is obtained using a psychometric diagram to get the WBT (Wet Bulb Temperature) value (Figure 6). This value is then used to determine the value of TE (Effective Temperature) using the CET nomogram for basic (0.5 clo) (Figure 7).

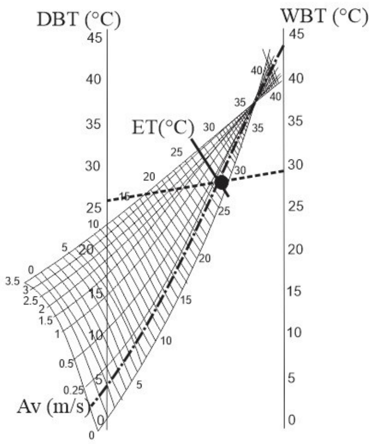


Figure 7. The Trace of DBT, WBT and Av on CET nomogram for basic (0.5 clo)

Table 1 shows that the average value of relative humidity is 61.86%. This result has exceeded the limit of SNI-03-6572-2001, which states that the relative humidity standard for the tropics is around 40-50%. In addition, it is also seen that the average value of the wind speed is 0.209 m/s (<0.25 m/s). This value is still below the standard set by SNI-03-6572-2001. The comparison between the air temperature value and the effective temperature is shown in Figure 8.
The calculation results are presented in the Table 1.

Table 1. Effective temperature value calculation data [author]

Hours	Ta Indoor (°C)	Va (m/s)	Rh (%)	WBT (°C)	TE (°C TE)
08.00	30,32	0,16	70,51	25,92	26,8
09.00	31,2	0,21	67,38	26,12	27,3
10.00	32,43	0,24	63,70	26,56	27,8
11.00	32,93	0,21	59,18	26,2	28
12.00	33,5	0,22	57,76	26,41	28,1
13.00	33,45	0,21	57,21	26,27	28,1
14.00	33,3	0,22	60,22	26,72	28,2
15.00	33,35	0,26	58,83	26,48	28,1
16.00	32,47	0,18	60,58	26,27	27,9
17.00	31,96	0,18	63,20	26,07	27,6
Avg	32,491	0,209	61,86	26,302	27,79
Min	30,32	0,16	57,21	25,92	26,8
Max	33,5	0,26	70,51	26,72	28,2

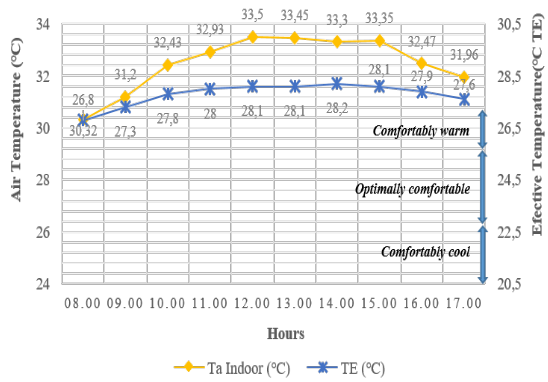


Figure 8. The performance of the effective temperature value with air temperature [author]

Based on Figure 8. it can be seen that the effective temperature values at every hour are mostly already above the comfort zone. Thermal comfort conditions can only be felt in the morning (08.00), while it is categorized as uncomfortable during the day and evening. These results indicate the thermal comfort at the Tgk. Dianjong Mosque cannot be reached due to the high effective temperature in the room (ET is dominated by values above 27 °C ET).

COMPARISON OF *INDOOR* AND *OUTDOOR* AIR TEMPERATURE VALUE

Based on the graph in Figure 9, it can be seen that in the morning, the indoor temperature value is still lower than the outdoor air temperature. However, this situation gradually changed at 13.00 WIB. The indoor temperature value is higher than the outdoor air temperature, which is indicated to occur due to the effect of solar radiation on the material in the mosque. In addition, high thermal mass materials such as concrete and brick contribute to the heat felt during the day due to their function, which can store more heat and then release it to the indoor area [14].

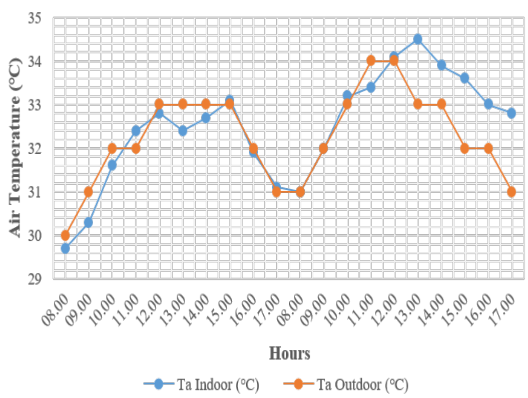


Figure 9. The performance of indoor air temperature values with outdoor air temperatures [author]

The use of fixed-type windows in the void area of the mosque is also assumed to be one of the factors that influence the increase in air temperature in the room. It follows the research conducted [14] on one of the modern mosques in Malaysia. One factor that affects the discomfort in the mosque is the use of fixed -type glass clerestory windows in the dome area, which allows the entry of direct solar radiation into the room, especially when the sun's position is high.

COMPARISON OF INDOOR WIND SPEED VALUE AT EACH MEASUREMENT POINT

The graph in Figure 10 shows that the average value of each measurement point is in the range of 0.1 m/s to 0.4 m/s. The wind movement conditions are quite comfortable (0.2 m/s to 0.5 m/s) only at points A, D, F, and G. At other points (B, C, E, H, and I), the wind movement is included in the unnoticed category.

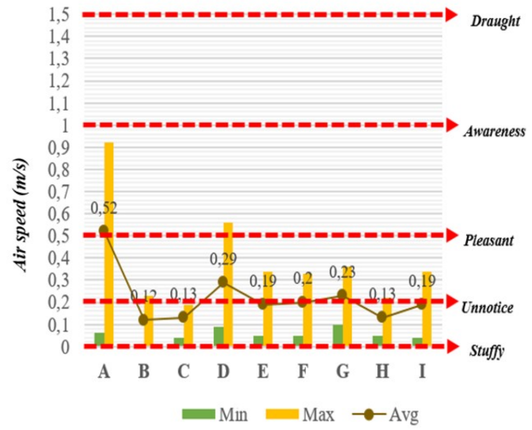


Figure 10. Comparison graph of indoor wind speed values at each measurement point [author]

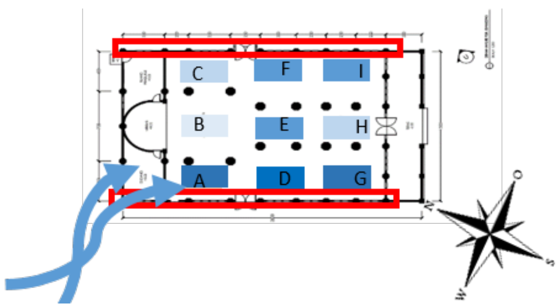


Figure 11. Indoor wind speed zoning for each measurement point in the prayer area [author]

Referring to Figure 11, it can be seen that the southwest side (points A, D, and G) of the mosque is the area with the highest wind speed value due to its position close to the opening so that it can directly receive the wind from the west (west monsoon). Most wind movement comes from the west because the measurement process was carried out in October (the beginning of the rainy season). On the other hand, point B is the area with the lowest wind speed value (marked in the lightest blue). It is assumed to occur due to the location of point B which is in the middle of the room and far from the opening.

In addition, another factor that is also considered to affect this is the existence of a fixed window-type opening in the void area (just above point B), which causes hot air to be trapped or trapped in the room so that the stack effect natural ventilation system cannot occur. The stack effect can also be applied even to mosques that use a dome on the roof structure. The openings around the dome can increase the natural ventilation emerging the stack effect inducing indoor thermal comfort [14] [15] [16].

Based on this, stack effect ventilation can be applied to buildings, provided that the outdoor air temperature is lower than the indoor air temperature so that warm air will come out through the top opening and be replaced with cooler air that enters through the bottom opening in the building [17].

EFFECT OF INDEPENDENT VARIABLES ON THERMAL CONDITIONS OF THE TGK. DIANJONG MOSQUE

To determine the effect of independent variables (air temperature, wind speed, and relative humidity) on the thermal conditions of the Tgk Mosque. Dianjong, it is necessary to analyze using linear regression between the values of the three independent variables with the TE (Effective Temperature) value as an index to calculate thermal comfort. The multiple linear regressions shown in this paper were analyzed using the Microsoft Excel scatter chart program:

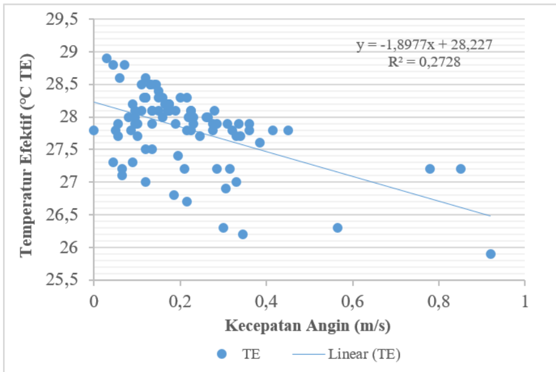


Figure 12. Linearity scatterplot graph of the effect of wind speed on effective temperature [author]

Figure 12. shows a linearity scatterplot graph of the effect of the three independent variables on the effective temperature. In general, it can be seen that the higher the wind speed, the lower the effective temperature at the mosque, which shows a negative (inversely proportional) relationship. Therefore, it can be concluded that the higher the rate of increase in the value of wind movement, the smaller the value of the effective temperature will be. Table 2 describes the results of calculations using regression between the three independent variables (wind speed, air temperature, and relative humidity) with the effective temperature.

Referring to Table 2., of the three independent variables, only air temperature with wind speed has the most significant effect on the effective temperature value (the significance value has been less than alpha = 0.05). Wind speed significantly influences the effective temperature value, with a significance value of 6.53142E-30. It shows that the wind speed can significantly reduce the value of the effective temperature at the Tgk. Dianjong Mosque. The air movement in the tropics is also significant in reducing odours and air pollution hence inducing good Indoor Environmental Quality (IEQ) [18].

Table 2. Regression interpretation data using Microsoft Excel [author]

	Va	Ta	Rh
Significance < Alpha = 0,05	6,5142E-30	4,28897E-12	0,061044
Correlation	0,9503 (very strong)		
Determination coefficiency (r^2)	0,899 (89,9%)		

The relative humidity variable is a variable that is not very significant in influencing the effective temperature value because the significance value is more than 0.05 (the relative humidity significance value is 0.061). Table 2 also shows that the value of the coefficient of determination of the independent variable is known that the independent variable can explain the dependent variable by 89.9%, and other factors influence the rest. Therefore, while the correlation value between the various independent variables and the dependent variable is 0.9503, this value is included in the strong category.

CONCLUSION

The traditionality of the Tgk Dianjong Mosque is shown by the shape of its roof structure which is without a dome (showing similarity to the typology of the Nusantara Mosque). This type of roof allows the application of a stack effect ventilation system by taking advantage of the exchange between hot air and cold air from outside that enters through the bottom opening on the ground floor.

However, in the case of the Tgk Dianjong Mosque, this natural ventilation system cannot occur, even though the design of the mosque has used a roof structure that allows the application of this system because the design of the upper opening in the void area of the mosque is a fixed window type with glass material, thus blocking the escape of hot air indoor. This opening is also assumed to contribute to the increase in indoor air temperature because it allows the entry of large amounts of light, which can have the effect of solar radiation on building materials. Only the openings on the ground, which are window blinds, allow a natural cross ventilation system to occur, which can increase the movement of wind in the room by significantly reducing the effect of heat in the room.

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