International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 14 Issue 8 ǁ August 2026 ǁ PP. 87-101

The role of wall materials in the thermal conditions of mosque prayer halls in the equatorial tropics: a case study of Nurul Yaqin Mosque, Palu City, Indonesia

Mohammad Yusuf[1], Anne Rufaida[1], Puteri Fitriaty[1, 2*], Andi Jiba Rifai Bassaleng[2], Nur Rahmanina Burhany[2]
[1*]*Master of Architecture Study Program, Faculty of Engineering, Tadulako University, Palu, Indonesia*
[2]*Department of Architectural Engineering, Faculty of Engineering, Tadulako University, Palu, Indonesia*
Corresponding Author: puteri_fitriaty@yahoo.com; puteri.f@untad.ac.id

Abstract
This study aims to evaluate the performance of wall materials as building envelope in relation to the thermal comfort of interior spaces at the Nurul Yaqin Islamic Center Mosque in Palu. The research method used is descriptive quantitative with a case study approach, combining primary data—such as observations and measurements of air temperature, humidity, and wall surface temperature—with secondary data, including climate data and technical building documents. The research results show that wall cladding made of red brick with a cement plaster finish and light-colored paint has moderate thermal conductivity (0.72 W/mK) at a thickness of 25 cm. Temperature measurements show that during the day, the surface temperature of the exterior wall reaches 34.47°C and the indoor temperature reaches 30.40°C, which are above the thermal comfort limits. This study indicates that the walls play a major role in heat transfer into the room, especially when solar radiation intensity is high. This study highlighting the importance of selecting the right materials and implementing passive design strategies to support thermal comfort in buildings, particularly in mosques located in humid tropical climates such as the city of Palu.
Keywords: *Thermal comfort, Wall cladding materials, Mosques, Tropical climate, Case study.*

Date of Submission: 05-08-2026 Date of acceptance: 17-08-2026

I. INTRODUCTION

A building's thermal performance is a key factor in ensuring occupant comfort, particularly in public buildings such as mosques. As places of worship, mosques have distinct spatial usage characteristics compared to other buildings; their large capacity and the duration of certain activities require a thermally comfortable environment without over-reliance on mechanical systems [1, 2, 3]. This becomes even more important for mosques located in humid tropical climates, such as the city of Palu in Central Sulawesi, which has relatively high air temperatures, humidity and radiation throughout the year [4]. Thus, it became evident that common issue with mosque buildings in tropical climates is suboptimal thermal performance [2].

One of the dominant factors affecting thermal performance is the building envelope material, particularly the walls [5, 6]. Walls serve as protective elements that are directly exposed to solar radiation and act as a medium for heat transfer from the exterior to the interior [7, 8]. The thermal characteristics of wall cladding materials—such as thermal conductivity, heat capacity, and thickness—significantly influence how much heat enters the interior and how quickly the walls release that heat [9, 10]. Materials with poor insulation properties will cause heat to accumulate inside the space, thereby reducing thermal comfort.

The Nurul Yaqin Islamic Center Mosque in Palu, one of the region's iconic mosques, exemplifies a building that faces the challenges of a humid tropical climate. The mosque was designed using a combination of modern and conventional materials, as evident in its wall elements. However, the thermal performance of the wall cladding materials used, as well as their impact on the thermal comfort of the prayer space, has not yet been extensively studied.

Given these circumstances, this study aims to evaluate the performance of wall cladding materials at the Nurul Yaqin Islamic Center Mosque in Palu City in terms of indoor thermal comfort. The evaluation was conducted by measuring room and wall surface temperatures and analyzing the thermal characteristics of the materials. This study providing a better understanding of the role of wall materials in supporting thermal comfort in mosque buildings in tropical equatorial climates and to serve as a basis for consideration in the design or renovation of similar buildings in the future.

As the buildings with both social and spiritual functions, mosques require a high level of indoor comfort, particularly in terms of thermal comfort. This poses a challenge for mosques located in humid tropical regions such as the city of Palu, which experiences relatively high air temperatures and significant humidity levels throughout the year. One of the key factors that influencing indoor thermal comfort is the wall material [6]. Wall materials serve not only as room dividers but also as elements that absorb, conduct, or block heat from the outside into the building. Materials with inadequate thermal characteristics can cause heat to accumulate during the day, causing indoor temperatures to rise and creating an uncomfortable environment for occupants [11].

The Nurul Yaqin Islamic Center Mosque in Palu City uses a combination of modern materials for its wall elements; however, it is not yet known exactly how these materials perform thermally in terms of supporting indoor comfort within the mosque. Given this situation, questions arise regarding the physical and thermal characteristics of the wall cladding materials used, as well as their impact on indoor temperature and thermal comfort for worshippers.

Therefore, the research questions for this study can be stated as follows:

1. What are the physical and thermal characteristics of the wall covering materials used at the Nurul Yaqin Islamic Center Mosque in Palu City?
2. How do these wall covering materials affect the thermal comfort of the interior space in a mosque?

These research questions serve as the basis for a comprehensive evaluation of the thermal performance of wall materials and their relationship to thermal comfort inside the mosque, thereby identifying potential improvements or developments in terms of building materials and design.

This study aims to evaluate the extent to which the wall cladding materials at the Nurul Yaqin Islamic Center Mosque in Palu City contribute to the thermal comfort of the interior space. The primary focus of this study is to analyze the physical and thermal characteristics of the wall materials used, as well as to measure and evaluate their impact on the thermal conditions inside the mosque's main hall. Through this approach, the study aims to understand the relationship between material properties—such as thermal conductivity, thickness, and surface finish—and the thermal performance of interior spaces, particularly in terms of reducing or retaining heat from the external environment. In addition, this research aims to assess the extent to which currently available wall covering materials are capable of meeting thermal comfort standards, both based on international standards such as ASHRAE and adaptations of these standards for the local tropical climate.

More specifically, the objectives of this study are:

1. To analyze the physical and thermal characteristics of the wall cladding materials used at the Nurul Yaqin Islamic Center Mosque in Palu.
2. To evaluate the contribution of wall cladding materials to the thermal comfort of the mosque's interior spaces, based on measurements of temperature, humidity, and applicable thermal comfort standards.

The results of this study are expected to serve as a basis for recommendations regarding the improvement of thermal performance through the selection of more suitable materials or improvements to the design of wall elements, to support the creation of a thermally comfortable worship space in a humid tropical climate.

This research contributes by enriching the field of architecture, particularly in the areas of building materials and thermal performance. These results can serve as a scientific reference for the development of building designs that take into account the thermal performance of materials, especially in places of worship such as mosques located in tropical climates. Additionally, it can serve as a foundation for further research related to the optimization of building materials to support passive thermal comfort. Furthermore, this study provides information and recommendations for designers, building managers, developers, and other relevant stakeholders in selecting and applying wall covering materials that can effectively support a building's thermal comfort. Specifically for the management of the Nurul Yaqin Islamic Center Mosque, the results of this study can serve as a basis for consideration when carrying out repairs, maintenance, or building improvements to enhance comfort for worshippers. In addition, the practical benefits can be more widely applied as a reference in designing or renovating mosques and other public buildings in tropical regions, to create comfortable spaces through a design approach that is more climate-friendly and energy-efficient.

1.1 Thermal Comfort in Tropical Buildings

Thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment [12]. In a humid tropical climate such as that of Palu, the main challenge to thermal comfort is the high air temperature and relative humidity, which can cause discomfort, particularly during the day when solar radiation is intense [13]. According to [14], thermal comfort in buildings in tropical climates is influenced by four main parameters: air temperature, relative humidity, wind speed, and heat radiation. Passive design strategies—such as the selection of building materials, building orientation, cross-ventilation, and shading—play a significant role in controlling indoor thermal conditions. Procedures for the Design of Ventilation and Air

Conditioning Systems in Buildings in Indonesia also emphasizes the importance of controlling external heat loads—particularly through wall and roof elements—to achieve thermal comfort [15].

1.2 The Role of Wall Materials in Thermal Performance

Wall materials play a vital role in controlling the heat that enters a building. Walls, as boundary elements, serve as protection against direct exposure to solar radiation and as a medium for the conductive transfer of heat from the exterior into the interior space. The thermal characteristics of building materials are influenced by several parameters [16], namely:

- Thermal conductivity (k): A material's ability to conduct heat. The lower the k value, the better the material is at resisting heat transfer.
- Heat capacity (Cp): A material's ability to absorb and store heat.
- Thermal mass: High-density materials tend to absorb and release heat slowly, thereby helping to stabilize temperature fluctuations.
- Material thickness: Increases resistance to heat flow.

Materials with low thermal conductivity and high heat capacity, such as bricks or lightweight blocks, can help slow the rate at which heat transfers from the outside into the space [17], although in humid tropical climates, heavy materials can also cause heat to be released at night if not accompanied by adequate ventilation [17]. A study by Santamouris [18] shows that walls with light-colored finishes can reflect more solar radiation than dark-colored ones, thereby reducing the wall's surface temperature by up to 10°C.

1.3 Tropical Building Design Strategies and Thermal Performance

The principles of tropical building design emphasize controlling heat gain through building orientation, ventilation openings, the use of shading, and the selection of appropriate materials. For wall elements, choosing the right materials can reduce cooling loads and improve thermal comfort [19]. According to Yeang [20], the principles of bioclimatic architecture recommend the use of well-insulated materials or materials with high thermal mass, combined with cross-ventilation, to mitigate heat loads in tropical climates.

1.4 Previous Research

Some previous studies relevant to this topic include:

- [21] investigated the thermal performance of wall materials in educational buildings in Surabaya. The results showed that red brick with cement plaster contributed significantly to the rise in indoor temperature during the day.
- [22] evaluated thermal comfort in traditional mosques in Makassar and found that wooden materials with cross-ventilation provide better comfort than concrete materials.
- [23], in their study of tropical coastal regions, found that the use of light-colored natural stone with a rough finish can contribute to lowering surface temperatures compared to plain concrete walls.

1.5 Framework

Based on the literature review above, it can be concluded that a building's thermal performance is also influenced by the physical and thermal characteristics of the wall cladding materials. In the context of the Nurul Yaqin Islamic Center Mosque, evaluating the performance of wall materials is crucial for determining the extent to which these materials contribute to maintaining the thermal comfort of the interior spaces. This study will analyze the relationship between material characteristics (thermal conductivity, heat capacity, thickness, and finish) and indoor thermal conditions based on measurement results and thermal comfort standard analysis.

Figure 1 illustrates the relationship between humid tropical climate conditions, heat exposure, wall material characteristics, wall thermal performance, and their impact on indoor thermal comfort. The evaluation results will be used to provide recommendations for material design and strategies to improve thermal comfort.

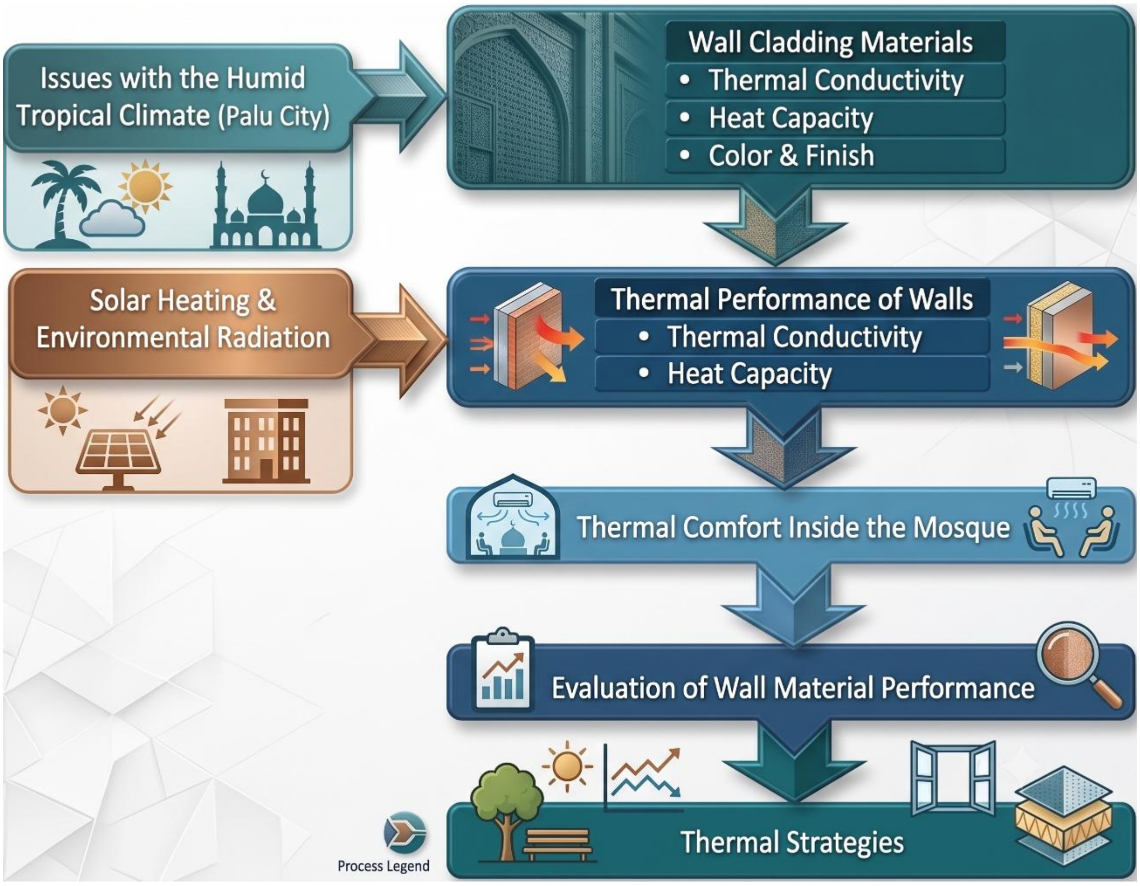


Figure 1: Conceptual Framework Diagram

II. RESEARCH METHOD

This study employs a descriptive quantitative approach using the case study method. The quantitative approach is used to obtain objective and measurable numerical data, particularly regarding the thermal conditions of the room and the characteristics of the wall covering materials. The data obtained from measurements of room temperature, wall surface temperature, and other environmental parameters will be statistically analyzed to accurately describe the thermal performance conditions. The descriptive approach aims to describe, explain, and interpret the existing conditions of the Nurul Yaqin Islamic Center Mosque building, particularly with regard to how wall cladding materials contribute to the thermal comfort of the interior spaces. This study does not manipulate any variables but rather analyzes the existing conditions based on data obtained from direct observations and measurements.

The case study method was chosen because the research focuses on a single building in depth and comprehensively. A case study allows researchers to evaluate in detail the building's physical characteristics, the condition of its materials, and its thermal performance within the context of the local climate. The results of this case study are expected to serve as a model or reference for similar buildings located in humid tropical climates. Using a descriptive quantitative approach and case studies, this research provides a concrete picture of how the characteristics of wall cladding materials affect the thermal comfort of the worship space at the Nurul Yaqin Islamic Center Mosque and offers data that can serve as a basis for improvements or the development of more climate-friendly building designs.

2.1 Research Location

The research location is the Nurul Yaqin Mosque, situated on Trans Sulawesi Road between Kebonsari and Tawaeli, Mamboro, North Palu District, Palu City, Central Sulawesi (Figure 2). The mosque covers an area of 2,220 m²; its architects were Dave Orlando and Fandy Gunawan.

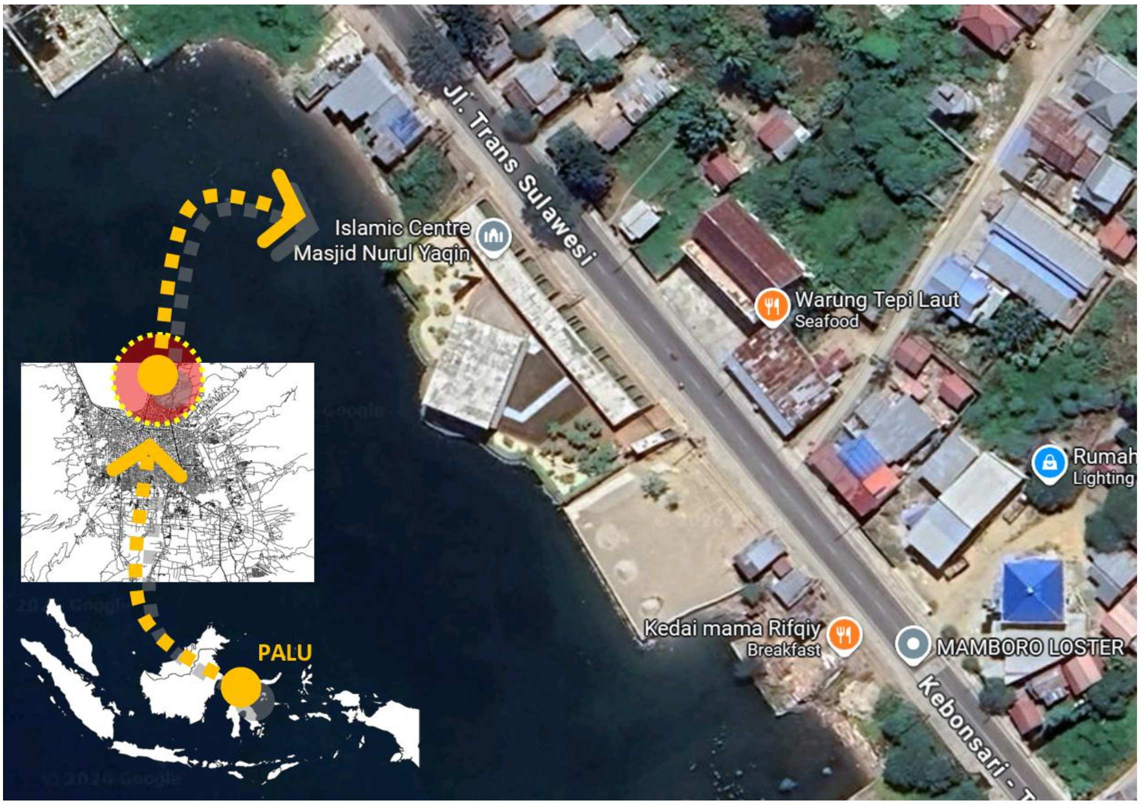


Figure 2: Research Location

2.2 Research Variables

In this study, research variables were formulated to support the analysis of wall covering materials' performance regarding indoor thermal comfort. The research variables consist of two main groups: independent variables and dependent variables (Table 1). Independent variables that influence the thermal comfort of interior spaces. Meanwhile, the dependent variable is the result or condition influenced by the independent variables, Control Variables To ensure data accuracy, control variables were also applied. By defining these variables, this study aims to understand the relationship between the characteristics of wall covering materials and the thermal comfort conditions inside the mosque in an objective and measurable manner (Table 1).

Table 1: Variable Considered in the study

Independent variables		Dependent Variable
Type of wall covering material	Thermal conductivity (W/mK)	Indoor air temperature (°C)
	Heat capacity of the material (J/kg·K)	Interior and exterior wall surface temperature (°C)
	Material thickness (cm)	Relative humidity (%RH)
	Wall color and surface finishing roughness b (reflective or absorptive)	Thermal comfort index, for example, as defined by ASHRAE Standard 55 or SNI 03-6572-2001.

2.3 Data Collection Methods

Data collection in this study was conducted using two main approaches: primary data collection and secondary data collection. These two types of data complement each other to provide a comprehensive picture of the performance of wall covering materials regarding thermal comfort at the Nurul Yaqin Islamic Center Mosque in Palu.

1. Primary Data Collection

Primary data was collected directly from the research site through field observations and physical measurements which included, field observation and physical and environmental measurement. Observation was conducted on physical condition of the building, particularly the wall elements. Observations include the type of materials, surface condition, exterior and interior finishes, and the orientation of the walls relative to the direction of solar radiation. At the same time, physical and environmental measurements were conducted to record thermal condition of prayer hall and surface temperature of walls which include indoor air temperature (T_i), interior and exterior wall surface temperatures (T_{sf}), relative humidity (RH), and indoor air velocity (v_i).

The measurements were performed at specific times (morning, noon, and afternoon) to determine thermal fluctuations throughout the day. The measuring instruments used include:

- Infrared thermometer (IR Thermometer) or thermal camera to measure the surface temperature of walls.
- Onset HOBO Data Logger for continuously recording temperature and humidity, if necessary.
- Fogger machine to visually observe the indoor air flow through smoke decay method.
- Digital anemometer to measure wind speed.
- Digital Camera used to capture the physical condition of the building, the condition of wall materials, openings, and the building's surrounding environment to support visual analysis in the study

Material Observations were done for technical data collection on wall material types, thickness, finishes, and existing conditions. This data is obtained through visual observation, direct measurement, confirmation with mosque management and the building contractor.

2. Secondary Data

Secondary data is collected from various relevant supporting sources, such as: 1) technical building documents (shop drawings, material specifications, and mosque construction documents); 2) climatic data for the city of Palu, including average air temperature, humidity, and daily solar radiation data from the Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG), 3) previous literature and studies discussed the characteristics of building materials and their thermal performance, whether from scientific journals, books, or technical standards such as ASHRAE or SNI.

3. Time and Frequency of Measurements

Measurements were taken on days with clear weather to ensure maximum solar radiation. Measurements were taken at several time intervals—morning (around 9:00 a.m.), noon (around 1:00–2:00 p.m.), and afternoon (around 4:00–5:00 p.m.)—to capture temperature changes throughout the day. This data collection method aims to obtain accurate information regarding the relationship between the characteristics of wall materials and indoor thermal comfort, so that it can be analyzed and developed into design recommendations or selections of materials that are more suitable for buildings in humid tropical climates.

2.4 Analysis Methods

Data analysis in this study was conducted using descriptive quantitative methods, with the aim of describing the relationship between the characteristics of wall covering materials and the thermal comfort conditions inside the mosque. The analysis process involved the following steps (Figure 3):

1. Analysis of Wall Covering Material Characteristics
   Data from observations and measurements of the materials were analyzed to determine their physical and thermal properties, including thermal conductivity, heat capacity, thickness, and surface finish type. If specific technical data on the material is not available, estimates will be made based on standard values for thermal conductivity and heat capacity from the literature or technical references (e.g., SNI, ASHRAE, or relevant scientific journals).
2. Thermal Environmental Data Analysis
   Data on air temperature, wall surface temperature (interior and exterior), and relative humidity are analyzed to identify temperature fluctuation patterns throughout the day (morning, afternoon, and evening). Measurement results are compared between walls directly exposed to sunlight and those not exposed, to identify differences in thermal performance based on wall orientation.
3. Indoor Thermal Comfort Analysis
   Air temperature and relative humidity data were analyzed using thermal comfort standards, such as: ASHRAE Standard 55 [12] and SNI 03-6572-2001 [15] on procedures for the design of ventilation and air conditioning. The analysis is performed by plotting temperature and humidity conditions on a psychrometric chart, or by using formulas to calculate thermal comfort indices such as the Thermal Comfort Zone or Effective Temperature (ET). An evaluation is performed to determine whether indoor conditions fall within the comfort zone or not, as well as to identify specific times when the space is most comfortable or least comfortable.
4. Analysis of the Relationship Between Materials and Thermal Performance
   Analyze the relationship between material characteristics (such as color, material type, thickness, and finish) and wall surface temperature and indoor air temperature. Comparing results between walls with different orientations and conditions, for example, west- facing walls (exposed to afternoon sun) compared to north- or south-facing walls.
5. Interpretation and Formulation of Recommendations
   Based on the analysis results, an interpretation is conducted to understand the extent to which wall covering materials influence an increase or decrease in indoor temperature. Formulation of recommendations

regarding material selection, finishing improvements, or additional design strategies (such as the addition of shading or vegetation) to enhance the thermal comfort of mosques.

This analytical method aims to provide a thorough and comprehensive overview of the thermal performance of wall cladding materials in mosque buildings in a humid tropical climate, as well as to generate data that can serve as a basis for consideration in designing more climate-responsive buildings.

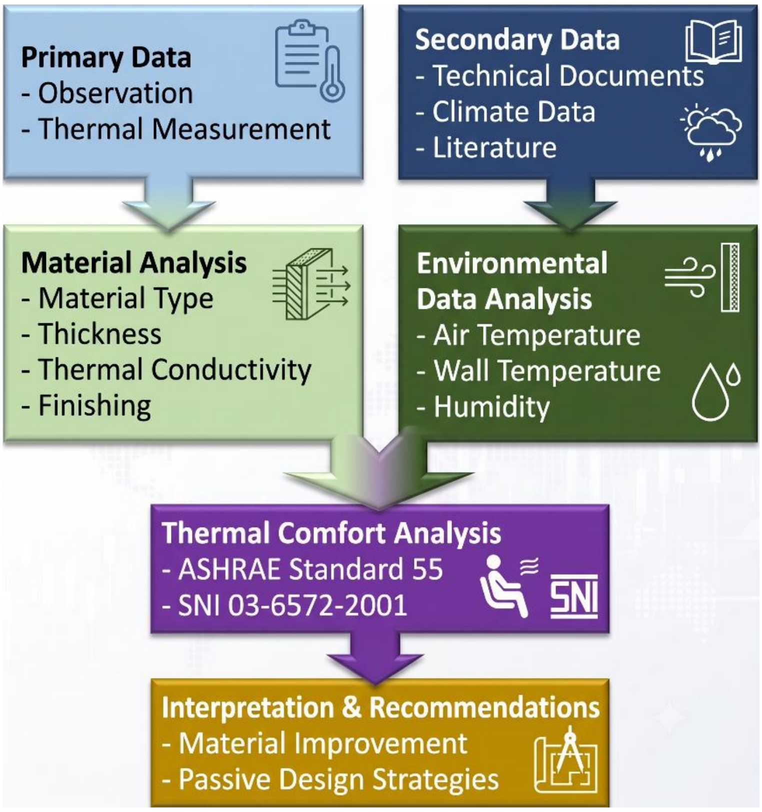


Figure 3: Analytical Methodology Framework Diagram

III. RESULT AND DISCUSSION

3.1 Description of the Mosque Building

This mosque features a minimalist, box-shaped design and lacks the dome typically found on mosques. This design makes the mosque stand out while also blending organically with the natural surroundings (Figure 4). According to the management, in addition to being a place of worship, this mosque also serves as a learning center and a memorial to the 2018 tsunami. There are two buildings within the mosque complex: a cube-shaped prayer hall and a rectangular utility room. The prayer hall has three entrances: one for the imam, one for male worshippers, and one for female worshippers (Figure 5).

This mosque is constructed of concrete and brick, with blue terrazzo accents on the floor. There are metal elements arranged to spell out the 99 names of Allah as ornamentation, and rusted steel ventilation grilles encircling the upper portion of the building. Additionally, a water pond surrounds the mosque, creating the impression that it is floating on the sea (Figure 6). This pond also helps lower the air temperature inside the prayer hall. Terrazzo was used for the pond's floor, giving it a seamless appearance. This building has no windows because it is designed to be ventilated through openings located at the top and bottom of the structure. The mihrab features a glass panel that serves as a marker and allows natural light to stream in, creating an aesthetically pleasing shadow.

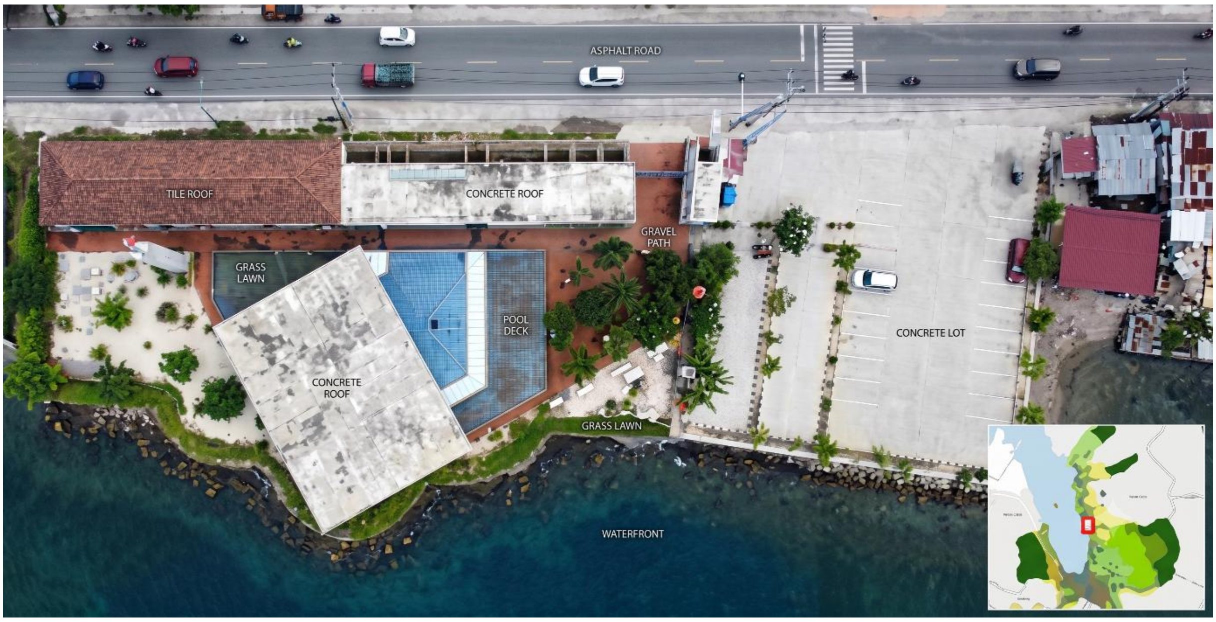


Figure 4: Top view of the Nurul Yaqin Mosque

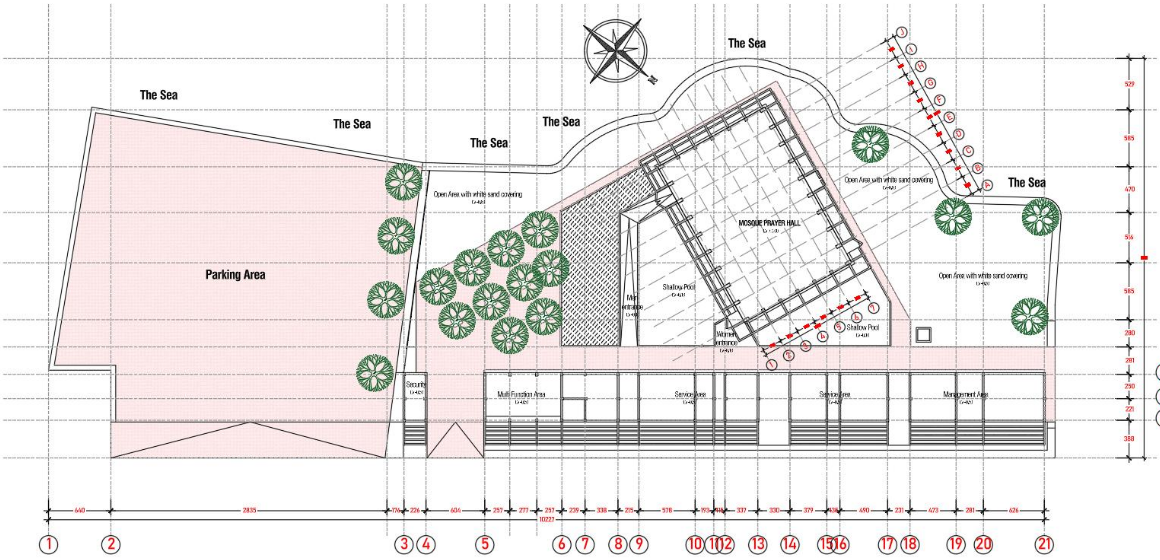


Figure 5: Site Plan of the Nurul Yaqin Mosque

Figure 6: Exterior and Interior View of the Nurul Yaqin Mosque

3.2 Field Measurement Results

Temperature and humidity measurements were taken at three observation times: morning (9:00 a.m. WITA), afternoon (1:00–2:00 p.m. WITA), and evening (4:00–5:00 p.m. WITA). Measurement results show that the surface temperature of the exterior wall during the day reached 34.47°C, while the interior surface temperature reached 32.49°C. This indicates significant heat transfer from the outside into the room through the wall.

Table 2: Room Temperature and Wall Surface Temperature Data

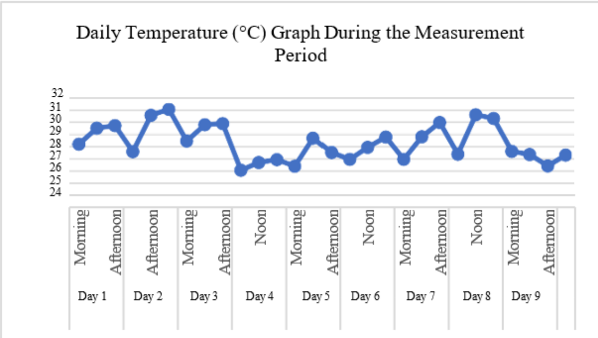
Time	Air Temperature (°C)	Relative Humidity (%)	Outer Wall Surface Temperature (°C)	Inner Surface Temperature (°C)	Condition
Morning	29.04	81.22%	30.47 °C	28.14 o C	Clear weather
Afternoon	30.40	79.50%	34.47°C	32.49°C	Maximum exposure
Late Afternoon	30.74	75.69%	32.71°C	32.18°C	Exposure Reduction

1. Daily Temperature Graph

Temperature patterns show consistent fluctuations, with temperatures tending to rise during the day and drop in the morning or at night. The highest temperatures range from 30°C to 32°C, especially during the day. Morning and nighttime temperatures tend to be lower, ranging from 27°C to 29°C, though they do not drop significantly (Figure 7 and 8). These fluctuations indicate that the heat accumulated during the day does not fully dissipate by night, causing temperatures to remain relatively high into the night.

2. Daily Humidity Graph

There is a trend of high humidity throughout the day, averaging between 70% and 90%. Humidity tends to decrease during the day as temperatures rise and then increase again from evening through the early morning. These high humidity conditions exacerbate thermal discomfort, as they slow down the body's cooling process through sweat evaporation.



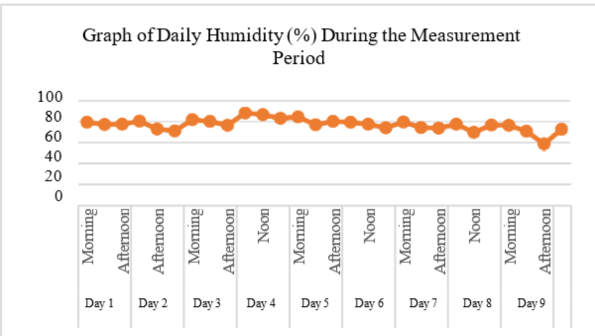


Figure 7: Typical Day Thermal Condition with Clear Sky Condition

The Thermal Performance Analysis (Figure 10):

- Daytime: The wall material absorbs a significant amount of solar radiation, as evidenced by the room temperature rising to nearly 32°C. The walls are unable to effectively resist heat transfer, resulting in the interior space experiencing a fairly high heat load.
- Night and Morning: Temperatures do not drop drastically because the walls release the heat they have stored throughout the day. This is consistent with the principle of thermal lag in high-density materials such as brick.
- Humidity: High humidity exacerbates thermal conditions. Humidity slows the body's ability to adapt to high temperatures, and at the same time, heat from the walls continues to be released into the interior space.

Daily temperature and humidity graphs show that wall materials have a significant impact on heat accumulation within the building. The thermal mass characteristics of brick materials cause heat to be not only absorbed during the day but also retained and released at night. This results in thermal discomfort that persists throughout the day, exacerbated by the high humidity typical of Palu's coastal tropical climate.

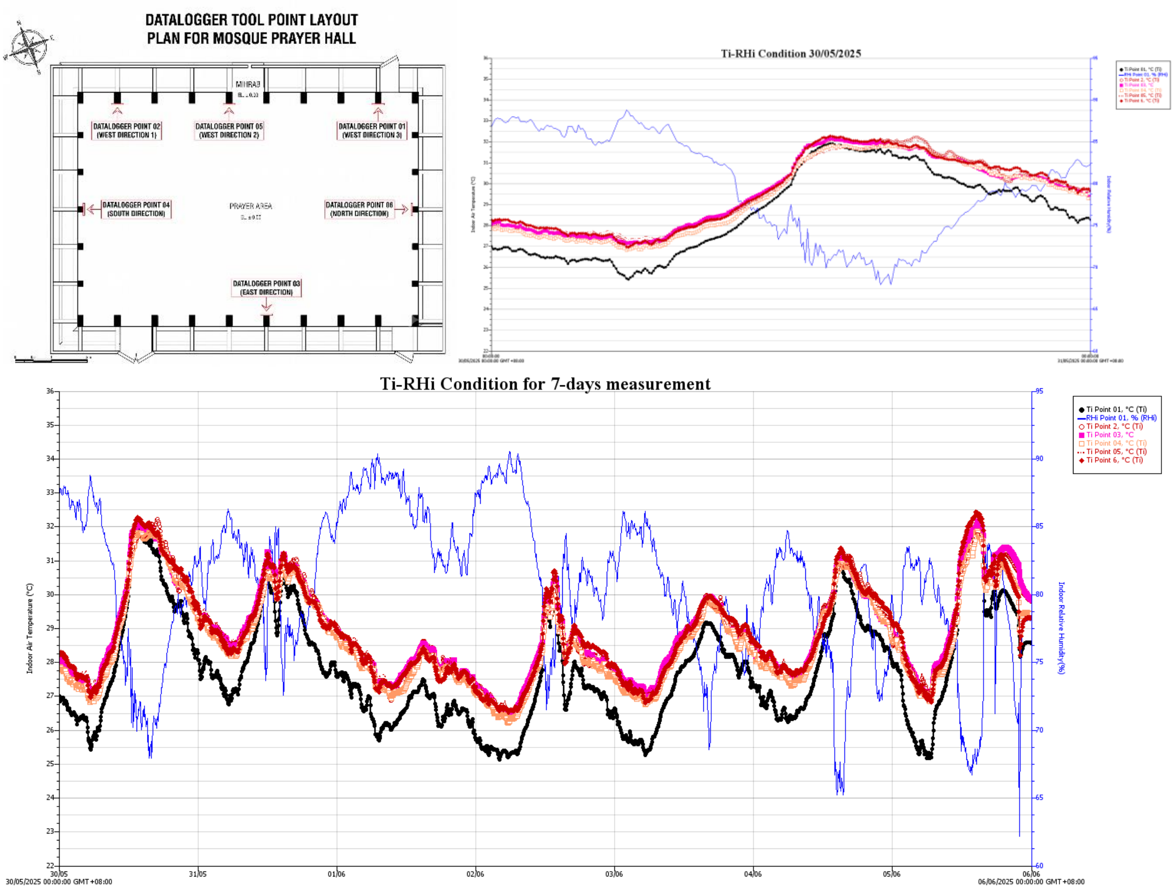


Figure 8. Indoor Air Temperature and Relative Humidity Result on Different Measurement Point for 7-day and Typical Sunny Day

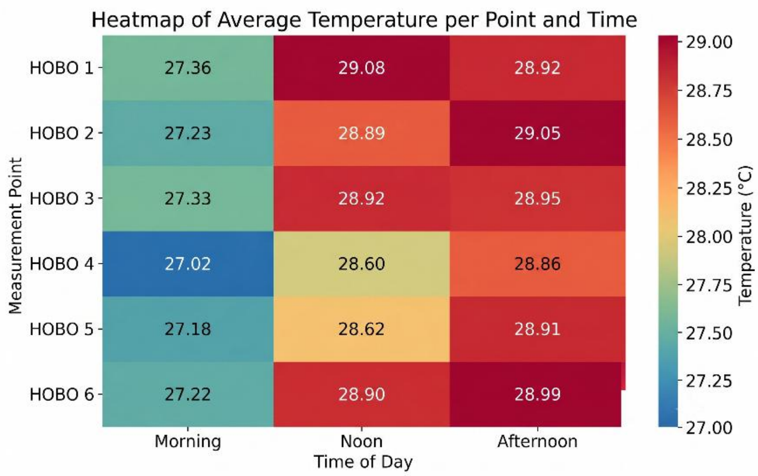


Figure 9: Temperature/Point and Time Distribution

Temperature Patterns by Time (Figure 9)

- Morning: The lowest temperatures recorded at all measurement points ranged from 27.18°C to 27.36°C. This indicates that the heat accumulated overnight is beginning to dissipate, and morning solar radiation has not yet significantly affected the surface temperature of the walls or the room temperature.
- Afternoon: All monitoring points showed a fairly significant increase in temperature, ranging from 28.60°C to 29.08°C. The stations with the highest temperatures were HOBO 1 (29.08°C) and HOBO 3 (29.02°C). This indicates that the areas at those stations received the greatest exposure to solar radiation or have materials with poorer thermal performance.
- Afternoon: Temperatures remained high, though not as intense as during the day. The average ranged from 28.86°C to 29.05°C, indicating a thermal lag effect—heat stored in the wall materials during the day was still being released into the interior space in the afternoon.

Temperature Patterns Based on Measurement Points (Figure 9)

- HOBO Points 2, and 3 tend to have higher temperatures during the day and in the afternoon compared to other points. This can be attributed to the position of the walls, which are more exposed to direct sunlight (for example, west- or east-facing walls).
- HOBO Points 5 and 6 tend to have lower morning temperatures, which may indicate locations with less exposure or more sheltered areas.

This temperature heat map makes it clear that the thermal characteristics of the wall cladding materials at the Nurul Yaqin Islamic Center Mosque are not yet capable of providing optimal protection against the heat load of the tropical coastal climate. Instead, the walls act as heat reservoirs and heat emitters, which affects thermal comfort inside the building throughout the day.

In general, although these walls store heat, efforts have been made to minimize excessive indoor temperatures through the building's design. However, at certain times, additional cooling measures—such as indoor fans—are still necessary.

Based on the ASHRAE 55 and SNI 03-6572-2001 thermal comfort standards, the comfortable temperature range for tropical climates is between 23°C and 27°C, with relative humidity between 50% and 70%. The results show that in the morning, indoor conditions remained within the comfort range. During the day, the indoor temperature reached 30.40°C, which is well above the comfort standard. In the afternoon, the temperature drops but still exceeds the comfort threshold (30.74°C).

3.4 Thermal Performance Analysis of Wall Materials

Observations show that the wall cladding materials at the Nurul Yaqin Islamic Center Mosque in Palu consist primarily of red brick with a cement plaster and paint finishing (Figure 10). The total wall thickness is approximately 25 cm, with light grey-colored paint on both the exterior and interior surfaces. Additionally, both internal and external wall surfaces were applied a layer of shotcrete, make the surface finishing roughness evident. Brick has moderate to high thermal mass, absorbing heat slowly and releasing it just as slowly. Based on reference values by Givoni, 1994; SNI 03-6572-2001 for material properties [15,17], the thermal characteristics of these materials are:

- Thermal conductivity (k) = 0.72 W/mK (for red brick)
- Specific heat capacity (Cp) = 840 J/kgK
- Material density = 1,800 kg/m³

Figure 10: Wall Elements of the Nurul Yaqin Mosque (Exterior View and Interior View)

Rough surface texture will slightly increase the exterior convective surface area exposed to airflow. This reduces the external surface resistance (Rse) minutely from roughly 0.040 to 0.037 m²K/W, but the effect on the overall U-value is less than 1%. In contrast, light grey colour does not alter the static U-value (which is purely conductive and independent of solar radiation). However, it significantly reduces solar radiation heat gain on the outer face during the daytime. Light grey finish has a low solar absorptivity (α ≈ 0.45 - 0.50) compared to standard dark brick (α ≈ 0.85), keeping external surface temperatures noticeably cooler in sunny conditions. The walls of Nurul Yaqin Mosque have several layers as shown in Table 3. With total thermal transmittance equivalent to 2.13 W/m2K.

Table 3. Thermophysical Properties of Nurul Yaqin Mosque Wall

Layer / Interface of Wall	Thickness (d), m	Thermal Conductivity (λ), W/m·K	Thermal Resistance (R), m²K/W
Internal Surface Resistance (Rsi)	—	—	0.130
Sprayed Concrete (Layer 1)	0.03	1.3	0.023
Inner Plaster	0.035	0.72	0.049
Solid Red Clay Brick	0.12	0.77	0.156
Outer Plaster	0.035	0.72	0.049
Sprayed Concrete (Layer 2)	0.03	1.3	0.023
External Surface Resistance (Rse)	—	—	0.040
Total Thermal Resistance (R)			0.470

1. Morning Conditions (sunny day)

In the morning, average air temperature falls on 29.04°C, with relative humidity 81.22%. Meanwhile, the exterior wall surface temperatures were 30.47°C and interior wall temperature were 28. 14°C. This happened when sky conditions were almost clear. Therefore, in the morning, the air temperatures were still quite comfortable despite the high relative humidity. The exterior wall temperature (30.47°C) was close to the air temperature, while the interior wall temperature was lower (28.14°C), indicating that the walls had not yet absorbed much heat from the outside. This shows that the thermal mass is still effective at retaining heat in the morning.

2. Afternoon Conditions (Maximum Exposure)

The average air temperatures in the early afternoon were 30.40°C combined with relative humidity of 79.50%. At the same time, the exterior wall surface temperatures were point at 34.47°C and interior wall temperature were showed at 32.49°C. The surface temperature of the exterior wall rose to 34.47°C, indicating that the wall was receiving the highest level of solar radiation at this time. The temperature of the interior wall also rose to 32.49°C, which is higher than the air temperature (30.40°C). This indicates that heat from the wall contributes significantly to the increase in indoor temperature. The wall material (cement-plastered brick) exhibits the characteristic of absorbing heat from the outside and transferring it into the room.

3. Late Afternoon Conditions (Reduced Exposure)

The average air temperatures in the late afternoon were 30.74°C followed by 75.69% relative humidity. Ander the reduced exposure, the exterior wall surface temperatures were pointed at 32.71°C while interior wall surface temperatures were shown at 32.18°C. Although sun exposure has decreased, the outer wall temperature remains high (32.71°C), and the inner wall temperature also remains high (32.18°C). This indicates that the walls store the heat absorbed during the day and release it into the room in the afternoon. As a result, even though the air temperature does not rise significantly, the interior of the room still feels hot due to radiation from the inner wall surfaces.

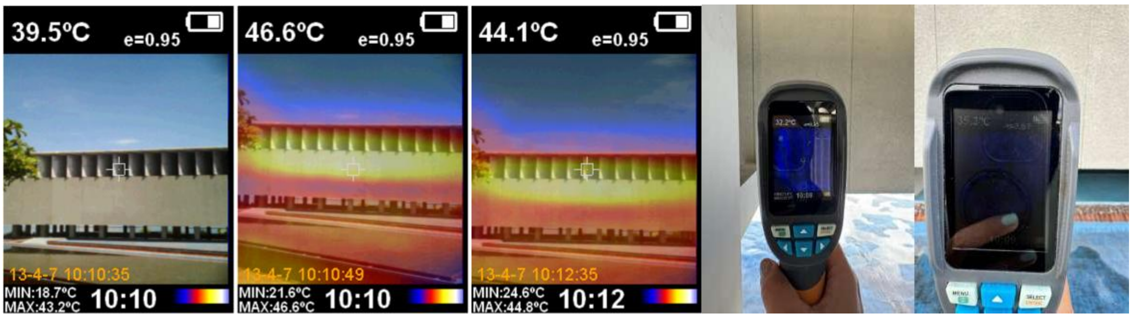


Figure 11: Result of Temperature measurements of the interior and exterior wall materials of the mosque

Measurement result for the walls surface temperature, it is evident that the average temperature difference between the outer and inner wall surface temperature is up to 2degC (Figure 11) where the fluctuations of surface temperature varied in three measurements time (morning, early afternoon, and late afternoon).

3.5 Discussion of Walls Material Performance

- Color Factor: The use of light colors on wall finishes has been shown to help lower the exterior surface temperature by 4–5°C compared to dark-colored walls [18] [24]. However, this effect is limited when heat loads are very high during the day.
- Thermal Mass: Brick walls have moderate thermal mass, meaning they can absorb heat and release it gradually [25]. This is beneficial at night, but during the day it causes heat to accumulate inside the space.
- Thickness: A wall thickness of 25 cm provides moderate thermal resistance but is not yet optimal for blocking high heat transfer in a tropical climate. In this mosque, the walls function as a secondary skin, as they are spaced away from the building's main support columns and there is a pool of water flowing beneath them, creating a cooling effect on the incoming breeze.
- Ventilation and Design Factors: Ventilation inside the mosque is excellent, as it effectively optimizes airflow in and out of the building. There are openings at the top and bottom of the walls to serve as vents. This was confirmed by a smoke test. When the device was turned on and emitted smoke, the smoke was drawn upward and downward through the existing vents.

3.6 Recommendations Based on the Analysis

Based on the results and discussion, the following recommendations can be made:

1. Use of Additional Materials: Adding an insulation layer to exterior walls, such as thermal insulation panels or lightweight hollow materials, can reduce heat transfer [26].
2. Finish Modifications: Using reflective paint or light-colored ceramic coatings on exterior surfaces to increase the reflection of solar radiation [27].
3. Ventilation Optimization: Adding upper ventilation openings and permanent vents to improve cross-ventilation, allowing accumulated heat to escape quickly [25].
4. Shading or Vegetation: Adding vertical shading or planting dense vegetation on the sides of walls directly exposed to the sun (especially the west and east sides) to minimize direct heat gain [25].

The wall cladding materials used at the Nurul Yaqin Islamic Center Mosque provide comfort from morning until midday. However, from midday through the afternoon, significant heat accumulation occurs due to heat transfer through the walls, influenced by the thermal properties of the materials and ventilation conditions. Therefore, improvements in material performance and passive design strategies are essential to support thermal comfort in the mosque.

IV. CONCLUSION

5.1 Conclusion

Based on the results of a study evaluating the performance of wall cladding materials on thermal comfort at the Nurul Yaqin Islamic Center Mosque in Palu, it can be concluded that:

1. The wall covering material used consists of red brick masonry with plaster finish cement and light- colored paint. This material has moderate thermal conductivity (0.72 W/mK) and a wall thickness of 25 cm, providing moderate thermal protection.
2. The thermal performance of the wall cladding material indicates that the walls contribute significantly to the rise in indoor temperature, especially during the day when solar radiation is intense. The outer wall surface temperature reached up to 34.47°C, and the indoor temperature reached 30.40°C, exceeding the thermal comfort limits based on ASHRAE Standard 55 and SNI 03-6572-2001 [28, 29].
3. Thermal comfort inside the room is only achieved in the morning. During the afternoon and evening, the indoor temperature rises significantly due to heat accumulation from direct solar radiation.
4. The results of the study indicate that cement-plastered brick walls are not optimal for reducing thermal loads in humid tropical climates, especially without adequate passive design strategies.

The conclusions of this study underscore the importance of selecting appropriate materials and implementing passive design strategies to support the thermal comfort of buildings, particularly mosques in humid tropical climates such as Palu.

5.2 Recommendations

Based on the research findings and analysis, the following recommendations can be made:

1. Improvements to wall materials:
   - Add thermal insulation material to the exterior or interior of the walls to reduce heat transfer.
   - Use surface finishes with reflective materials or special thermal paint to increase the reflection of solar radiation.
2. Building design optimization:

- Add shading elements (canopies, secondary skins, or vertical shading) primarily to the west- and east-facing walls.
- Improve cross-ventilation by enlarging or adding openings at the top of the building to accelerate heat dissipation.
- Utilizing vegetation (such as vines or shade trees) around the building to reduce direct heat gain.

3. Future research:
   - It is recommended to conduct thermal simulations using software such as EnergyPlus or Ecotect to evaluate various improvement scenarios.
   - Future research could expand the scope to include other mosques in tropical coastal regions to obtain more generalizable results.

REFERENCES

[1] I. M. Budaiwi, "Envelope thermal design for energy savings in mosques in hot-humid climate," *Journal of Building Performance Simulation,* vol. 4, no. 1, pp. 49-61, 2010. https://doi.org/10.1080/19401491003746639

[2] A. B. Atmaca, G. Z. Gedík and A. Wagner, "Determination of Optimum Envelope of Religious Buildings in Terms of Thermal Comfort and Energy Consumption: Mosque Cases," *Energies,* vol. 14, no. 20, pp. 6597-6597, 2021. https://doi.org/10.3390/en14206597

[3] N. A. Azmi, A. Baharun, M. Arıcı and S. H. Ibrahim, "Improving thermal comfort in mosques of hot-humid climates through passive and low-energy design strategies," *Unimas Institutional Repository (Universiti Malaysia Sarawak),* vol. 12, no. 2, pp. 361-385, 2022. https://doi.org/10.1016/j.foar.2022.07.001

[4] M. M. Kotowska, R. M. Link, A. Röll, D. Hertel, D. Hölscher, P. Waite, G. M. Moser, A. Tjoa, C. Leuschner and B. Schuldt, "Effects of Wood Hydraulic Properties on Water Use and Productivity of Tropical Rainforest Trees," *Frontiers in Forests and Global Change,* vol. 3, 2021. https://doi.org/10.3389/ffgc.2020.598759

[5] H. Hermawan and J. Švajlenka, "Building Envelope and the Outdoor Microclimate Variable of Vernacular Houses: Analysis on the Environmental Elements in Tropical Coastal and Mountain Areas of Indonesia," *Sustainability,* vol. 14, no. 3, pp. 1818-1818, 2022. https://doi.org/10.3390/su14031818

[6] V. Gupta and C. Deb, "Envelope design for low-energy buildings in the tropics: A review," *Renewable and Sustainable Energy Reviews,* vol. 186, pp. 113650-113650, 2023. https://doi.org/10.1016/j.rser.2023.113650

[7] N. Jannat, A. Hussien, B. M. Abdullah and A. Cotgrave, "A Comparative Simulation Study of the Thermal Performances of the Building Envelope Wall Materials in the Tropics," *Sustainability,* vol. 12, no. 12, pp. 4892-4892, 2020. https://doi.org/10.3390/su12124892

[8] Y. Chen, M. Quan, D. Wang, H. Du, L. Hu, Y. Zhao, M. Guo and Y. Liu, "Optimization and comparison of multiple solar energy systems for public sanitation service buildings in Tibet," *Energy Conversion and Management,* vol. 267, pp. 115847-115847, 2022. https://doi.org/10.1016/j.enconman.2022.115847

[9] J. Lizana, R. Chacartegui, Á. B. Padura and J. M. Valverde, "Advances in thermal energy storage materials and their applications towards zero energy buildings: A critical review," *Applied Energy,* vol. 203, pp. 219-239, 2017. https://doi.org/10.1016/j.apenergy.2017.06.008

[10] B. Ozarisoy and H. Altan, "Systematic literature review of bioclimatic design elements: Theories, methodologies and cases in the South-eastern Mediterranean climate," *Energy and Buildings,* 2021. https://doi.org/10.1016/j.enbuild.2021.111281

[11] M. Iqbal, A. Ozaki, Y. Choi and Y. Arima, "Performance Improvement Plan towards Energy-Efficient Naturally Ventilated Houses in Tropical Climate Regions," *Sustainability,* vol. 15, no. 16, pp. 12173-12173, 2023. https://doi.org/10.3390/su151612173

[12] ASHRAE, "Thermal Environmental Conditions for Human Occupancy," American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2017.

[13] J. Gamero-Salinas, A. Monge-Barrio, N. Kishnani, J. López–Fidalgo and A. S.-O. Gutiérrez, "Passive cooling design strategies as adaptation measures for lowering the indoor overheating risk in tropical climates," *Energy and Buildings,* vol. 252, pp. 111417-111417, 2021. https://doi.org/10.1016/j.enbuild.2021.111417

[14] V. Olgyay, A. Olgyay, D. Lyndon, V. W. Olgyay, J. Reynolds and K. Yeang, Design with Climate, Princeton University Press, 2015. https://doi.org/10.1515/9781400873685

[15] National Standardization Agency, "Guidelines for the Design of Ventilation and Air Conditioning Systems in Buildings," National Standardization Agency (BSN), 2001.

[16] F. Ascione, R. F. d. Masi, F. d. Rossi, S. Ruggiero and G. P. Vanoli, "Energy refurbishment of existing buildings through the use of phase change materials: Energy savings and environmental impact reduction," *Energy and Buildings,* vol. 138, pp. 99-112, 2016. https://doi.org/https://doi.org/10.1016/j.enbuild.2016.12.046

[17] B. Givoni, Passive low energy cooling of buildings, John Wiley & Sons, 1994.

[18] M. Santamouris, "Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments," *Solar Energy,* vol. 103, pp. 682-703, 2012. https://doi.org/10.1016/j.solener.2012.07.003

[19] R. Hyde, Climate-Responsive Design: A Study of Buildings in Moderate and Hot Humid Climates, Earthscan, 2008.

[20] K. Yeang, Ecodesign: A Manual for Ecological Design, Japan Society of Medical Entomology and Zoology, 2004.

[21] A. Wicaksono, L. Y. Prakoso and N. Yuliastuti, "Evaluation of Wall Materials on Thermal Comfort in Educational Buildings in Surabaya," *Jurnal Arsitektur Nusantara,* vol. 9, no. 1, pp. 35-44, 2020. https://doi.org/10.24843/JAN.2020.v09.i01.p04

[22] M. Hasyim, M. Hasanuddin and Syamsiar, "Analysis of Thermal Comfort in Traditional Mosques in Makassar," *Journal of Tropical Architecture,* vol. 7, no. 2, pp. 45-52, 2019.

[23] R. Susanti, I. Wahyuni and A. Kurniawan, "A Study of Building Materials and Their Thermal Performance in Tropical Coastal Regions," *Journal of Architecture and Environment,* vol. 18, no. 1, pp. 12-20, 2021. https://doi.org/10.24167/jal.v18i1.456