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Thermal Performance Assessment of Traditional Stilt Houses in Wana Village, Indonesia: Field Measurement and Simulation

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Abstract

Traditional stilt houses in tropical regions are commonly considered climate-responsive, yet empirical evaluations of their thermal behaviour under contemporary modifications remain limited. This study assesses the thermal performance of a traditional stilt house in Wana Village, East Lampung, Indonesia, using field measurements and solar exposure simulations. Surface temperatures of walls, roofs, and floors were measured using a FLIR C2 thermal imaging camera, while envelope heat exposure was analysed through Autodesk FormIt based on site-specific orientation and climate. The results show that envelope configuration and material layering significantly influence thermal behaviour. The double-layer wooden wall with an air cavity on the southern façade, which was constructed primarily for cultural representation, privacy, and structural emphasis rather than solar control, exhibits lower internal surface temperatures compared to single-layer walls on the east and west façades that receive higher solar radiation. Roof measurements indicate substantial heat retention by historic clay tiles, while the presence of a wooden ceiling effectively reduces heat transfer to interior spaces. Enclosure of the under-stilt space alters the floor's thermal behaviour by limiting airflow beneath the building, resulting in higher surface temperatures. This study characterizes how vernacular architectural elements and subsequent adaptations interact with tropical climatic conditions to moderate heat gain. The findings provide empirical evidence to inform climate-responsive design strategies while supporting the sustainable conservation of traditional stilt houses.

1.0 INTRODUCTION

Wana Village is nestled within the Melinting District of East Lampung Regency and is renowned for its deep cultural heritage. Recognized as a cultural village, Wana is one of the seven villages that constitute the Melinting Lampung community, a group that has meticulously preserved the ancient cultural traditions of the Melinting kingdom (Setianingrum, 2021; Prameswari & Hardilla, 2024). The other villages—Tebing, Tanjung Aji, Maringgai, Nibung, Pempen, and Negeri Agung Kecil—together with Wana, form a cluster where the essence of traditional Lampung culture remains vibrantly alive. These villages are distinguished by their commitment to upholding the age-old customs, with traditional stilt houses standing as a testament to this heritage. Many of these houses, constructed in the 1920s, still stand robust, showcasing the enduring craftsmanship and cultural significance they embody (Mr. Iskandar Zulkarnain, the local administrator; Rostiyati, 2013). In Wana Village, these traditional houses are not only cherished as residences but also serve as important venues for customary gatherings and ceremonies that continue to be practiced today (Figure 1).

Based on the Köppen–Geiger classification, Wana Village which is located in East Lampung, Sumatera, Indonesia, falls under the Af/Am category (Figure 1), indicating a tropical rainforest/monsoon climate with consistently high temperatures and significant annual rainfall. Buildings in tropical regions experience high cooling loads due to elevated outdoor temperatures and high humidity levels. In Southeast Asia, cooling accounts for 40–60% of total household energy consumption (IEA, 2022). This condition highlights the importance of passive design in reducing dependence on mechanical cooling systems.

Like most traditional buildings on the Sumatera Island, the traditional buildings of Wana Village are also in the form of stilt houses. The traditional stilt house can be categorized as naturally ventilated building, structures that do not rely on Heating, Ventilation, and Air Conditioning (HVAC) systems, instead depending on their design and interaction with the surrounding environment to maintain comfortable indoor conditions (Sakiyama et al., 2020). By harnessing natural airflow and passive cooling techniques, these buildings offer a sustainable alternative to energy-intensive mechanical systems, making them both environmentally friendly and economically advantageous (Sakiyama et al., 2020). The open design also allowed air to circulate freely beneath the house, enhancing its thermal performance. This passive cooling technique is particularly useful in hot climates, reducing reliance on artificial cooling systems and increasing occupant comfort. From a building physics perspective, the open space plays a crucial role in regulating the thermal environment of the house, allowing air to move freely around and beneath the structure, thereby cooling the interior (Jin & Zhang, 2021).

However, over time, the use of stilt houses and their space underneath stilt has evolved, leading to significant changes in their function and design. Whereas the space was traditionally left open or enclosed with natural materials, many stilt houses have undergone modifications to convert this space into a more secure, enclosed area. Walls have been added to protect and define the space, transforming it into additional living or storage space, reflecting shifts in the residents' needs and influenced by changes in tradition, culture, and social context (Darmayanti & Bahauddin, 2020). These alterations provide new features and functionality that accommodate the contemporary needs of the inhabitants while retaining the essence of the traditional design. In practice, many of the space underneath stilt house are covered with brick to create a room. The current trend of using bricks to enclose the space underneath stilt, rather than the traditional wooden materials, can be attributed to the increasing scarcity of quality wood. As high-quality timber becomes harder to source, its price naturally escalates due to its durability and high market demand (Tienthavorn, 2024). Additionally, deforestation and overexploitation of forests have contributed to the diminishing availability of certain wood species traditionally used in construction. This scarcity, combined with economic considerations, often forces homeowners to opt for more affordable and readily available materials like bricks (Wicaksono et al., 2019).

Traditional stilt houses in tropical regions are often regarded as climate-responsive; however, empirical studies that quantify their thermal performance under contemporary modifications remain limited. Most existing research emphasizes theoretical vernacular principles or relies on simulation-based analysis, with limited integration of in-situ thermal measurements, particularly for traditional houses that have experienced partial enclosure and material adaptation. This gap is evident in rural tropical contexts where such buildings continue to be inhabited and incrementally transformed. Therefore, this study aims to examine the thermal performance of a traditional stilt house in Wana Village using a combined approach of field measurements and simulation. The objectives are to analyse indoor air and surface temperature characteristics, evaluate the thermal behaviour of key envelope components, and interpret the influence of material selection and spatial configuration on indoor thermal conditions in a tropical climate.

2.0 LITERATURE REVIEW

2.1 Tropical Climate Characteristics and Passive Architectural Response

Tropical climates are characterized by consistently high air temperatures, intense solar radiation, and elevated relative humidity throughout the year. In regions classified under the Köppen–Geiger system as tropical rainforest and monsoon climates (Figure 1), daily temperatures typically remain above 25°C, while relative humidity frequently exceeds 70%, creating persistent thermal discomfort when buildings are not adequately adapted (Rattanongphisat & Rordprapat, 2014a). Under such conditions, cooling energy demand constitutes a substantial proportion of building energy consumption, particularly in residential buildings where mechanical air-conditioning is commonly employed to maintain indoor comfort (Kumar & Suman, 2013).

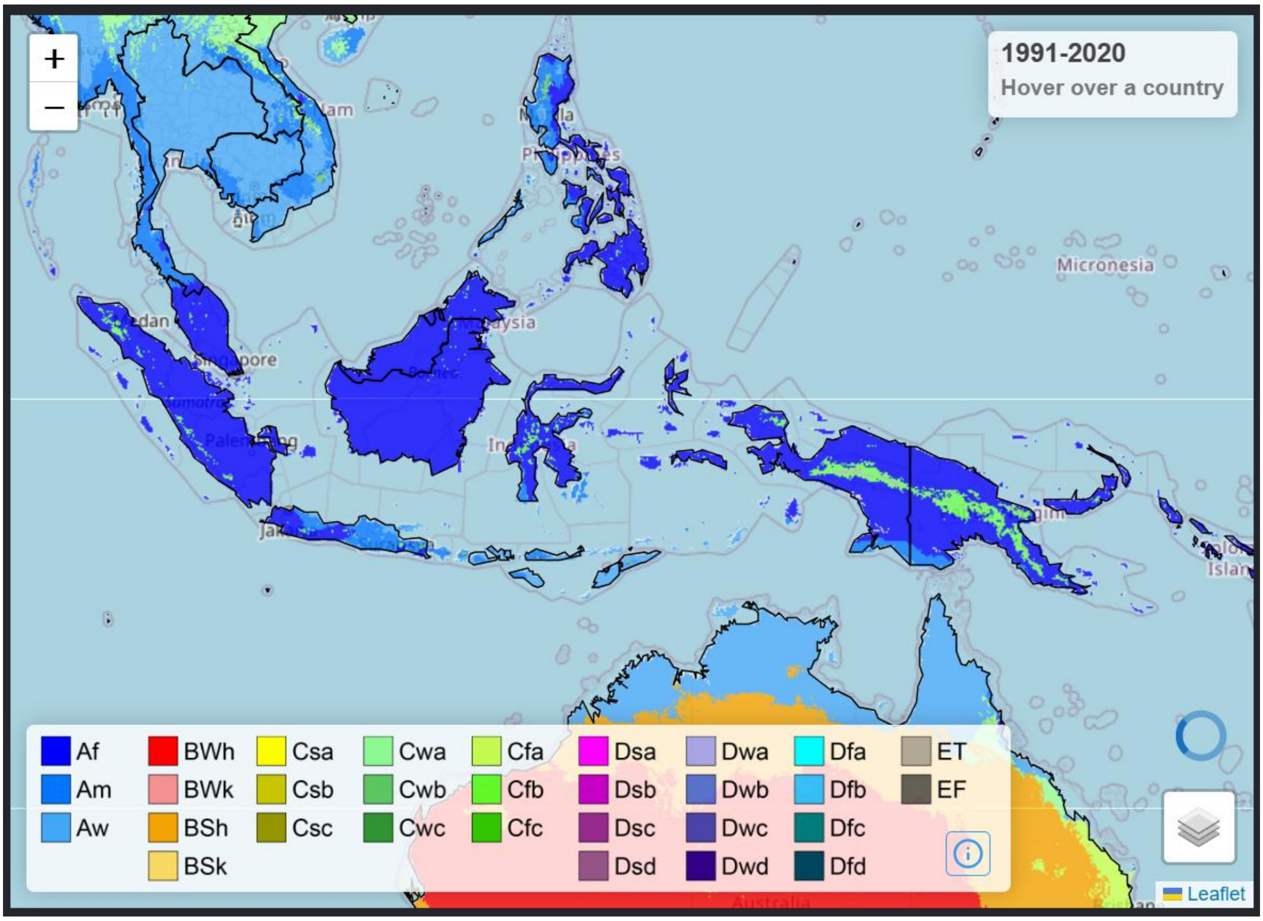


Figure 1. Köppen–Geiger climate zone of Indonesia. (Source*:* https://koppen.earth/)

Architectural responses to tropical climates therefore emphasize strategies that minimize heat gain and enhance heat dissipation through passive means. Shading, lightweight construction, elevated floors, and effective natural ventilation are widely recognized as key principles for reducing indoor temperatures without reliance on mechanical systems (Awang et al., 2019). Naturally ventilated buildings utilize pressure differentials and wind-driven airflow to remove accumulated heat and moisture, making them particularly suitable for tropical environments where diurnal temperature variation is limited (Sakiyama et al., 2020).

2.2 Vernacular Architecture and Thermal Adaptation in Tropical Regions

Vernacular architecture in tropical regions reflects long-standing empirical knowledge of climate-responsive design. Traditional buildings commonly employ low thermal mass materials such as wood and bamboo, which allow rapid heat release during periods of reduced solar exposure and prevent prolonged heat storage within the building envelope (Rattanongphisat & Rordprapat, 2014a). The spatial configuration of vernacular houses often prioritizes cross-ventilation through operable openings and permeable walls, enabling continuous airflow that mitigates both sensible heat and indoor humidity (Ulum et al., 2023).

Stilt houses are a prominent vernacular typology across tropical regions. The elevated structure improves thermal performance by allowing air movement beneath the floor, reducing conductive heat transfer from the ground and enhancing convective cooling (Jin & Zhang, 2021). In addition to climatic benefits, stilt construction provides protection against flooding and facilitates functional flexibility within the undercroft, reinforcing its widespread adoption in humid tropical regions.

2.3 Thermal Performance of Building Envelope Systems in Tropical Climates

The building envelope plays a critical role in mediating the interaction between tropical outdoor conditions and indoor thermal environments. Roofs and walls are the primary pathways for solar heat gain, with roofs often receiving the highest solar radiation due to their horizontal or near-horizontal orientation (Kumar & Suman, 2013). As a result, traditional tropical buildings frequently incorporate ventilated roof spaces, multi-layered roofing systems, or lightweight ceiling materials to limit heat transfer into occupied spaces.

The thermal performance of a building is also influenced by a complex interplay of factors, including not only the materials used but also the specific design and construction characteristics of its walls. These walls interact directly with external climate conditions and significantly impact the internal thermal environment. The effectiveness of these walls in managing heat transfer is critical for maintaining a comfortable indoor climate and optimizing energy efficiency. One of the key factors in thermal performance is the size of the air gap within wall assemblies. Research conducted by Abdullah and Faraj (Kareem Abdullah & Hashim Faraj, 2022) highlights the importance of this parameter, demonstrating that an air gap thickness of 6 cm is optimal for reducing heat gain. This configuration achieves a substantial 19.45% reduction in heat transmission compared to a thinner air gap of 1 cm. The insulating effect of the air gap is a result of the reduced heat transfer through conduction and convection, which helps to maintain a stable indoor temperature. The use of double walls with insulating air gaps, also known as sandwich systems, has a profound impact on the building's thermal performance. This design approach lowers the surface transmission coefficient, a measure of how effectively heat passes through the wall material. Depending on the type of wall material used, the surface transmission coefficient can decrease significantly, ranging from 35.63% to 47.48%. This reduction underscores the effectiveness of incorporating air cavities into wall systems to enhance thermal insulation.

2.4 Adaptation of Traditional Stilt Houses under Contemporary Conditions

Despite their climatic suitability, many traditional stilt houses have undergone spatial and material modifications in response to changing social needs and material availability. The enclosure of the undercroft, often using masonry materials, is a common adaptation intended to increase usable space and improve security (Wicaksono et al., 2019). This transformation is frequently driven by the scarcity and rising cost of durable timber, resulting from long-term deforestation and increased demand for wood resources (Tienthavorn, 2024).

While such adaptations enhance functionality, they may compromise the original passive cooling performance by restricting airflow beneath the structure and increasing heat accumulation. However, empirical studies that quantify the thermal implications of these changes remain limited, particularly in the context of tropical vernacular houses that retain traditional materials and spatial layouts above the enclosed undercroft. This gap underscores the importance of integrating field measurements with simulation-based analysis to evaluate how traditional design principles perform under evolving environmental and socio-cultural conditions.

3.0 METHODOLOGY

The data for this research were meticulously gathered through a series of direct, on-site observations, concentrating on the selected case study building. To capture the surface temperature of indoor surfaces and assess the influence of solar radiation through the envelope material, a FLIR C2 thermal imaging camera was employed (Arminda & Kamaruddin, 2021). This advanced handheld thermography device is exceptionally sensitive to heat, operating by detecting and displaying infrared radiation emitted by objects. By capturing radiation within the long-wave infrared spectrum, the FLIR C2 (Figure 2) generates detailed thermal images that reveal the temperature distribution across the building's surfaces. This imaging technique offers crucial insights into the thermal performance and heat retention characteristics of the materials used in the structure.

Figure 2. FLIR C2 Thermal Camera

To enhance and complement the field data, the research incorporated advanced simulations using industry-standard BIM platforms. Autodesk Revit was utilized to create highly detailed 3D models of the building, providing an accurate representation of its architectural features and structural elements. These models served as a foundation for in-depth analysis, facilitating a comprehensive understanding of the building's thermal behaviour.

Additionally, Autodesk FormIt was employed to simulate the heat exposure experienced by the building envelope. This software offers a thorough analysis of solar radiation and various environmental factors, allowing for a detailed assessment of the building's response to external heat sources (Luziani & Muslim, 2019; Arminda et al., 2024). Autodesk FormIt has been applied in previous academic studies as an early-stage building performance analysis tool, particularly for evaluating solar exposure and heat distribution in tropical climates. Studies have demonstrated that FormIt's simulation capabilities are suitable for exploratory and comparative assessments of thermal behaviour based on geometric configuration and material assumptions, even when full quantitative validation against long-term field measurements is not available (Effendi et al., 2024). Accordingly, in this study, FormIt is used to support qualitative interpretation of thermal patterns and relative façade performance rather than to produce fully calibrated predictive results.

By integrating empirical field data with these simulation tools, the research delivers a comprehensive view of the thermal dynamics within the case study building, offering valuable insights into the effectiveness of traditional design elements in maintaining thermal comfort and optimizing energy efficiency.

3.1 Case Study Description

The case study building is located in Wana Village, East Lampung, Indonesia, with geographic coordinates 5°21'21"S and 105°44'41"E (Figure 3). The traditional houses in Wana Village are architecturally significant, designed as stilted structures that echo the traditional Lampung house known as *Nuwo Sesat* (Setianingrum, 2021) (Figure 4). The term *Nuwo Sesat* is composed of two elements: *"Nuwo,"* meaning house, and *"Sesat,"* meaning custom or tradition. As with other stilt houses, the main body of the house is elevated above the ground, supported by wooden pillars, which prevents direct contact with the earth. The elevated structure of these stilt houses creates an open space beneath *(bah lamban)*, which is the area between the ground and the bottom of the house floor. Historically, this space was left open and served multiple practical purposes. It provided protection from wildlife, kept the house safe from flooding, and increased the structure's resilience against earthquakes. In the past, the space underneath stilt was not typically utilized for specific functions, other than for storage or to house livestock. It also provided a sheltered space for processing and storing agricultural products, pounding rice, and keeping farming or household equipment (Rostiyati, 2013); (Rostiyati, 2017); (Wicaksono et al., 2019).

The architectural integrity of these buildings is upheld through the use of traditional materials and construction techniques. The local administrator (Mr. Iskandar Zulkarnai) said that this traditional house was predominantly built using high-quality Kenanga wood, a material renowned for its exceptional durability (Rostiyati, 2017); (Setianingrum, 2021). This also stated by Rostiyati (2017), who found that most of the traditional houses in Desa Wana were built using Merbau wood and Kenanga or *Kenango* wood. Many of these structures have stood for 50 to 100 years, demonstrating the wood’s resistance to decay and pests, which has made it a favoured choice among local builders for generations (Setianingrum, 2021).

The typical roof design in Wana Village features a pyramid shape, with four sloping sections meeting at a central ridge that runs from the front to the back of the house (Rostiyati, 2013). Originally, the roofs of traditional houses in Wana Village were crafted from woven thatch, providing a natural and breathable covering. Over time, evolving construction practices led to the replacement of thatched roofs with clay tiles, offering better protection against the tropical climate. The clay tiles manufactured by the historic Tan Liok Tiauw brand, known for their longevity. These tiles, some of which are around 100 years old, include a unique historical detail: every 1000th tile is stamped with the phrase “Tan Liok Tiauw BATAVIA.” This feature not only reflects the brand’s heritage but also adds a distinct historical character to the building (refer to Figure 5).

Figure 3. Wana village, East Lampung, Indonesia.

Figure 4. Building case study. (facing South)

Figure 5. Roof (left) and floor (right) covering materials.

3.2 Room Layout and Function

The house's elongated, rectangular body extends toward the rear, with its spatial hierarchy carefully organized to reflect the customs and social structure of the local community (Figure 6). The elevated design necessitates the use of stairs to access the interior. The spatial layout of a traditional Wana Village house, extending from the front to the back, includes:

a. Ladder *(Ijan)* – The entryway to the house, often symbolizing the transition from the outside world to the sacred interior space.
b. Veranda *(Tepas)* – A semi-public space used for receiving guests and engaging in social interactions.
c. Living Room *(Pengindangan Ragah / Khagah)* – A communal area primarily for men, where important discussions and decisions are made.
d. Family Room *(Pengindangan Sebay)* – A private space for women, serving as the heart of domestic life.
e. Bedroom *(Pates)* – Sleeping quarters, especially for girls or woman.
f. Back Room *(Juyew Pates)* – The area that holds a profound philosophy, symbolizing the place where a person first enters the world and where they ultimately close their eyes for the final time.
g. Connecting Space *(Jembat)* – A transitional area linking different parts of the house, often used for circulation.
h. Kitchen *(Dapukh)* – The area where food is prepared, often considered a sacred space in traditional culture.
i. Back Porch *(Tadah Embun)* – An outdoor area used for various household activities, including drying food and performing daily chores.

In traditional houses of Wana Village, there are stairs to access the house. The stairs in regular houses are usually placed on the right edge of the front of the house, whereas, in more luxurious houses, there are typically two entrance stairs located on the left and right edges of the front. In the past, at the top of the stairs, there was a small area called *gakhang hadap*, which served as a place to clean one's feet with water before entering the veranda.

The veranda *(tepas)* is semi-open, where the front and sides are only bordered by wooden railings. The first room encountered upon entering the house is the *pendiangan ragah*, which functions as a meeting space for men. It is also commonly used as a sleeping area for men by laying out mattresses. Based on its hierarchy, the r*agah* room has the highest floor level compared to other rooms.

Beyond the *ragah* room, through a door located at the side or middle of the partition, lies a large room divided into four functions: a meeting space for women and a sleeping area for women *(pendiangan sebay),* a dining room to host guests, a sleeping room *(pates)* separated by partition walls, and a special room *(juway pates)* used occasionally for family members who are sick, elderly, giving birth, or as a place to bathe deceased family members. The floor in the *juway pates* room typically consists of wooden planks with wider gaps to make it easier to clean, allowing water to flow directly downward.

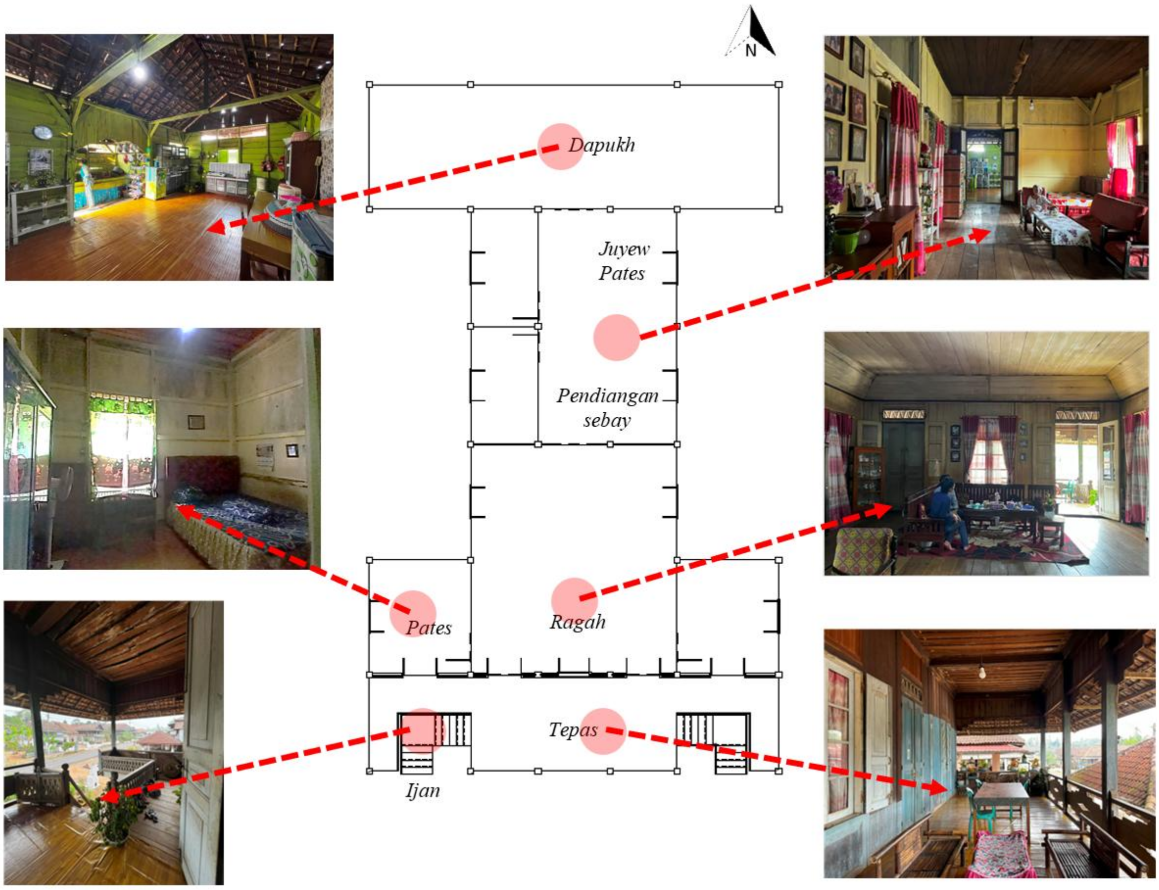


Figure 6. Building layout.

3.3 Building Materials and Structure

This structure exemplifies a traditional architectural style commonly found in the region—a house on stilts with an underlying pit that traditionally serves various functional purposes. In this case, the front portion of the building has been enclosed, transforming the space beneath the house into an additional, functional room (see Figure 4).

The building envelope exhibits a combination of construction systems, most notably on the southern façade, which is composed of a double-layer wooden wall incorporating an air cavity of approximately 5 to 8 cm. This wall configuration contributes to thermal regulation by reducing heat transfer through the creation of an insulating buffer zone. In contrast, the remaining façades retain a single-layer wooden wall system that reflects prevailing traditional construction practices. Despite these variations, each stilt house in Wana Village is spatially detached from adjacent buildings, allowing unobstructed access to daylight and natural airflow that supports indoor environmental quality. Importantly, the application of the double-layer wall on the southern façade was not primarily intended as a response to solar exposure, which is relatively limited on this orientation, but rather as a result of cultural representation, privacy requirements, and structural considerations. The south façade is traditionally regarded as the principal frontage of the house and is therefore constructed with greater thickness and solidity, illustrating how vernacular design priorities may diverge from contemporary passive design conventions while still influencing thermal performance.

4.0 RESULTS AND DISCUSSIONS

4.1 Field Measurements

4.1.1 Wall Surface Temperature

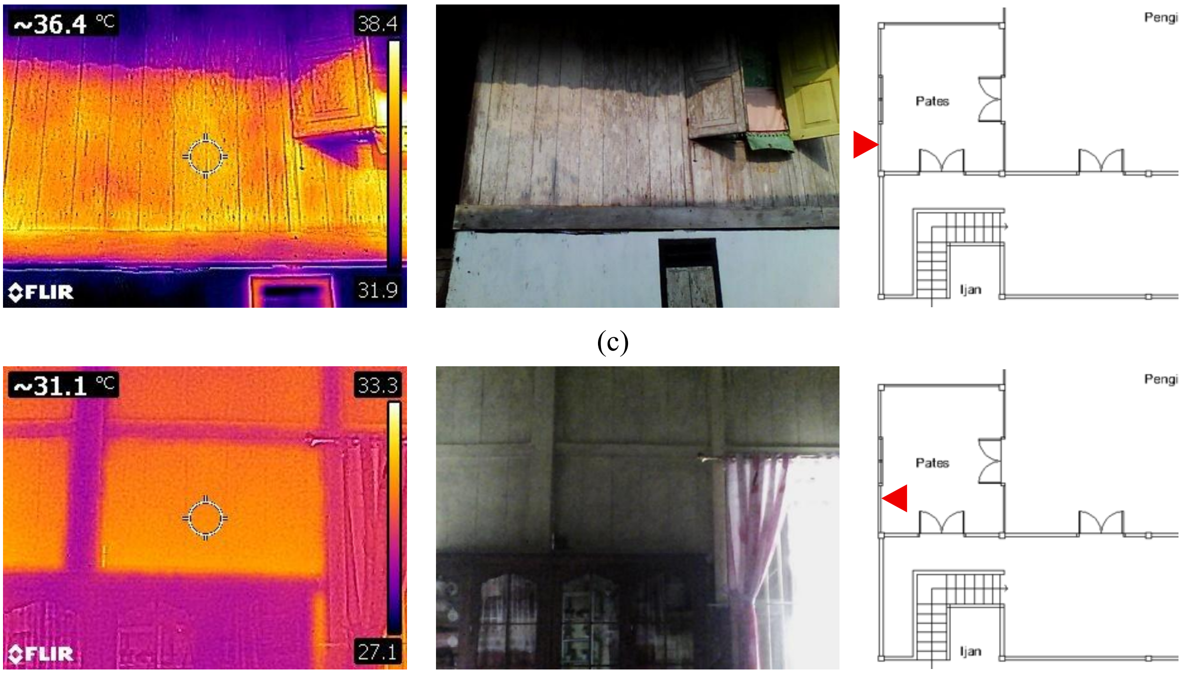
The observed building is oriented with its main façade facing south toward the primary access road, resulting in minimal direct solar exposure on this side. This orientation influences the thermal behaviour of the building envelope, particularly the surface temperatures of the walls. Thermal imaging measurements indicate that the external surface of the southern wall reached 31.4°C, while the corresponding internal surface recorded a slightly lower temperature of 30.3°C, producing a temperature differential of 1.1°C. This relatively small difference suggests that although the southern façade is less affected by direct solar radiation, heat transfer through the wall remains detectable.

In contrast, the west-facing wall, which is constructed using a single-layer system, exhibits a higher thermal gradient. The external surface temperature reached 36.4°C, while the internal surface temperature was measured at 31.1°C. This larger temperature difference highlights the stronger influence of solar exposure on west-facing walls and underscores the comparative thermal performance between single-layer and double-layer wall systems. The double-layer wall, commonly referred to as a sandwich system, incorporates an air cavity between two wooden layers that functions as a thermal buffer, effectively reducing heat transfer from the exterior to the interior.

Figure 7 illustrates the thermal response of the double-layer wall system and its role in moderating heat transmission, thereby contributing to improved indoor thermal conditions. It is important to note that the application of the double-layer wall on the southern façade was not primarily intended as a solar protection strategy, as this orientation receives limited solar radiation. Instead, the design reflects cultural, privacy, and structural considerations, as local builders traditionally emphasize the southern façade as the principal representative frontage of the house and therefore construct it with greater thickness and solidity. This condition reveals a divergence between vernacular architectural priorities and contemporary passive design principles, while simultaneously demonstrating how culturally driven design decisions can still yield measurable thermal benefits.

(a) Surface temperature of outside wall (facing South)

(b)



(c)

(d)

Figure 7. Differences in wall surface temperature; (a) Surface temperature of outside wall facing South (double layer), (b) Inner surface temperature of double layer wall facing South, (c) Surface temperature of outside wall facing West (single layer), (d) Inner surface temperature of single layer wall facing West.

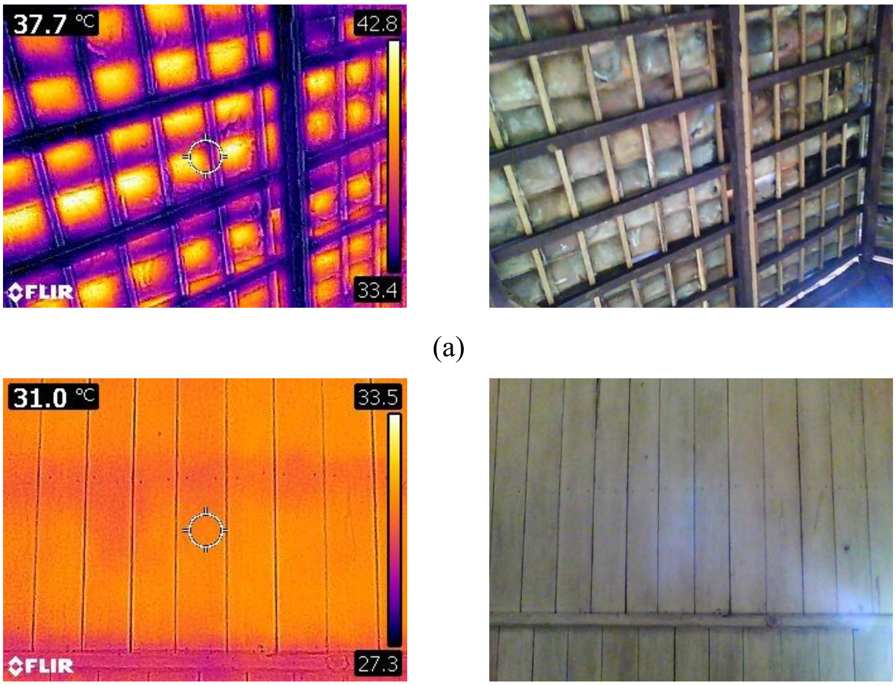
4.1.2 Roof Surface Temperature

The traditional house under study features a tile roof that has been in place for nearly a century, with its condition and performance still observable from the open section of the kitchen that lacks a ceiling. Thermal imaging reveals that the inner surface temperature of this historic tile roof reaches 37.7°C. This temperature measurement underscores the significant heat retention capability of the old clay tiles, even though they are known for their durability and heat resistance.

In contrast, when a wooden ceiling is installed in the same setting, the surface temperature of the ceiling drops to 31.0°C (refer to Figure 8). This substantial reduction illustrates the crucial role of the ceiling in mitigating direct heat transfer from the roof to the interior space. The wooden ceiling acts as an insulating layer that intercepts and absorbs heat before it reaches the living areas, thereby enhancing indoor comfort and reducing the immediate impact of external temperature variations.

This observation highlights that, despite the inherent heat resistance of clay roof tiles, they are not entirely sufficient on their own to prevent heat from affecting indoor temperatures. The addition of a ceiling becomes necessary to manage and control the transfer of heat, ensuring that the interior environment remains more temperate and comfortable for occupants.

Furthermore, previous studies indicate that wooden ceilings in traditional houses tend to exhibit better thermal performance than gypsum ceilings commonly used in modern buildings. Arminda & Kamaruddin (2021).reported a gypsum ceiling surface temperature of 37.1°C in a modern residential house with a metal zinc roof located in Lampung, Indonesia, which lies within the same tropical climatic region as the present case study. Although differences in building configuration and materials remain, the comparable climatic context allows this reference to be used as a contextual comparison to support the observed performance of the wooden ceiling in the traditional house. This comparison underscores the superior insulating properties of traditional roofing systems and their ability to maintain lower indoor temperatures despite the age of the materials. The traditional house's ceiling, therefore, demonstrates that older construction methods and materials can still offer effective thermal management and comfort, surpassing some modern alternatives in terms of heat insulation.



(a)

(b)

Figure 8. Differences in surface temperature; (a) Internal surface temperature of clay tile roof (kitchen, no ceiling), (b) Surface temperature of wooden ceiling installed below same roof.

4.1.3 Floor Surface Temperature

Traditionally, the space beneath the stilt house was open, allowing for free airflow underneath. This open area facilitated natural ventilation, where wind currents could flow unobstructed beneath the building (Jin & Zhang, 2021). Such airflow helps to carry away heat, effectively cooling the space and maintaining a lower temperature for the floor above. The elevated design was originally intended to provide not only protection from flooding but also to enhance natural cooling through this passive airflow.

However, the space beneath the stilt house has been enclosed and converted into a room. This modification significantly alters the building's thermal dynamics. The newly added walls and the enclosed room restrict the natural flow of air that previously contributed to cooling the underside of the floor. Without the benefit of this passive ventilation, the cooling effect of the wind is lost, resulting in a higher floor temperature that is more akin to that of modern buildings with floors directly on the ground. In this building, the floor surface temperature has a measured of 30.8°C (see Figure 9).

This temperature is surprisingly close to that of floors in modern buildings, which are typically situated directly on the ground (Arminda & Kamaruddin, 2021). In modern buildings, floors in contact with the ground are influenced by the thermal mass of the soil and the surrounding environment. These floors often experience a temperature equilibrium with the ground, which can be affected by factors such as insulation, moisture content, and thermal conductivity of the soil (Kacálek et al., 2014; Nawalany & Sokołowski, 2019; Zdankus et al., 2025). This similarity is intriguing, given that stilt houses are traditionally designed to leverage natural ventilation and cooling effects provided by their elevated structure. By contrast, the stilt house's floor, while still elevated, now experiences a similar temperature range as modern floors due to the lack of natural cooling from the previously open space.

This change highlights the impact of architectural modifications on a building's thermal performance. Enclosing an area that was once open to airflow can significantly alter the building's thermal behaviour. The loss of natural ventilation results in a floor temperature that approaches the thermal characteristics of modern buildings, underscoring how traditional design elements interact with environmental factors to influence indoor comfort and energy efficiency.

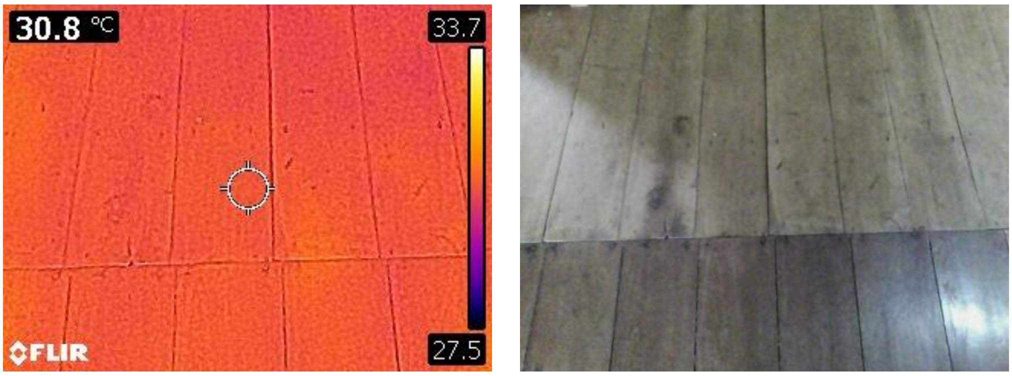


Figure 9. Surface temperature floor covering materials

Table 1. Summarise of surface temperature from field measurement on August

Element	Orientation	Material / System	Surface Temp (°C)	Δ Surface Transmission (°C)
Wall	South	Double-layer wood (External)	31.4	1.1 °C
Wall	South	Double-layer wood (Internal)	30.3	
Wall	West	Single-layer wood (External)	36.4	5.3 °C
Wall	West	Single-layer wood (Internal)	31.1	
Roof	Horizontal	Clay tile without ceiling	37.7	-
Roof	Horizontal	Clay tile + wooden ceiling	31.0	-
Floor	Horizontal	Wooden plank	30.8	-

4.2 Simulation

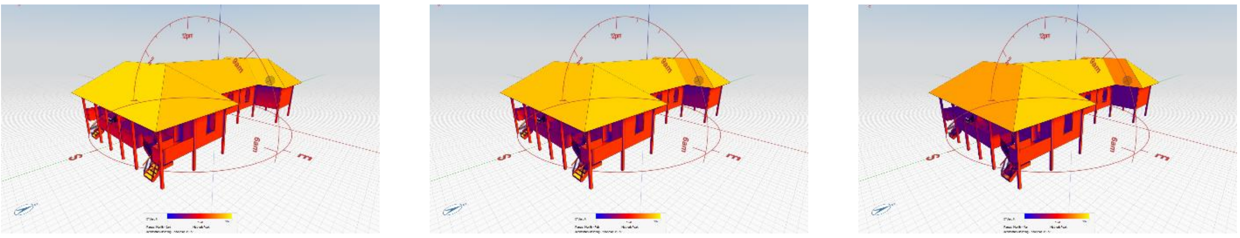
Simulations were conducted to analyse the exposure of traditional house buildings to solar radiation across different months of the year. The location and orientation of the building in the simulation are made the same as the original, where the building facade faces South. The building envelope, which includes the roof and walls, is particularly vulnerable to external environmental factors such as sunlight, outside temperature, wind, and rain (Kumar & Suman, 2013); (Awang et al., 2019). These elements have a significant impact on the building's thermal performance and overall comfort.

According to the simulation results (refer to Figure 10), the roof is the most exposed part of the house to direct sunlight, receiving the highest levels of solar radiation from January to March and again from October to December. These months represent peak periods of solar intensity, during which the roof absorbs a significant amount of heat due to its large surface area and direct orientation to the sun. The continuous and concentrated exposure during these times leads to higher thermal loads on the roof, which in turn increases the heat transferred into the building. This heightened thermal load directly affects the indoor temperature, potentially raising it to uncomfortable levels and reducing the building's overall energy efficiency by increasing the need for cooling.

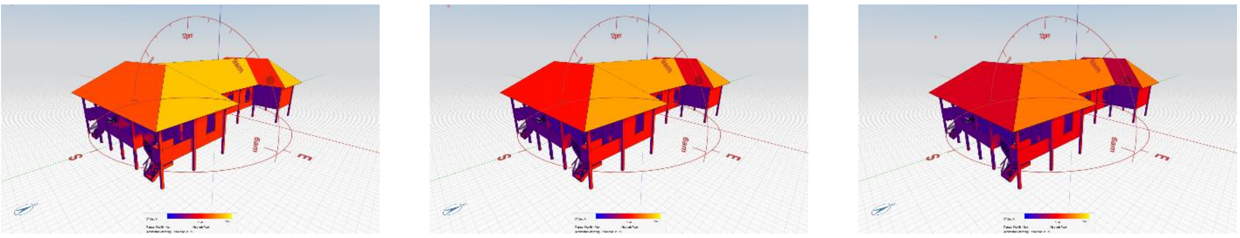
Similarly, the East and West walls of the house experience substantial solar exposure during these same months. These walls are aligned with the path of the rising and setting sun, which means they endure direct sunlight for extended periods each day. As a result, both walls contribute significantly to the overall heat gain in the building, adding to the thermal load and impacting the indoor comfort levels. The increased heat gain from these walls can lead to higher indoor temperatures, especially during the hottest hours of the day, further straining any passive cooling strategies and increasing the potential reliance on mechanical cooling systems.

In contrast, the southern wall, which serves as the building's front façade, receives considerably less solar radiation throughout the year. This reduced exposure is partly due to the orientation of the wall and the added presence of a terrace that provides additional shading. The terrace acts as a natural barrier, blocking much of the direct sunlight that would otherwise strike the southern wall. By serving as a shading device, the terrace minimizes the heat gain in this area, which helps to maintain lower indoor temperatures and improve the building's thermal performance. The reduced solar exposure on the southern façade further highlights the importance of thoughtful design elements like shading structures in mitigating heat gain and enhancing the overall energy efficiency of traditional houses.

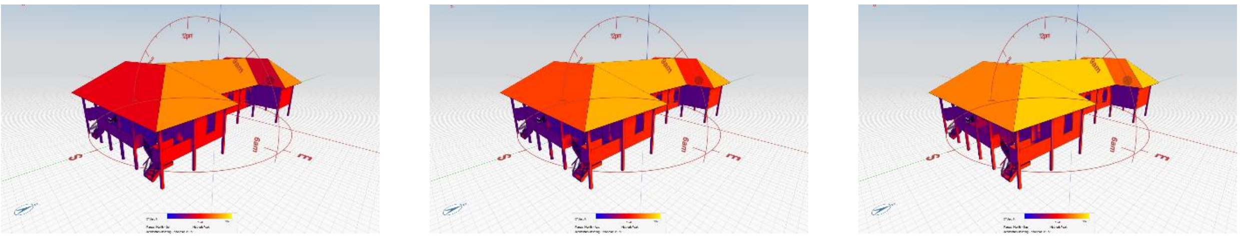
Overall, these simulations provide valuable insights into how different parts of the building envelope interact with solar radiation throughout the year. Understanding these exposure patterns helps in designing more effective passive cooling strategies and optimizing the thermal comfort of traditional houses.



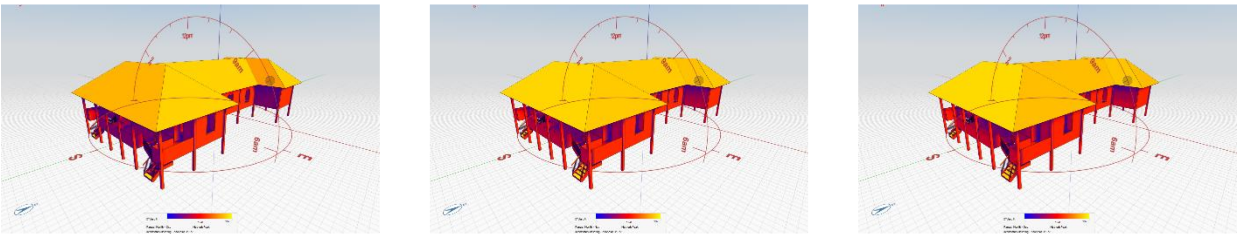
January February March



April May June



July August September



October November December

Figure 10. Monthly solar radiation

In contemporary architectural practice, secondary skins or shading devices are commonly applied to east and west façades to mitigate intense solar exposure. In contrast, the traditional building examined in this study incorporates a double-layer wall system on the south façade, which receives relatively limited solar radiation. Field measurements indicate that this double-layer configuration produces a lower internal surface temperature compared to single-layer walls, demonstrating its effectiveness in reducing heat transfer despite its orientation. Conversely, the east and west façades, which experience higher solar exposure as confirmed by simulation results, are constructed with single-layer wooden walls enclosing key living spaces such as bedrooms and family rooms. Rather than reflecting a deliberate solar-oriented passive strategy, this configuration arises from cultural representation, privacy, and structural considerations that prioritize the south façade as the principal frontage of the house. This finding highlights how vernacular architecture may diverge from contemporary passive design conventions while still achieving acceptable thermal performance through a combination of material selection, natural ventilation, and spatial context.

Furthermore, the indoor air temperature and surface temperature within this traditional building are strongly influenced by the choice of construction materials. The use of low thermal mass materials such as wood and bamboo, which are porous and well suited to tropical climates, allows heat to be absorbed and released rapidly, facilitating faster cooling of interior spaces when combined with natural ventilation (Rattanongphisat & Rordprapat, 2014b; Awang et al., 2019; Kamaruddin et al., 2021; Ulum et al., 2023). This behaviour is reflected in the simulation results shown in Figure 8, where indoor air temperatures remain relatively stable despite periods of higher external heat exposure. The widespread use of wooden materials and the strategic placement of openings in each room enable the building to dissipate accumulated heat efficiently over the course of the day.

Adding to its thermal efficiency, the building features a multi-tiered roof design that facilitates air circulation through the roof space, enhancing the overall cooling effect (as illustrated in Figure 11). The natural ventilation system employed here works by allowing air to flow in and out, maintaining a stable indoor temperature. Such systems are not only crucial for thermal comfort but also play a significant role in expelling or diluting indoor pollutants (Kamaruddin et al., 2021). This is particularly effective when utilizing a cross-ventilation strategy, which leverages airflow from opposite sides of the building to enhance ventilation efficiency (Mohd Arshard et al., 2022). This design approach, though simple, underscores the building's response to its environmental context, demonstrating a deep understanding of passive cooling techniques within traditional architecture.

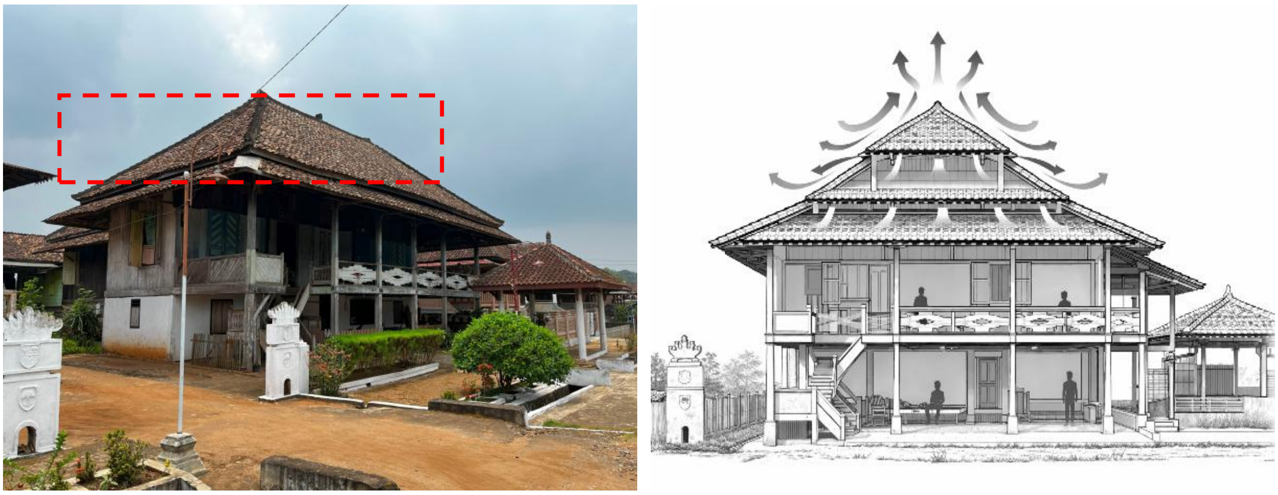


Figure 11. A tiered roof on a traditional south-facing building; (left) original photo, (right) AI illustration showing the cross-ventilation strategy on a tiered roof.

The simulation was conducted to analyse the temperature variations across different rooms within the case study building (Table 2 and illustrated in Figure 12). The primary objective was to evaluate the average temperature and relative humidity in each room over a full year. The building was divided into seven distinct zones, each representing a specific area within the structure, as illustrated in Figure 1.

Zone 1 corresponds to the *dapukh*, or kitchen, which is situated in the northern part of the building. Zone 2 encompasses the *juway pates* and *sebay*, or family room, located in the eastern section of the building. This area serves as a communal space, where thermal comfort is essential due to frequent occupancy. Zones 3 and 4 represent the *pates*, or back bedrooms, which are positioned in the western part of the building. Bedrooms are typically designed to maintain comfortable temperatures for sleeping, making these zones important for assessing nighttime thermal conditions. Zone 5 refers to the *ragah*, or living room, centrally located within the building. This zone is unique as it features windows facing both east and west, which could significantly affect temperature and humidity levels due to solar gain from both directions. Zones 6 and 7 correspond to the *pates*, or front bedrooms, located on both the western and eastern sides of the building. Similar to Zones 3 and 4, these zones are crucial for understanding the thermal environment in sleeping areas, particularly as they are exposed to varying solar radiation throughout the day. The simulation results provide insights into how each zone's location, orientation, and function influence its thermal behaviour over an extended period. This comprehensive data serves as a foundation for optimizing thermal comfort and energy efficiency in traditional building designs.

Table 2. Cooling peak condition of the case study.

Zone	Outside Dry Bulb Temperature (C)	Outside Wet Bulb Temperature (C)	Zone Dry Bulb Temperature (C)	Zone Relative Humidity (%)	Outside Air Flow (m3/s)	Peak Sensible Load (W)
1	35,39	22,45	23,86	56,75	0,12	7863,01
2	35,25	22,41	21,66	56,11	0,02	2139,97
3	34,53	22,21	23,88	49,31	0,01	688,28
4	34,53	22,21	23,88	49,47	0,01	629,27
5	33,84	24,76	21,66	58,34	0,03	2786,17
6	33,54	24,69	23,88	52,59	0,01	1072,53
7	34,26	24,87	23,88	53,4	0,01	923,28

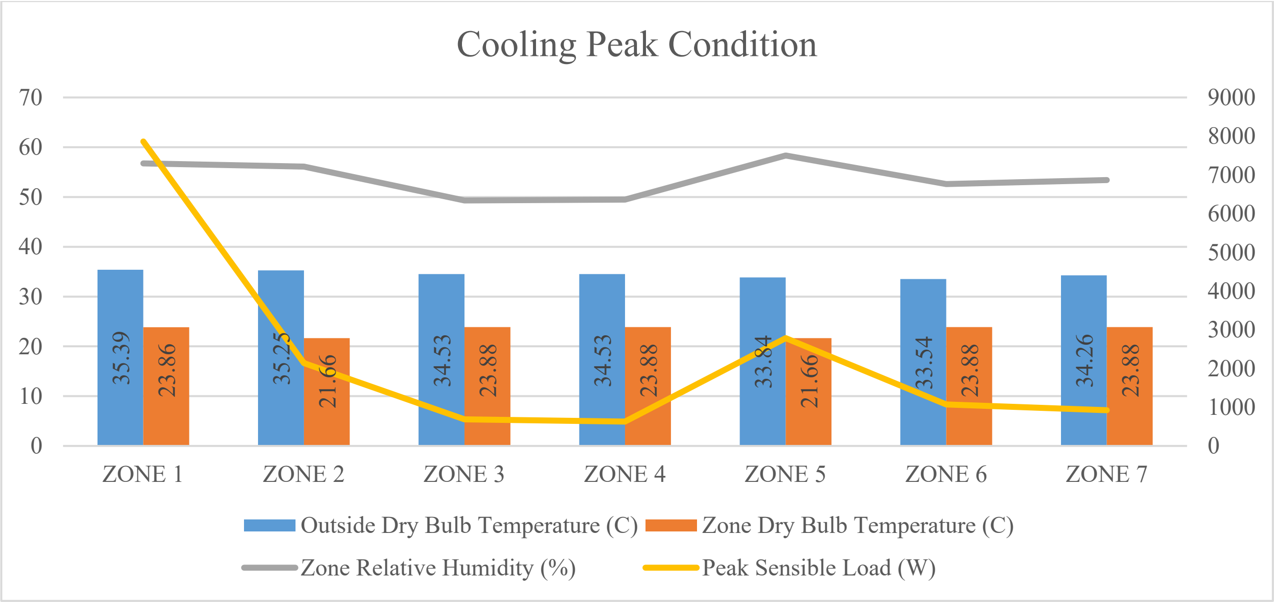


Figure 12. Cooling peak condition on the room in case study.

The simulation data includes key parameters that influence the building's thermal environment, such as the outside dry bulb temperature (°C), which measures the air temperature outside without accounting for moisture content, and the outside wet bulb temperature (°C), which considers moisture content and indicates the actual temperature felt due to humidity. Additionally, the zone dry bulb temperature (°C) measures the air temperature inside each zone, while the zone relative humidity (%) represents the moisture level in the air within the zone. The data also includes the outside air flow (m^3/s), which tracks the rate of airflow entering the zone from outside, and the peak sensible load (W), which reflects the maximum sensible heat load needed to maintain the zone's temperature within a comfortable range.

4.2.1 Temperature and Humidity Correlation

The data reveals a noticeable correlation between the dry bulb temperature and the relative humidity across the different zones. Generally, zones with higher dry bulb temperatures, around 23.88°C, exhibit relative humidity levels ranging between 49% and 58%. This suggests that as the indoor air temperature increases, the ability of the air to hold moisture remains relatively stable, resulting in moderate humidity levels. However, an exception to this pattern is observed in Zone 5, where the dry bulb temperature is lower at 21.66°C, yet it records the highest relative humidity at 58.34%. This deviation could indicate factors such as reduced air circulation or increased moisture infiltration in Zone 5, which lead to higher humidity despite the cooler temperature. Such conditions may challenge the efficiency of thermal regulation within this zone.

4.2.2 Impact of Outside Air Flow on Sensible Load

The effect of outside air flow on the peak sensible load is particularly evident in the comparison of zones. Zone 1, which experiences the highest outside air flow rate of 0.12 m^3/s, also records the highest peak sensible load at 7863.01 W. This suggests that the introduction of a larger volume of outside air into the zone significantly increases the cooling demand, as more energy is required to cool this air to the desired indoor temperature. In contrast, zones with lower outside air flow rates, such as Zones 3, 4, 6, and 7, exhibit much lower peak sensible loads. This indicates that limited air exchange with the outside reduces the amount of heat introduced into the zone, thus lowering the cooling energy required. The data implies that managing outside air flow is crucial for controlling the sensible load and optimizing energy efficiency across the building.

4.2.3 Sensible Load and Temperature

The relationship between outside dry bulb temperature and peak sensible load is further emphasized when examining the data across all zones. Generally, zones with higher outside dry bulb temperatures tend to experience higher peak sensible loads. For example, Zone 1, with an outside dry bulb temperature of 35.39°C, has the highest peak sensible load. This suggests that as the external temperature rises, more energy is needed to counteract the heat entering the zone. However, this pattern is not solely dependent on temperature. Zone 2 has an outside dry bulb temperature close to that of Zone 1 (35.25°C), yet its peak sensible load is significantly lower at 2139.97 W. This discrepancy points to the importance of additional factors, such as lower outside air flow rates, which in Zone 2, reduce the amount of heat entering the zone, thereby decreasing the cooling load. The data highlights that sensible load is a multifaceted metric influenced not only by temperature but also by air flow, humidity, and zone-specific design characteristics.

4.2.4 Relative Humidity and Air Flow Impact

Across all zones, the relative humidity is maintained within a moderate range, between 49.31% and 58.34%. This consistency suggests that the building's moisture control systems are effective, preventing drastic humidity fluctuations that could complicate thermal management. Zones with higher outside air flow rates, such as Zone 1, tend to have higher peak sensible loads, likely because the increased volume of outside air introduces more heat and moisture, demanding greater cooling energy. Conversely, zones with minimal air flow, like Zones 3, 4, 6, and 7, experience reduced peak sensible loads, underscoring the impact of controlled ventilation in minimizing energy consumption.

4.2.5 Cooling Energy Demand and Zone Characteristics

Zone 1 stands out not only for its high sensible load but also for its significant cooling energy demand. This suggests that the zone may either be more extensive in size, have greater exposure to external heat sources, or both. Enhancing insulation or adjusting airflow in this zone could lead to considerable energy savings. On the other hand, Zone 5 presents a unique scenario with both high relative humidity and a notable peak load. This could indicate inefficiencies in moisture control, potentially due to inadequate sealing or ventilation issues. Addressing these factors could improve thermal performance and reduce the cooling burden.

The analysis suggests that optimizing airflow management and improving insulation could substantially lower peak sensible loads, particularly in zones like Zone 1, where high airflow contributes to increased energy demands. Additionally, better control of humidity and moisture infiltration, especially in zones like Zone 5, could enhance cooling efficiency. By targeting these factors, the overall energy consumption for maintaining comfortable indoor conditions across the building can be significantly reduced, leading to a more sustainable and cost-effective thermal management strategy.

5.0 CONCLUSIONS

This study assessed the thermal performance of a traditional stilt house in Wana Village, East Lampung, Indonesia, using a combination of field measurements and envelope-level simulation. The findings indicate that thermal behaviour within the building is shaped by the interaction of envelope configuration, material layering, and spatial modification rather than by a single passive design strategy.

The double-layer wooden wall with an air cavity on the southern façade exhibits lower internal surface temperatures than the single-layer walls on the east and west façades, which are exposed to higher levels of solar radiation. Although this wall configuration was not originally intended as a passive thermal control measure (being driven primarily by cultural representation, privacy, and structural hierarchy) it nonetheless provides a measurable thermal buffering effect. Roof measurements show that historic clay tiles retain substantial heat, while the addition of a wooden ceiling significantly limits heat transfer to occupied spaces. In addition, the enclosure of the previously open under-stilt space alters the building's thermal dynamics by restricting underfloor airflow, resulting in floor surface temperatures comparable to those of modern ground-contact buildings.

These findings should be interpreted within the study's methodological scope. The analysis is based on short-term field measurements and a single case study, and the simulation was applied to evaluate relative solar exposure rather than fully calibrated indoor thermal comfort. Consequently, the results do not represent universal thermal performance but instead provide a context-specific characterization of how vernacular architectural elements and subsequent adaptations influence heat behaviour in a tropical environment.

Despite these limitations, the study demonstrates that traditional stilt houses achieve moderated thermal conditions through the combined use of low thermal mass materials, selective envelope layering, elevated structures, and natural ventilation. This integrated performance highlights the relevance of vernacular design principles as references for contemporary climate-responsive architecture. Future research should therefore extend monitoring across multiple seasons and building typologies, incorporate dynamic thermal comfort indices and occupant behaviour, and further investigate how underfloor ventilation strategies may be reinterpreted in modified stilt houses to reconcile functional demands with passive cooling performance.

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6.0 REFERENCES

Arminda, W., & Kamaruddin, M. (2021). Heat Transfer Through Building Envelope Materials and Their Effect on Indoor Air Temperatures in Tropics. *Original Article Journal of Science and Applicative Technology*, *5*(2), 403–410. https://doi.org/10.35472/jsat.v5i2.630

Awang, H., Arminda, W., & Richard, A. O. (2019). Reduction of indoor air temperature by using pofa foamed concrete block. *International Journal of Integrated Engineering*, *11*(9 Special Issue).

Darmayanti, T. E., & Bahauddin, A. (2020). Pengaruh perubahan sirkulasi terhadap fungsi ruang di rumah Peranakan, Kampung Babagan, Lasem. *ARTEKS : Jurnal Teknik Arsitektur*, *5*(2), 265–276. https://doi.org/10.30822/arteks.v5i2.403

Jin, Y., & Zhang, N. (2021). Comprehensive assessment of thermal comfort and indoor environment of traditional historic stilt house, a case of dong minority dwelling, China. *Sustainability (Switzerland)*, *13*(17). https://doi.org/10.3390/su13179966

Kamaruddin, M., Arminda, W., & Sukrayane, K. (2021). Application of Natural Ventilation Principle in Bandar Lampung Office Building Design. *Advanced Sustainable Engineering*, *01*(01).

Kareem Abdullah, H., & Hashim Faraj, S. (2022). Experimental study for the effect of air gap in building walls on heat gain reduction. *Materials Today: Proceedings*, *61*, 1043–1051. https://doi.org/https://doi.org/10.1016/j.matpr.2021.10.308

Kumar, A., & Suman, B. M. (2013). Experimental evaluation of insulation materials for walls and roofs and their impact on indoor thermal comfort under composite climate. *Building and Environment*, *59*(2013), 635–643. https://doi.org/10.1016/j.buildenv.2012.09.023

Mohd Arshard, W. N. R., Arminda, W., & Raja Abdul Kadir, T. A. Q. (2022). Indoor and Outdoor Air and Lighting Quality Assessment in High-Rise Lo-Cost Housing in Penang. *PLANNING MALAYSIA*, *20*(21 SE-Article). https://doi.org/10.21837/pm.v20i21.1107

Rattanongphisat, W., & Rordprapat, W. (2014). Strategy for energy efficient buildings in tropical climate. *Energy Procedia*, *52*, 10–17. https://doi.org/10.1016/j.egypro.2014.07.049

Rostiyati, A. (2013). Typology of Traditional House of Wana Village in East Lampung. *Patanjala*, *5*(3), 459–474.

Setianingrum, L. (2021). Susunan Spasial Desa Wana sebagai Desa Tradisional Keratuan Melinting, Lampung Timur. *Jurnal Planoearth*, *6*(1), 62–70.

Tienthavorn, T. (2024). Conserving Thailand’s Wooden Built Heritage: Developments, Approaches, and Current Challenges. *Nakhara: Journal of Environmental Design and Planning*, *23*(1), 1–20. https://doi.org/10.54028/NJ202423404

Ulum, M. S., Arminda, W., Kamaruddin, M., & Satria, W. D. (2023). Ventilation Performance of Air Duct in Double Loaded Corridor Building: A Case Study. *Civil Engineering Journal (Iran)*, *9*(10), 2445–2455. https://doi.org/10.28991/CEJ-2023-09-10-06

Wicaksono, B., Siswanto, A., Kusdiwanggo, S., & Anwar, W. F. F. (2019). Functional changes of under stilt houseas an effort of adaptation and adjustment in settlement. *International Journal of Engineering and Advanced Technology*, *9*(1), 3543–3551. https://doi.org/10.35940/ijeat.A2684.109119