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Thermal Comfort Evaluation of Baitul Makmur Mosque in Kapuas Coastal Area

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Abstract—Thermal comfort is a critical factor in supporting worship activities in mosque buildings, particularly in humid tropical coastal environments. Masjid Baitul Makmur, located along the Kapuas River in Pontianak, experiences significant thermal discomfort due to high temperature and humidity levels. This study aims to evaluate existing thermal conditions and formulate appropriate passive design strategies. A quantitative approach was applied through field measurements and Computational Fluid Dynamics (CFD) simulation. Thermal data, including air temperature, relative humidity, and airflow velocity, were collected over 30 consecutive days at five daily prayer times. The results were analyzed based on ASHRAE 55 standards. The findings indicate that indoor temperatures exceed comfort limits, reaching 32–35°C during the afternoon (Ashar), while relative humidity remains high at 65–85%. The rear zone was identified as a stagnant airflow pocket with heat accumulation. Airflow measurements show that wind potential from the Kapuas River is not effectively utilized, resulting in poor cross-ventilation. CFD simulation confirms uneven airflow distribution. The main cause of thermal discomfort lies in the building's inability to capture and distribute airflow effectively. Passive strategies such as full-height louver openings, improved upper ventilation, and shaded verandas are proposed to enhance airflow and reduce heat accumulation.

Keywords: thermal comfort; passive design; coastal mosque; humid tropical climate.

1. Introduction

Mosques serve as primary worship facilities for Muslim communities and require adequate environmental quality to support spiritual activities. Indoor environmental comfort, particularly thermal comfort, plays a significant role in maintaining concentration and worship performance (Gunawan, 2021). In humid tropical climates, achieving thermal comfort becomes challenging due to high air temperature and relative humidity levels.

Thermal comfort is defined as a condition of mind expressing satisfaction with the surrounding thermal environment (Fanger, 1970). Several environmental factors influence thermal comfort including air temperature, humidity, airflow, and radiant heat, while personal factors such as clothing and activity level also contribute significantly (Santoso, 2012).

Many mosque buildings in tropical regions rely on natural ventilation as a primary cooling strategy. Passive design approaches such as cross-ventilation, shading elements, and appropriate material selection are widely recognized as effective strategies to improve thermal performance in hot-humid climates (Kalandara, 2023). However, previous studies mostly focus on urban or highland mosque environments, while research on coastal humid tropical mosque architecture remains limited.

Masjid Baitul Makmur, located along the Kapuas River, represents a typical coastal mosque exposed to high humidity and solar radiation throughout the year. The mosque originally utilized timber materials and natural ventilation systems that provided adequate cooling performance. Recent renovations replaced traditional materials with masonry walls and metal roofing, which potentially increased heat absorption and reduced ventilation effectiveness.

This research aims to evaluate the existing thermal comfort conditions of Masjid Baitul

Makmur and develop passive design strategies suitable for humid tropical coastal environments. The novelty of this research lies in integrating empirical field measurement with airflow simulation to produce context-specific passive design recommendations for coastal mosque buildings.

However, most previous studies focus on mosque buildings located in urban or highland environments, while studies addressing thermal performance in humid tropical coastal areas remain limited. Coastal environments such as the Kapuas River area present unique challenges due to high humidity levels, strong solar radiation, and dynamic airflow patterns influenced by river breezes.

Therefore, this study offers a contextual approach by focusing on a coastal mosque building and integrating empirical field measurement with CFD simulation. This combination allows a more accurate understanding of thermal behavior and airflow patterns, providing site-specific passive design recommendations.

2. Methods

This study applied a quantitative research approach combining field measurement and computational simulation to evaluate thermal performance and airflow behavior in the mosque building. Field measurements were conducted at Masjid Baitul Makmur over a 30-day period. Air temperature and relative humidity were measured using thermohygrometers, while airflow velocity was measured using anemometers. Measurement devices were placed at six representative interior points including front, middle, and rear prayer hall zones.

Data collection was conducted during five daily prayer periods to capture thermal variation throughout the day. The collected data were analyzed descriptively and compared with ASHRAE 55 thermal comfort standards (Ashrae, 2020). The airflow measurement and ventilation performance evaluation conducted in this study refer to Indonesian national standards for ventilation system design in buildings. The standard provides guidelines for airflow performance assessment and ventilation effectiveness in naturally ventilated buildings (Indonesian National Standard, 2001).

Computational Fluid Dynamics (CFD) simulation was conducted to analyze airflow distribution inside the mosque building. Simulation scenarios included land wind during daytime, river wind during afternoon, and river wind during nighttime. The simulation results were validated using field measurement data to ensure accuracy and reliability. CFD simulation was conducted using Autodesk CFD software. The simulation was performed under three environmental scenarios: daytime land wind, afternoon river wind, and nighttime river wind. Airflow velocity inputs were based on field measurements, while temperature values were adjusted according to empirical data to represent actual thermal conditions.

The simulation aimed to analyze airflow distribution, identify stagnant zones, and evaluate the effectiveness of natural ventilation. Validation was conducted by comparing simulation results with field measurement data, ensuring consistency between modeled and actual airflow behavior.

3. Results and Discussion

Baitul Makmur Mosque is located in Bansir Laut coastal settlement directly adjacent to the Kapuas River. The building environment is influenced by river airflow patterns, high solar radiation, and humid tropical climate conditions.

Existing Thermal Condition of Baitul Makmur Mosque

Field observation indicates that the mosque has undergone structural renovation compared to its original form. The original building used timber walls and ulin shingle roofing, which provided natural thermal insulation and ventilation performance. The renovation replaced these materials with masonry walls and metal roofing, which significantly changed the thermal behavior of the building envelope.

Figure 1. Site condition of Baitul Makmur Mosque adjacent to Kapuas River
Source: Fitriyanto, et.al, 2025

Thermal measurements were conducted using digital thermohygrometers installed at six representative interior measurement points covering the front, middle, and rear zones of the prayer hall.

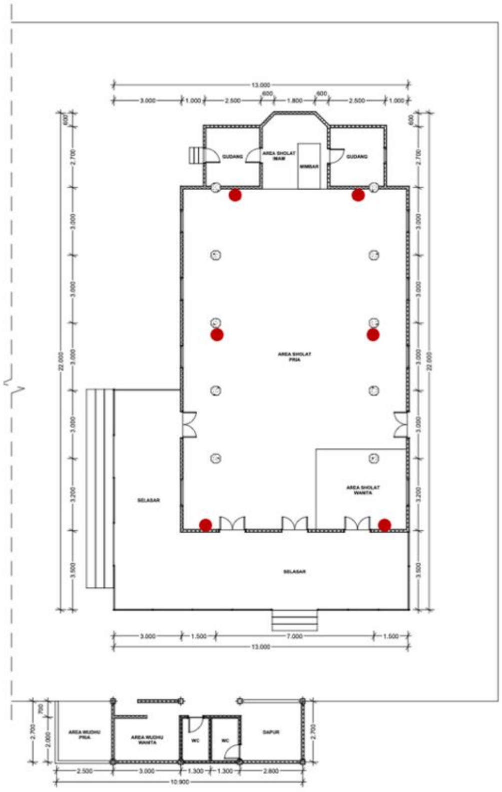

Figure 2. Placement of thermal measurement instruments inside mosque
Source: Fitriyanto, et.al, 2025

Thermal data were recorded continuously for 30 days during five daily prayer periods. The results show that thermal conditions inside the mosque consistently exceed thermal comfort limits.

Temperature and Relative Humidity Distribution

Heatmap analysis of daily temperature measurements indicates that indoor temperature remains generally high throughout the observation period. The temperature during Subuh prayer already shows warm indoor conditions and gradually increases during daytime periods. The most critical thermal discomfort occurs during Ashar prayer, where indoor temperature frequently reaches between 32°C and 35°C. Even during Magrib and Isya prayers, indoor temperature remains relatively warm, indicating delayed heat dissipation caused by high thermal storage behavior of masonry walls and metal roofing materials.

The transformation of building materials from timber to masonry walls and metal roofing significantly contributes to heat accumulation. Materials with high thermal mass absorb solar heat during the day and release it slowly at night (heat lag effect), which explains why indoor temperatures remain above 31°C even during evening prayer times.

Average Temperature Distribution

The results indicate that peak thermal conditions occur during Ashar prayer, particularly in the rear zone of the mosque. The persistence of elevated temperature during evening prayer periods confirms slow heat release behavior from the building envelope. The rear zone of the mosque consistently functions as a stagnant airflow pocket, where both temperature and humidity reach their highest levels. This condition is caused by the failure of cross-ventilation, resulting in limited air exchange and accumulation of heat and moisture.

Table 1. Average Temperature Distribution Based on Prayer Time

Prayer Time	Average Temperature
Subuh	±27°C
Zuhur	±31°C
Ashar	±33°C
Magrib	±31–32°C
Isya	±31°C

Sources: Fitriyanto, et al., 2025.

Average Relative Humidity Distribution

Relative humidity analysis also shows consistently high moisture levels throughout daily cycles. The highest humidity occurs during Subuh prayer, often exceeding 85%, while the lowest humidity occurs during Ashar prayer, averaging approximately 70%. However, humidity levels never fall below 65%, indicating persistent humid conditions inside the building.

Table 2. Average Relative Humidity Distribution Based on Prayer Time

Prayer Time	Average Relative Humidity
Subuh	>85%
Zuhur	65–75%
Ashar	±70%
Magrib	>70%
Isya	>70%

Sources: Fitriyanto, et al., 2025.

The mosque's location adjacent to the Kapuas River contributes significantly to high humidity levels, creating a sensation of thermal discomfort even when temperature decreases. Spatial analysis reveals uneven temperature and humidity distribution across interior zones. The rear zone consistently records the highest thermal values, indicating the formation of stagnant airflow pockets. These stagnant zones trap heat and moisture due to insufficient natural ventilation and airflow obstruction caused by building configuration.

Airflow Pattern Analysis

Airflow measurement was conducted to evaluate natural ventilation performance inside the mosque building. The airflow behavior observed in this study is consistent with previous research showing that mosque buildings in tropical regions rely heavily on natural ventilation performance to maintain indoor comfort (Rahman, et al., 2019).

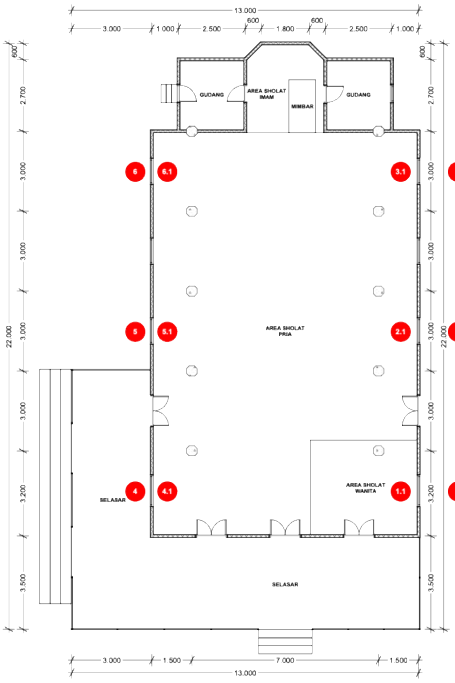

Figure 3. Airflow measurement points inside and outside mosque
Source: Fitriyanto, et.al, 2025

Wind speed measurement results show that strong airflow potential originates from the river direction during afternoon periods. However, airflow velocity inside the building significantly decreases, indicating ineffective cross ventilation.

Table 3. Average Airflow Velocity Measurement

Measuremment Location	Average Air Velocity
Exterior River Side	High
Interior Front Zone	Moderate
Interior Rear Zone	Low

Sources: Fitriyanto, et al., 2025.

Airflow velocity increases during nighttime periods, which indicates stack effect ventilation where warm indoor air exits through upper openings and cooler outdoor air enters through lower openings.

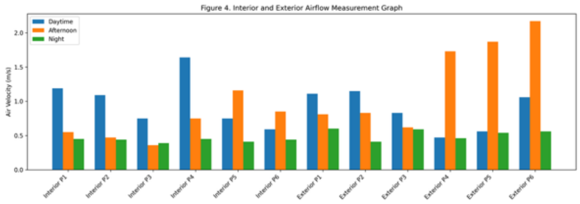

Figure 4. Interior and exterior airflow measurement graph
Source: Fitriyanto, et.al, 2025

Although strong wind potential from the Kapuas River is available during the afternoon, the building fails to capture and distribute this airflow effectively. This indicates that the main issue is not environmental limitation, but architectural configuration. This finding is consistent with previous studies showing that airflow plays a critical role in achieving thermal comfort in naturally ventilated buildings, particularly in tropical climates where air movement significantly influences heat dissipation and occupant comfort (Rijal, et al., 2021).

Occupant Density and User Perception

Thermal comfort inside the mosque is also influenced by congregation density and user behavior.

Table 4. Congregation Density During Prayer Time

Prayer Time	Average Occupancy
Daily Prayer	20-40 worshippers
Interior Rear Zone	±70 worshippers

Sources: Fitriyanto, et al., 2025.

Higher occupancy significantly increases metabolic heat gain, contributing to elevated indoor temperature. User perception analysis involving mosque worshippers confirms measured environmental conditions.

Table 5. User Thermal Comfort Perception

Comfort Level	Percentage
Comfortable	13%
Less Comfortable	60%
Uncomfortable	27%

Sources: Fitriyanto, et al., 2025.

Most respondents identify poor airflow and heat radiation from roofing materials as primary causes of thermal discomfort.

CFD Airflow Simulation Analysis

CFD simulation was conducted to visualize airflow behavior under three environmental wind scenarios.

Daytime Land Wind Scenario

Simulation results demonstrate uneven airflow distribution inside the mosque. Airflow velocity decreases significantly after entering building openings, forming stagnant airflow zones corresponding with areas of highest temperature concentration.

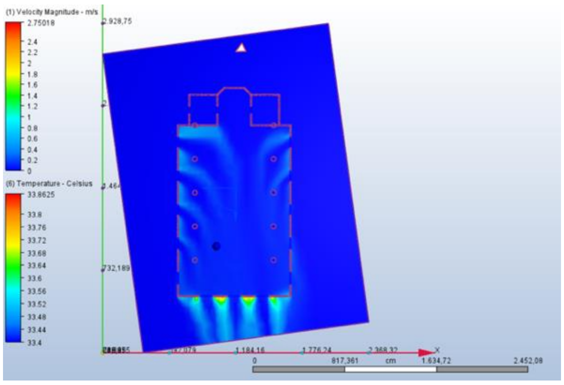

Figure 5. CFD simulation of daytime land wind airflow pattern
Source: Fitriyanto, et.al, 2025

Afternoon River Wind Scenario

CFD simulation confirms that airflow inside the mosque building is ineffective due to building configuration and limited ventilation openings. Similar findings have been reported in mosque thermal comfort studies where natural ventilation plays a dominant role in indoor environmental performance (Indonesian National Standard, 2011).

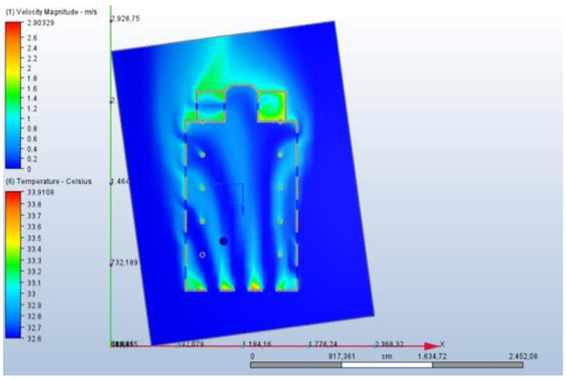

Figure 6. CFD simulation of afternoon river wind airflow pattern
Source: Fitriyanto, et.al, 2025

Night Time River Wind Scenario

Nighttime simulation shows improved vertical airflow circulation through stack effect ventilation. Although this airflow circulation supports gradual cooling, it remains insufficient to offset daytime heat accumulation. The increased airflow observed during nighttime is attributed to stack effect ventilation, where warm air rises and exits through upper openings while cooler air enters from lower openings. This natural mechanism contributes to gradual cooling (night flushing), although it is insufficient to offset daytime heat accumulation.

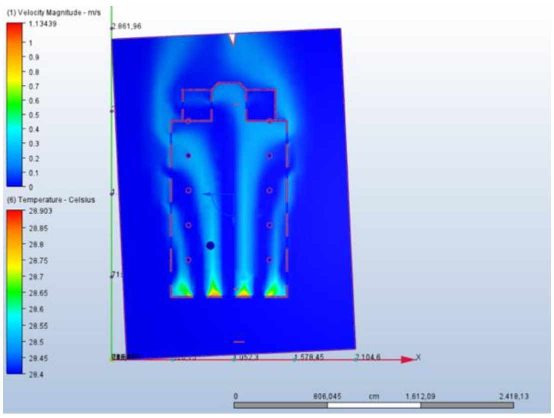

Figure 7. CFD simulation of night time river wind airflow pattern
Source: Fitriyanto, et.al, 2025

Passive Design Implications

Based on empirical measurement, airflow analysis, and simulation results, passive design improvements are proposed to enhance natural ventilation performance and reduce heat accumulation. Passive cooling strategies have been widely recognized as effective approaches to improve thermal performance in tropical buildings (Nguyen, et al., 2020).

Figure 8. Existing window opening condition
Source: Fitriyanto, et.al, 2025

The recommended strategies include optimizing cross ventilation openings, improving upper ventilation outlets, and adding shaded veranda spaces as thermal buffer zones. These interventions are expected to improve airflow distribution and reduce solar heat gain inside the mosque. These findings support previous studies emphasizing the importance of passive cooling strategies such as ventilation optimization and shading in tropical climates (Nguyen, et al., 2020).

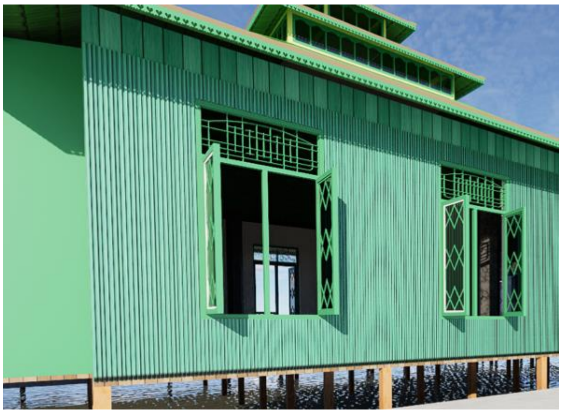

Figure 9. Proposed full-height louver window design
Source: Fitriyanto, et.al, 2025

Figure 10. Proposed veranda shading addition
Source: Fitriyanto, et.al, 2025

4. Conclusion

This study evaluates the thermal comfort performance of Baitul Makmur Mosque located in the coastal area of the Kapuas River, Pontianak. Field measurements and airflow simulations indicate that the mosque consistently experiences thermal discomfort due to high indoor temperature and relative humidity levels. The highest thermal stress occurs during afternoon prayer periods when indoor temperature frequently exceeds thermal comfort thresholds, while humidity levels remain persistently high throughout daily prayer cycles. This condition is strongly influenced by the building materials used, as materials with high thermal mass tend to store heat during the day and release it gradually at night, contributing to delayed heat dissipation (heat lag effect).

The results demonstrate that renovation changes from traditional timber construction to masonry walls and metal roofing significantly contribute to heat accumulation inside the building. Additionally, the existing natural ventilation system is unable to distribute airflow effectively, particularly in the rear zone of the prayer hall, resulting in stagnant airflow pockets and uneven thermal distribution.

Airflow measurement and CFD simulation confirm that although the mosque is located in a wind-rich coastal environment, the current building configuration fails to utilize the available natural airflow potential. Stack effect ventilation contributes to partial cooling during nighttime periods but remains insufficient to reduce daytime thermal discomfort. This finding highlights the importance of climate-responsive design, in which building configuration should be aligned with local environmental conditions to achieve optimal thermal comfort in tropical climates.

Based on the empirical findings, passive design improvements such as optimization of cross-ventilation openings, enhancement of upper ventilation outlets, and addition of shaded veranda elements are recommended to improve indoor thermal performance. These passive strategies provide sustainable and context-sensitive solutions for mosque buildings located in humid tropical coastal environments.

This study contributes to the development of passive thermal design knowledge for religious buildings in coastal tropical regions and provides practical design recommendations for future mosque renovation and architectural planning.

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