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THERMAL COMFORT ANALYSES OF THE OLD MOSQUE IN A HUMID CLIMATE A CASE STUDY ON OLD MOSQUE GUNONG KLENG, ACEH BARAT, INDONESIA

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ABSTRACT

Old mosques have a typology that reflects the traditions and culture of the community which has local wisdom values. Indonesia has a tropical climate that influences aspects of life, one of which is the shape of buildings that adapt to natural conditions. The Old Mosque Gunong Kleng is a historic and oldest mosque in West Aceh Regency, Indonesia, which was built in 1927. This research aims to identify the effect of openings on thermal comfort and evaluate the thermal comfort felt by visitors to the Tuha Gunong Kleng Mosque. This research uses quantitative methods by collecting data from questionnaires using the Thermal Sensation Vote (TSV) method as well as field measurements consisting of air temperature, humidity, and air velocity. The measuring instruments used were the USB Data Logger, Anemometer, and Weather Station. The results of this research were then compared with the effective temperature of SNI 036572-2001. The results of field measurements of air temperature variables do not comply with comfort standards, in contrast to wind speed and humidity. However, this is inversely proportional to the perception of respondents who can accept the thermal environment.

Keywords: *Thermal Comfort, Old Mosque, Aceh Barat, Humid*

INTRODUCTION

West Aceh is a region of Indonesia that has a humid tropical climate with characteristics of air humidity reaching 80%, air temperature reaching 26ºC, and intense solar radiation that has a rainy season and a dry season (Santosa & Mutiari. 2022). Climatic factors greatly influence several aspects of human life, including architecture. The shape of the building will adjust to natural conditions, sun, wind, weather, and even climate. (Su et al., 2021).

The mosque is a place of worship for Muslims as well as the center of the Islamic religious community. Mosques also function as places for activities or celebrations of certain holidays, religious studies, lectures, discussions, and places to study the Al-Quran. According to Sari (2023), historic mosques are a reflection of the traditions and culture of the people who have local wisdom values that have stood the test of time thanks to their ability to adapt to the environment.

The Old Mosque Gunong Kleng is a historic mosque in West Aceh Regency and has been included in the cultural heritage site. According to Sabil (2010), this mosque which was built in 1927, has a mosque construction with 5 domes as a philosophy of the number of pillars of Islam. The Old Mosque Gunong Kleng has not undergone many changes from the past with a stepped roof structure made of Ketapang wood with a main pillar made of Merbau wood which still survives today, and a mosque niche made of sand and egg white mixture with a height of 250 cm.

Thermal comfort is a sensation of satisfaction with environmental conditions. Factors that influence thermal comfort are air temperature, air humidity, and air velocity (Amaripadath et al., 2023). Matschi & Nemeth (2022) explain that thermal comfort will get different results depending on the building design, air opening design, internal factors, and external factors. So thermal comfort is very important to pay attention to because a comfortable room can meet thermal comfort standards.

In providing thermal comfort, the Old Mosque Gunong Kleng still adopts a natural ventilation system. This can be seen from the ventilation window openings on various sides of the building and the building design with a stepped pyramid roof. However, in this mosque, there is also a fan installed which turns on under certain conditions. Therefore, comfort in the mosque is an important aspect that must be presented. Thereis a close connection between worship activities and the comfort of the mosque space. However, if the space does not physically support the time of worship, then comfort is not easy to achieve (Candra & Azizah, 2023).

There is still little research on thermal comfort in historic mosques in tropical climates. Apart from that, Old Mosque Gunong Kleng has a typology similar to historical mosques in Indonesia, so it can be the latest comparison or review in thermal comfort with similar research. This research focuses on several aspects, namely, identifying the level of thermal comfort felt by visitors, and evaluating the influence of thermal comfort performance at the Old Mosque Gunong Kleng, West Aceh so that it is hoped that it can create a comfortable space for the congregation of the historic mosque by the effective standard SNI 036572-2001.

Thermal Comfort

Thermal comfort is a condition where a person feels comfortable psychologically, physiologically, and behaviorally when carrying out activities in an environment at a certain temperature (Zhao et al., 2023). Thermal comfort is an important element in the comfort aspect. As is known, humans feel hot or cold on the skin, a type of sensory sensation related to environmental temperature stimulation (Dzyuban, 2022). According to Yao (2022), thermal comfort comes from creating a balance between human body temperature and environmental temperature, because if there is a significant temperature difference between human body temperature and environmental temperature, a feeling of discomfort will arise.

Muslimsyah (2021) describes factors that create thermal comfort are: air temperature; relative humidity; airspeed; and radiation temperature. Widyakusuma (2022) added body metabolism; clothing; and clothing insulation. The factors that can influence thermal comfort in a building are air temperature; humidity; airspeed; clothing insulation; and activities (Choudhary, 2023). However, Yusof (2020) also added ventilation openings;

heat transfer, and opening dimensions.

The thermal sensation indicator felt by residents uses the Thermal Sensation Vote (TSV) which is obtained from the use of seven measurement sensation scales, namely; very hot (+3), hot (+2), warm (+1), neutral/ comfortable (0), cool (-1), cold (-2), and very cold (-3). Variables that influence thermal comfort are climate and humans. Microclimate variables consist of temperature, humidity, and wind speed. These three variables can be combined into an effective temperature variable using psychometric charts. Apart from that, there are personal factors in adaptive thermal comfort consisting of activities and clothing (Azli et al., 2022).

Indonesia sets standards that can determine the basic temperature or reference temperature for thermal sensations. This study refers to the thermal comfort standard SNI 033572-2001. (Table 1) has 3 criteria: air temperature, wind speed, and air humidity, while the thermal sensation consists of comfortable cool, optimal comfort, and almost comfortable. Based on the three thermal sensations above, it can be seen that the lowest air temperature was 20.5°C and the highest was 27.1°C. The highest wind speed is >0.25 m/sec and the lowest is 0 m/sec. and relative air humidity is low at 50% and high 80%.

Table 1. The Thermal Comfort Range Based on The Indonesian Standard

Thermal sensation	Air temperature	Air velocity	Relative Humidity
Cool comfortable	20,5°C – 22,8°C	> 0.25 m/s	50%-80%.
Optimal comfort	22,8°C – 25,8°C	0,15 - 0,25 m/s	70%-80%
Almost comfortable	25,8°C – 27,1°C	0 - 0,15 ms	60%-70%.

Source: Author

Thermal Comfort in Old Mosques

The old mosque is a traditional mosque, a mosque that was built at the time when Islam first entered Indonesia and has a shape that adapts to the situation and conditions of that time and is based on the community's mindset with the concept of local traditions (Sari et al., 2023). Apart from that, traditional mosques in Indonesia were born and developed as a result of interactions between social elements of society in Indonesia, the archipelago, and the world.

In research on thermal comfort in old mosques, the research variables are temperature and humidity which exceed comfort limits as in research by Santosa & Mutiari (2022), Rabul & Nugroho (2020), and Novita et al., (2023). Apart from that, the low level of air velocity in buildings inside Indrayadi (2011), and Yusoffa (2020) is an obstacle in achieving thermal comfort in historic mosque buildings located in tropical climates.

According to Ritva (2017) when taking measurements in the field, the results depend on the position of the measurement point. Caused by the difference in wind speed on the building terrace and inside the building due to the uneven wind distribution process. Apart from that, Khalit et al., (2023) explained that the measurement point was not close to the ventilation, causing the wind speed obtained to be quite low.

In another study Fitria (2018), Apart from that, natural openings and ventilation influence the speed of wind entering inside which greatly influences changes in air circulation, so that large ventilation openings cause air exchange which can reduce the comfortable room temperature. However, with the type of ventilation modification in the study Novita (2023), the terraced roof covered with glass material prevents air from entering the mosque and causes rapid heat transfer. The choice of roof material greatly influences the level of comfort, such as the use of zinc or metal roof tiles which do not provide thermal insulation or a process of reducing the heat transfer rate (Sari, 2019; Salsabilla, 2023).

RESEARCH METHOD

Location and Time of Research

Tuha Gunong Kleng Mosque is located in Gunong Kleng Village, District. Meureubo, West Aceh Regency, Aceh Province Indonesia (Figure 1), this mosque which is 8 km from Maulaboh City, was founded in 1927 and is 96 years old, making it one of the oldest mosques in West Aceh.

The shape of the Old Mosque Gunong Kleng has a typology that is almost similar to other old mosques in Aceh. This mosque has a tower with a cup dome on top with the number 5 or Tampong Limong with the applied philosophy of the 5 pillars of Islam. There is a tower that used to function as a place for the Muezzin to make the call to prayer.

Figure 1. Location and Mosque Appearance
Source: Google Maps & Author

Based on (Figure 2), the mosque building measures 8x8 meters with a stepped roof structure made of Ketapang wood and the main pillar uses Merbau wood which is in good condition until present. The boundary wall as high as 80 cm from the ground is made of concrete and then used wood. and the mosque niche is made of sand and egg white mixture with a height of 250 cm. The opening in the Old Mosque Gunong Kleng has 1 main door and 10 windows, each consisting of two covering boards with grilles, making it easier for light to enter the mosque and exchange air flow by implementing cross ventilation with a size of 150 x 130 cm.

This research was conducted on 19 – 25 July 2023 to determine air temperature, air velocity, and humidity every 30 minutes from 09.00 AM – 5.00 PM.

Data Collection

This research uses quantitative methods with a descriptive approach. The data collection method is carried out by obtaining primary and secondary data related to the problem being researched. There are techniques for collecting data, namely primary and secondary.

Primary data was obtained from the results of field surveys, including field measurements to determine the variables of air temperature, wind speed, and humidity, and distributing questionnaires to respondents. Meanwhile, secondary data comes from books, journals, and similar and relevant research.

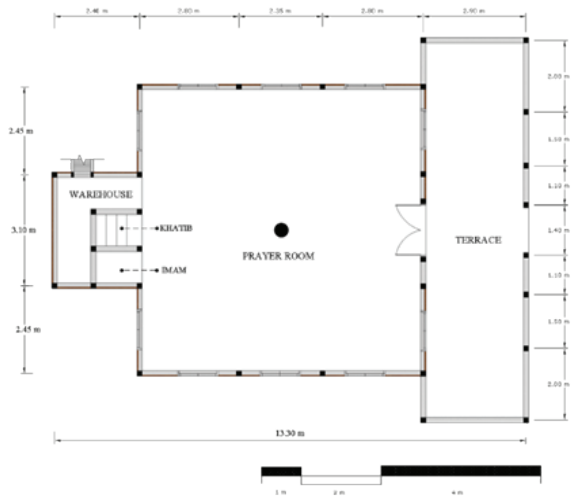

Figure 2. Mosque Floor Plan

Source: Author

Field Measurement

Measurement tools in the form of an Anemometer, USB Data Logger, and Weather Station (Table 2) are measured simultaneously or simultaneously according to the measurement point. These tools are measured simultaneously or simultaneously according to the measurement points at a predetermined time, to find out the facts that occurred in the field for 7 days fill in the measurement table and document it in the form of images as data to support research.

Table 2. Field Measurement Tool

Tool	Function Tool	Image
Anemometer	Used to measure air velocity.	
Temperature and Relative Humidity USB Data Logger	To measure the temperature and relative humidity of room air	
Weather Station	Weather observation test equipment. Observations using a weather station emphasize air pressure, temperature, humidity, wind speed, wind direction, rainfall, radiation,	

Source: Author

Measurement Time

The time of research was carried out on 19 – 25 July 2023, because in that month Indonesia is experiencing summer. After all, the sun is in the middle position based on the sun path diagram. Data was carried out for 7 days from 9.00 to 17.30. Measurements are carried out simultaneously or simultaneously according to the measurement point (Figure 3).

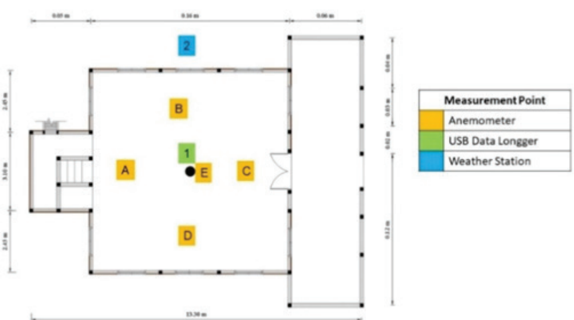

Figure 3. Measurement Point

Source: Author

Questionnaire

Evaluation of thermal comfort based on visitor perceptions was carried out by distributing a questionnaire in the form of questions asked to 30 respondents or visitors regarding thermal comfort at the Old Mosque Gunong Kleng, West Aceh (Table 3) to know visitor perceptions using the thermal sensation vote (TSV) method.

Table 3. TSV Questionnaire

Do you feel comfortable now? ☐ Comfortable (+2) ☐ Rather comfortable (+1) ☐ A bit uncomfortable (-1) ☐ Uncomfortable (-2)	What do you like to be about the air velocity? ☐ Increase velocity (+1) ☐ No change (0) ☐ Decrease velocity (-1)
How do you feel the air temperature right now? ☐ Cold (+3) ☐ Cool (+2) ☐ slightly cool (+1) ☐ Neutral (0) ☐ Slightly warm (-1) ☐ Warm (-2) ☐ Hot (-3)	How do you feel about the humidity in the room at this moment? ☐ Much too humid (+3) ☐ Too humid (+2) ☐ Slightly humid (+1) ☐ Just right (0) ☐ Slightly dry (-1) ☐ too dry (-2) ☐ Much too dry (-3)
What air temperature do you want? ☐ Cooler (+1) ☐ Unchanged (0) ☐ Warmer (-1)	What relative humidity do you want at this time? ☐ More humid (+1) ☐ Do not change (0) ☐ Drier (-1)
How do you feel about the air velocity in the room at this moment? ☐ Too still (+3) ☐ Still (+2) ☐ Slightly still (+1) ☐ Just right (0) ☐ Slightly breezy (-1) ☐ breezy (-2) ☐ Too breezy (-3)	How do you accept the current thermal environmental conditions? ☐ Very acceptable (-2) ☐ Acceptable (+1) ☐ Not acceptable (-1) ☐ Totally unacceptable (-2)

Source: Author

Limitations of the Study

This research has limitations, including being located in Gunong Kleng, West Aceh with the Qibla direction to the west. Apart from that, it only measures thermal comfort which consists of air temperature, wind speed, and humidity. The scope of measurements only consists of the inside and outside of the Old Mosque Gunong Kleng. Apart from that, the questionnaire is only addressed to visitors during the measurement process.

RESULTS

Mosque Thermal Performance

Air temperature (Ta)

When measuring the air temperature in the mosque room, 5 measurement points are using a Hot Wire Anemometer. The overall average result at all measurement points has a value of 30.37ºC. The highest air temperature value was 34.2ºC at 13.00 on day 6 and the lowest temperature behavior was 24.7ºC at points A and 2 at 10.00 on days 1 and 2. Overall the air temperature measurement in the mosque was based on SNI standards 036572-2001 in (Table 5) is dominated by 79% very uncomfortable hot, 11% uncomfortable hot, 7% comfortable warm, and 3% optimal comfortable.

One of the factors causing high air temperatures is the use of zinc or metal roof tiles, according to research (Sari, 2019; Ritva, 2017). So it does not provide thermal insulation or reduce the heat transfer rate. Apart from that, changes in the design of the roof cause wind to enter the building only through the windows. As in the case Novita (2023) there is no decrease in room temperature.

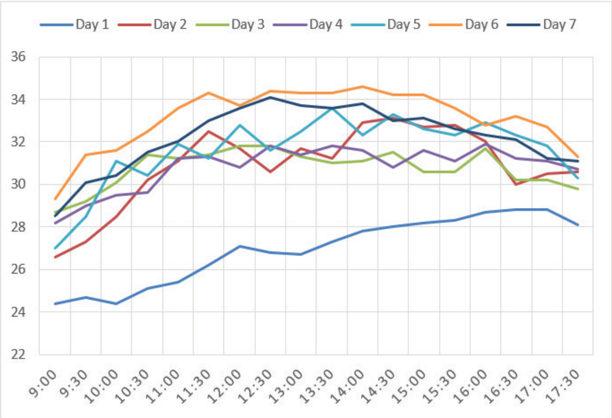

Figure 4.Air Temperature Measurement Results for 7 days

Source: Author

Table 4. Air Temperature (oC)

Point	Air temperature (oC)			Standard Deviation
	Average	Maximum	Minimum	
A	30.25079	34.1	24.7	2.14064
B	30.31984	34.2	24.7	2.157785
C	30.42381	34.1	24.9	2.181285
D	30.41667	34	24.9	2.125273
E	30.47302	34.1	24.9	2.153897

Source: Author

Table 5. Percentage of SNI 036572-2001 Air Temperature Comfort Level

Thermal Standards	Mark	Percentage
Cold	0	0%
Cool slightly cool	0	0%
Neutral	4	3%
Slightly warm	9	7%
Warm	14	11%
Hot	99	79%

Source: Author

Air Velocity (Av)

Wind speed inside a building is greatly influenced by the amount of airspeed outside the building. Apart from that, the dimensions of the openings and their location greatly influence the incoming airflow. Based on the measurement results (Table 6), the wind speed has met the optimal comfort standard. The highest indoor wind speed value is at point D with 0.967 m/s. This is caused by the door opening being large compared to the window on the other side, as well as the lowest wind speed being 0. The average wind speed is 0.21 m/s. Wind speed outside the building also influences entry into the building with an average of 0.39 m/s and a maximum of 1.7 m/s.

The use of a stepped roof covered with wood causes the wind flow not to enter from the roof but only through the windows, as in Novita (2023) which experienced changes in the roof ventilation design. So the air exchange from the roof is not maximized even though the air entering the mosque is sufficient. Different from the research of Indrayadi (2011), the direction of the wind coming from outside the building is from the southwest. Meanwhile, the Old Mosque Gunong Kleng is dominated by the east of the building (Figure 6). Because at point D in the mosque, there is a lot of wind the air distribution is uneven.

Table 6. Indoor Air Velovity Measurement Results (m/s)

Point	Air Velocity (m/s)			Standard Deviation
	Average	Maximum	Minimum	
A	0.17146	0.676	0	0.17146
B	0.218056	0.834	0	0.218056
C	0.253437	0.8	0	0.253437
D	0.278568	0.967	0	0.278568
E	0.152817	0.93	0	0.152817

Source: Author

Figure 5. The Direction of Wind Entry Is From Outside The Building
Source: Author

Relative Humidity (Rh)

The Old Mosque Gunong Kleng indoor humidity as shown inTable 7, averages 74.6% with a maximum value of 91.5% and a lowest value of 63.5%. Meanwhile, for outside the building, the average was 72.6% with a maximum of 95% and the lowest value of 59%. Based on the measurement results (Table 8), the relative humidity in the room complies with SNI 036572-2001 standards with 40% cool comfortable, 24% optimal comfort 15% almost comfortable, and 21% upper threshold.

Because this high relative humidity ratio in the morning and evening is common in equatorial countries and gradually decreases as the daytime air temperature increases (Khalit, et al. 2023). Air humidity with a natural ventilation system can be a natural cooling strategy needed in mosques (Rabul & Nugroho, 2020).

Table 7. Humidity Measurement Results (RH %)

Values	Indoor	Outdoor
Average	76.21825397	72.62302
Maximum	92	95
Minimal	63.5	59
Standard Deviation	7.795118546	7.945421

Source: Author

Table 8. Humidity According to SNI 033572-2001

Thermal sensation	Standart	Total	Percentage
Cool comfortable	50%-80%.	83	40%
Optimal comfort	70%-80%	51	24%
Almost comfortable	60%-70%.	32	15%
Upper Threshold	< 80%	43	21%

Source: Author

User Response to The Thermal Environment

Most visitors to the Tuha Gunong Kleng Mosque come from the local community. During this research, immigrants from outside the West Aceh area were also often visited. In general, the characteristics of visitors to the Tuha Gunong Kleng Mosque are dominated by older people aged > 36 years 55% female and 45% male (Table 9) due to the recitation or wirid performed at the mosque (Figure 6).

Aspects of thermal comfort felt by visitors as a whole, respondents felt somewhat comfortable when inside the mosque with 33% feeling somewhat warm. Meanwhile, users generally feel more neutral about comfort, with 67% accepting the thermal conditions at the Tuha Gunong Kleng Mosque.

Perception of the thermal environment of the sexes is influenced by clothing, resulting in different perceptions. Based on the results of the answers, male respondents wear long trousers and short-sleeved shirts. Meanwhile, women wear long robes with hijabs. Based on (Figure 7), the response to gender and clothing is dominated by slightly warm and warm for men. This value is not far from women who are slightly warm and neutral. So it can be concluded that women are more able to tolerate thermal conditions in the mosque compared to men.

Figure 6. Activities and Distribution of Questionnaires
Source: Author

Table 9. Gender, Age and Activity Respondents

Gender		Age		Activity	
Male	45%	17-20	3%	Visit	45%
Female	55%	21-25	10%	Recite	34%
		31-35	7%	Pray	21%
		36-40	34%		
		41-45	40%		
		46-50	3%		
		51-55	3%		

Source: Author

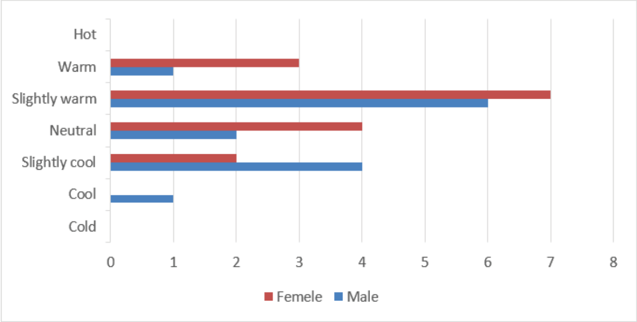

Figure 7. Responses of Women and Men to Thermal Comfort
Source: Author

Visitor Response to Thermal

Visitors' responses to the thermal environment regarding air temperature (Table 10) with results were slightly warm 44%, warm 20%, slightly cool 13%, and 3% cold and cool. Meanwhile, the desired change is more towards cold 50% and unchanged 50%. This is because visitors have adapted to their environment so that the body's heat reception can be tolerated.

At air velocity, the results were slightly breezy 46%, to breezy 27%, just right 20%, and slightly still 7%. Meanwhile, changes in wind speed conditions are desired, with 63% not changing and 37% changing to increase wind speed. This is caused by the large number of openings so that the air flow entering the building can be received by users.

Based on the interview results obtained from respondents, 53% were just right, 30% were slightly humid, 10 to humid, and 3% much too humid. Apart from that, acceptance of relative humidity shows that 70% accept or do not change the sensation of humidity in the room, while the remaining 30% want it to be more humid. This shows that the relative humidity is in accordance with the comfort of visitors and not many people want to change it.

Table 10. Results of TSV Respondents

User response to thermal comfort					
Air temperature		Air Velocity		Relative Humiditi	
Cold (+3)	3%	Too still (+3)	0%	Much too humid (+3)	3%
Cool (+2)	3%	Still (+2)	0%	Too humid (+2)	10%
slightly cool (+1)	17%	Slightly still (+1)	7%	Slightly humid (+1)	34%
Neutral (0)	20%	Just right (0)	20%	Just right (0)	53%
Slightly warm (-1)	44%	Slightly breezy (-1)	46%	Slightly dry (-1)	
Warm (-2)	13%	breezy (-2)	27%	too dry (-2)	
Hot (-3)	0%	Too breezy (-3)	0%	Much too dry (-3)	
Acceptance of thermal comfort					
Cooler (+1)	50%	Increase velocity (+1)	37%	More humid (+1)	30%
Unchanged (0)	50%	No change (0)	63%	Do not change (0)	70%
Warmer (-1)	0%	Decrease velocity (-1)	0%	Drier (-1)	0%

Source: Author

CONCLUSION

This research shows that the variable air temperature is not in accordance with comfort standards, but is different from wind speed and humidity which are already comfortably cool. However, it is inversely proportional to the respondent's perception of the thermal environment because it can receive air temperature, wind speed, and air humidity in the Tuha Gunong Kleng Mosque.

The results of field measurements can be analyzed for thermal comfort where the air temperature variable does not meet the SNI 036572-2001 thermal comfort standard of 79% which is still categorized as slightly warm with an average air temperature of 30.4º. Wind speed and humidity in the building have met optimal comfort standards.

Based on the results of a questionnaire regarding the overall thermal comfort felt by visitors, respondents felt slightly warm 44% and neutral 20%. Meanwhile, users' acceptance of the thermal environment is more neutral with 67% accepting the thermal conditions, 22% not accepting, 7% very acceptable, and 3% very unacceptable thermal conditions.

Based on the results of this research, it is hoped that in future research, we can add strategies for implementing thermal comfort using digital simulation analysis so that we can choose strategies for using design forms and materials that are appropriate to historical mosques to create better thermal comfort.

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AUTHOR CONTRIBUTIONS

All authors contributed to the planning and research process including data observation, data analysis, and writing. All authors have also read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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