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Bengkilas in the Palembang *Limas* House, Indonesia: Integration of Thermal and Social Zoning

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Abstract

Limas houses in Palembang exemplify vernacular architectural systems that embody both cultural identity and climate-responsive design. Among their defining spatial features is the *bengkilas*, a tiered, partitionless floor system traditionally linked to social hierarchy. This study investigates the *bengkilas* as an integrated spatial mechanism for vertical thermal zoning and social stratification. Employing a mixed-methods approach within a multi-case study design, data were collected through architectural observation, occupant interviews, and systematic thermal measurements (temperature, relative humidity, and air velocity) across two seasonal periods. The results reveal a consistent pattern of vertical temperature stratification (up to 4.6°C difference), where upper tiers are cooler and better ventilated. Qualitative findings further demonstrate that spatial elevation corresponds with perceived comfort and with varying levels of privacy and symbolic meaning. These converging insights support the formulation of a thermal–social zoning model rooted in cultural logic and passive environmental performance. The study contributes a contextual framework for sustainable tropical housing design that integrates spatial, thermal, and social dynamics within a unified architectural strategy.

1.0 INTRODUCTION

Climate change and increasing urban temperatures have emerged as major challenges in the design of tropical buildings, particularly in Southeast Asia, where high thermal stress and extreme humidity are prevalent. The rising cooling load due to the urban heat island effect, coupled with the inefficiency of ventilation systems, demands design strategies that are not only energy-efficient but also socially and ecologically contextualized (Numan et al., 2024; Ramezani & Reza, 2022). In this context, passive design has regained a strategic position in achieving natural thermal comfort without reliance on mechanical systems (Chen et al., 2020; Shaeri et al., 2018).

Studies on tropical passive design strategies have generally concentrated on horizontal elements such as building orientation, cross-ventilation, and the use of local materials (Austin et al., 2022; Taheri et al., 2022). In contrast, the potential of vertical thermal zoning, particularly when rooted in vernacular architectural traditions, has received limited scholarly attention. Traditional stilt houses in Southeast Asia have long utilized elevation differences and large roof volumes to facilitate natural airflow and temperature gradation (Lotfabadi & Hançer, 2019; V. Rahman & Wibowo, 2021).

One notable example of Indonesian vernacular architecture with such potential is the *Limas* house in Palembang, which features a unique architectural element known as *bengkilas*, a tiered floor system without solid partitions. Historically, this element was employed to organize social hierarchy and domestic rituals, yet its thermal performance remains underexplored. Previous studies have largely focused on the symbolic and spatial functions of the *bengkilas* (Aziz et al., 2021; Choo et al., 2024; Kustiani et al., 2023), while indications of its capacity to regulate thermal comfort have remained mostly speculative.

This research responds to the need to bridge the gap between spatial socio-cultural meaning and thermal performance in tropical architectural practices. Employing a multiple-case study design and a mixed-methods approach, this study investigates how the vertical configuration of *bengkilas* generates natural temperature stratification while simultaneously accommodating social structures within a single spatial system. Here, *Limas* houses are positioned as a culturally adaptive system that integrates ecological and social logic into its spatial configuration.

The main contribution of this research is the formulation of an integrated vertical zoning model, a spatial system that is simultaneously thermally effective and socially meaningful. This model broadens the discourse on contextual sustainability and reinforces the relevance of vernacular architecture as a valuable knowledge source for future tropical design strategies. The study aims to contribute to a broader theoretical framework regarding how tropical residential typologies can be developed through interdisciplinary approaches that combine microclimatic and socio-cultural resilience.

By focusing on actively inhabited houses in the Palembang area as the primary case context, this study strengthens the argument that indoor comfort in tropical climates cannot be adequately assessed solely through physical parameters; rather, it must be understood as the result of interactions among spatial configurations, occupant behavior, and internalized local value systems. To reinforce this understanding, the study proposes enriching the theoretical framework through integration of a socio-ecological resilience approach (Latif & Kosman, 2017). Within this framework, traditional architecture is conceived as a socio-ecological system capable of adapting to environmental change while preserving cultural identity. This principle enables the reinterpretation of elements such as *bengkilas* as trans-systemic design models, elements that are simultaneously ecological, social, and symbolic, supporting the development of contextual tropical architecture that is resilient to both climatic and socio-cultural transformations (Maharika et al., 2020; Salura et al., 2020)

2.0 LITERATURE REVIEW

2.1 Social Zoning in Traditional Architecture

In traditional architecture, space is organized not only functionally but also socially. Differences in elevation, materials, orientation, and accessibility often reflect social status and establish gradations between public and private zones (Tondi & Iryani, 2018; Widodo, 2012). These boundaries can be physical or symbolic, marked by ornaments, colors, or invisible customary norms (Aslan, 2017; Ibrahim et al., 2020). Furthermore, the spatial division in many vernacular traditions reflects cosmological systems, such as the separation between the profane and the sacred. As argued by Oliver (2007) and Rapoport (1969), traditional space is not merely physical, but part of a system of meanings that governs how people live and interact with the universe.

2.2 Thermal Zoning Principles and Strategies

Thermal zoning aims to create temperature and airflow gradients within a space, allowing occupants to adapt to more comfortable sub-zones according to their needs (V. Rahman & Wibowo, 2021; Shaeri et al., 2018). This strategy involves the interaction of natural factors such as sunlight, wind, and humidity with the properties of building materials (Austin et al., 2022; Wu et al., 2022). In tropical regions, thermal zoning has long been practiced through natural ventilation, strategic building orientation, use of local materials, and high roof structures that promote passive cooling (Allouzi et al., 2022; Nawayai et al., 2023; Rizal et al., 2021; Taheri et al., 2022). These techniques enable the design of tropical spaces that are adaptive, energy-efficient, and environmentally responsive.

2.3 Linkages between Social and Thermal Zoning

In vernacular architecture, social and thermal zoning are often interrelated, forming an integrated spatial system. The arrangement of space typically accounts for both thermal comfort and social hierarchy (Aslan, 2017; Tondi & Iryani, 2018). Public areas are usually designed to be open and cool, while private spaces tend to be quieter and thermally stable (Shaeri et al., 2018). The type of activity also influences thermal design: spaces for active functions require ample air circulation, while reflective or contemplative spaces benefit from thermal stability (Nicol, 2004; Wu et al., 2022). Cultural values play a central role in defining comfort, making the socio-thermal connection essential (Fouseki et al., 2020), particularly when analyzing architectural elements like *bengkilas* in *Limas* houses.

2.3 Bengkilas as a Socio-Spatial Element

The *bengkilas* in *Limas* houses is not merely a visual feature, but a spatial structure that reflects and organizes social order through its varying tiered elevations (Aziz et al., 2021; Choo et al., 2024). The highest tier is typically reserved for honored guests, the middle tiers for family members and close associates, and the lowest tier for casual visitors or everyday public interactions, symbolizing a social structure internalized within the built environment. Although the cultural significance of *bengkilas* has been widely discussed, its thermal aspects remain underexplored. In practice, these elevation differences likely create variations in temperature and air circulation that naturally support passive thermal comfort.

2.4 Conceptual Synthesis and Direction of Study

Understanding *bengkilas* as both a social and a thermal element requires an interdisciplinary approach. This study combines physical data, including measurements of temperature, wind speed, and relative humidity, with occupant perceptions to understand how thermal comfort and social structure interact within a single spatial system (Nicol, 2004; Wu et al., 2022). Previous research shows that even modest elevation differences can generate significant vertical microclimates (Lotfabadi & Hançer, 2019). The study also considers vertical air circulation and hygrothermal conditions typical of humid regions such as Palembang (Hermawan et al., 2020; Muslimsyah et al., 2024). By linking objective data with subjective experiences, this research positions *bengkilas* as a comprehensive social-and-thermal zoning system, which is relevant for developing efficient, contextual, and locally grounded tropical architecture.

3.0 METHODOLOGY

3.1 Research Approach

This research applied a mixed-methods approach in a multi-case study design, combining qualitative and quantitative techniques in an integrated manner. Such an approach is appropriate for studying complex socio-physical phenomena, particularly those related to the thermal and social functions of architectural elements in specific cultural contexts (Creswell & Clark, 2017). The use of multiple case studies allows for an in-depth exploration of the *bengkilas* space in functioning *Limas* houses in Palembang, South Sumatra.

3.2 Geography and Climatic Conditions in Palembang

Palembang is characterized by a humid tropical climate, with high annual rainfall exceeding 2,800 mm and average air temperatures ranging between 24 °C and 33 °C (Siswanto & Kusumawaty, 2021). Relative humidity frequently surpasses 75%, even at night, and is accompanied by low wind speeds, conditions that make passive ventilation strategies particularly critical (Figueiredo et al., 2021). Culturally, Palembang retains a household social structure that continues to utilize tiered domestic spaces in *Limas* houses, especially during traditional ceremonies and daily extended-family activities (Al-Faris & Herwandi, 2024; Aziz et al., 2021; Aziz & Aziz, 2022).

3.3 Case Selection Technique and Characteristics

Three *Limas* houses were selected using purposive sampling based on the functionality of the *bengkilas* space, the authenticity of the structure, and the status of active occupancy. These houses represent variations in the number of *bengkilas* tiers (two, three, and four tiers), capturing a spatial spectrum relevant for thermal and social analysis. Details of the case study characteristics and selection considerations are presented in **Table 1**.

Table 1. Characteristics and Selection Rationale of Case Studies

No	Location	Number of *Bengkilas* Tiers	Occupancy Status	Building Condition	Selection Rationale
1	Palembang	2 tiers	Active	Authentic	Represents minimum zoning configuration
2	Palembang	3 tiers	Active	Authentic	Medium type, balanced representation
3	Palembang	4 tiers	Active	Authentic	Highest spatial complexity

3.4 Data Collection Technique

The data collection process integrated architectural observations, in-depth interviews, and systematic measurements of thermal parameters across two different seasons. Each method was tailored to the specific data needed and was implemented consistently across all case study houses. **Table 2** summarizes the data types, collection methods, and technical details of implementation.

Table 2. Data Collection Techniques and Instruments

Data Type	Method / Source	Instruments / Quantity	Timing & Duration	Primary Objective
Observation	Direct architectural documentation	Camera, sketches, field notes	August 2024	Spatial and material identification of *bengkilas*
Interview	Semi-structured interviews	Audio recorder; 6 residents + 2 experts	August 2024	Perceptions of comfort and social function
Temperature & RH	Automated logging (HOBO MX2302A)	5 points per house (each tier + one exterior)	August 2024 (dry season) & January 2025 (rainy season)	Seasonal temperature and humidity stratification profiles
Air Velocity	Automated logging (hot-wire anemometer)	5 points per house (each tier + one exterior)	August 2024 & January 2025	Seasonal inter-tier natural ventilation profiles
Measuremen t Points	*Applied to all sensor measurements*	1.1 m above floor level (per point)	Consistent across all case houses	Representative of occupants' typical activity height zones
Recording Interval	*Applied to all sensor measurements*	Automated logging every 15 minutes	24 hours x 5 days per season x 3 houses	Aggregated to construct representative daily trends

Interviews were conducted with six residents from the three case-study houses, along with two local cultural figures. Participants were purposively selected to represent a range of domestic roles, including heads of households, homemakers, and younger family members, in order to capture diverse perspectives on thermal comfort and on the socio-spatial meanings of the *bengkilas* configuration. The inclusion of cultural informants provided additional context to strengthen the interpretation of *bengkilas* spatial arrangements from a socio-cultural perspective.

Thermal data collection was carried out during two main seasonal periods, the dry season (August 2024) and the rainy season (January 2025), with each monitoring phase lasting five full days per house. Data were recorded automatically every 15 minutes over 24-hour cycles, generating representative daily patterns for analyzing temperature, humidity, and wind speed variations across the vertical zones created by the *bengkilas* structure.

3.5 Data Analysis Technique

The analysis in this study used a convergent mixed-methods approach, where qualitative and quantitative data were analyzed separately before being integrated to form a comprehensive understanding of the thermal–social zoning phenomenon in the elevated spaces. The analysis process was designed to explore the interrelationships between user perceptions, spatial characteristics, and empirical thermal condition data. Details of the analytical techniques for each data type are presented in **Table 3**.

Table 3. Summary of Data Analysis Techniques

Data Type	Analytical Technique	Reference / Approach	Analytical Objective
Qualitative	Thematic analysis of interviews	Braun & Clarke (2006)	Identify perceptions of thermal comfort, spatial function, and social meanings
	Spatial analysis of documentation	Field observations, sketches, photographs	Map physical arrangements, airflow patterns, and *bengkilas* spatial form
Quantitative	Descriptive statistics (mean, min, max)	Aggregation of 15-min logger data	Construct temperature, RH, and air velocity profiles by tier and time period
	Comparative analysis	Cross-case and indoor–outdoor (seasonal) comparisons	Identify vertical thermal zoning patterns across cases and conditions
Integrative	Explanation building	Complementarity principle (Creswell & Clark, 2017)	Interpret the social meanings of measurable thermal phenomena
	Triangulation of findings	Convergent interpretation of qualitative and quantitative results	Develop a comprehensive understanding of the *"thermal–social zoning"* concept

To clarify the progression of the study, the four methodological stages described above are visually summarized in **Figure 1**.

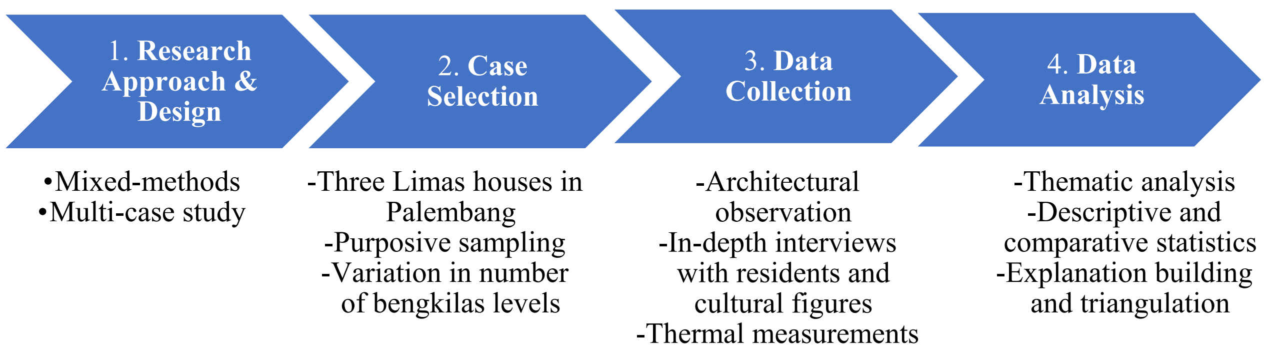


Figure 1. Research methodology stages in a mixed-methods approach

4.0 RESULTS AND DISCUSSIONS

4.1 Spatial Characteristics of *Bengkilas* in the Case Studies

All three case study houses have a *bengkilas*, a multi-tiered floor integrated into the main living space. Although the basic concept is similar across houses, the number of *bengkilas* tiers varies (two, three, and four tiers), reflecting differences in building length and, in some cases, the socio-economic status of the homeowner. Spatially, the width of each tier is generally determined by the module of the *dulang* (a traditional Palembang serving tray), resulting in an order derived from local cultural dimensions (Aziz et al., 2021). The length of each tier spans the full width of the house, creating elongated platforms without permanent internal partitions. This design allows for visual, social, and functional boundaries that are implicit yet strongly observed in daily practice.

The difference in floor height between adjacent tiers, ranging from approximately 30 to 50 cm, has a significant psychological and visual effect on the perception of space. This change in elevation also influences thermal distribution within the house, given that vertical displacement of air interacts with the large interior volume created by the typical high-pitched *Limas* roof. The roof serves as both a visually iconic element and a thermal buffer, amplifying natural temperature dynamics and ventilation effects over the *bengkilas* area. Figures 2 and 3 illustrate how the number of tiers shapes the spatial character of the house both visually and functionally.

(a)

(b)

Figure 2. *Limas* House with (a) Four *Bengkilas* Tiers and (b) Two *Bengkilas* Tiers

(a)

(b)

Figure 3. Interior of a *Limas* House with (a) Four *Bengkilas* Tiers and (b) Two *Bengkilas* Tiers

4.2 Thermal Performance and Zoning

Quantitative data on temperature, wind speed, and relative humidity in *Limas* houses with varying numbers of *bengkilas* tiers are summarized in **Tables 4–6**. The analysis revealed a consistent temperature stratification pattern: temperature tends to decrease as the *bengkilas* tier level increases, in both rainy and dry seasons. All case studies exhibited this phenomenon, indicating the natural formation of vertical thermal zones. Warmer air accumulates near the lower areas and circulates upward, dissipating heat as it rises; accordingly, the upper tiers remain cooler. This reinforces the role of the *bengkilas* spatial configuration in supporting effective passive thermal performance.

Table 4. Temperature, Air Velocity, and Relative Humidity in a *Limas* House with Four *Bengkilas* Tiers

Time (HH:MM)	**Season**	**Temperature (°C), Air Velocity (m/s), and Relative Humidity (%)**				
		Outdoor	***Bengkilas* 1 (Lowest)**	***Bengkilas* 2**	***Bengkilas* 3**	***Bengkilas* 4 (Highest)**
Morning (06:00–08:00)	Dry	26.5 / 1.2 / 90	25.8 / 1.0 / 88	25.5 / 0.9 / 87	25.3 / 0.8 / 86	25.0 / 0.7 / 85
	Rainy	26.8 / 1.5 / 92	26.2 / 1.3 / 90	26.0 / 1.2 / 89	25.8 / 1.1 / 88	25.5 / 1.0 / 87
Midday (12:00–14:00)	Dry	34.0 / 2.3 / 68	32.5 / 1.9 / 66	31.8 / 1.7 / 65	31.0 / 1.5 / 64	29.4 / 1.3 / 63
	Rainy	32.8 / 2.6 / 72	31.2 / 2.3 / 70	30.6 / 2.1 / 69	30.0 / 2.0 / 68	29.5 / 1.8 / 67
Afternoon (16:00–18:00)	Dry	30.8 / 1.9 / 76	29.5 / 1.6 / 74	28.8 / 1.5 / 73	28.2 / 1.4 / 72	27.8 / 1.3 / 71
	Rainy	29.3 / 2.3 / 79	28.2 / 2.0 / 77	27.8 / 1.9 / 76	27.5 / 1.8 / 75	27.2 / 1.7 / 74
Night (22:00–24:00)	Dry	27.0 / 1.1 / 86	27.3 / 0.9 / 84	27.5 / 0.8 / 83	27.8 / 0.7 / 82	28.0 / 0.6 / 81
	Rainy	24.8 / 1.4 / 89	25.3 / 1.2 / 87	25.5 / 1.1 / 86	25.8 / 1.0 / 85	26.0 / 0.9 / 84

Table 5. Temperature, Air Velocity, and Relative Humidity in a *Limas* House with Three *Bengkilas* Tiers

Time (HH:MM)	**Season**	**Temperature (°C), Air Velocity (m/s), and Relative Humidity (%)**			
		Outdoor	***Bengkilas* 1 (Lowest)**	***Bengkilas* 2**	***Bengkilas* 3 (Highest)**
Morning (06:00–08:00)	Dry	26.5 / 1.2 / 90	25.8 / 1.0 / 88	25.4 / 0.9 / 87	25.0 / 0.8 / 86
	Rainy	26.8 / 1.5 / 92	26.2 / 1.3 / 90	25.9 / 1.2 / 89	25.5 / 1.1 / 88
Midday (12:00–14:00)	Dry	34.0 / 2.3 / 68	32.2 / 1.9 / 66	30.8 / 1.7 / 65	30.0 / 1.5 / 64
	Rainy	32.8 / 2.6 / 72	31.0 / 2.3 / 70	29.8 / 2.1 / 69	28.8 / 2.0 / 68
Afternoon (16:00–18:00)	Dry	30.8 / 1.9 / 76	29.3 / 1.6 / 74	28.2 / 1.5 / 73	27.5 / 1.3 / 72
	Rainy	29.3 / 2.3 / 79	28.0 / 2.0 / 77	27.5 / 1.9 / 76	27.0 / 1.8 / 75
Night (22:00–24:00)	Dry	27.0 / 1.1 / 86	27.2 / 0.9 / 84	27.5 / 0.8 / 83	27.8 / 0.7 / 82
	Rainy	24.8 / 1.4 / 89	25.2 / 1.2 / 87	25.5 / 1.1 / 86	25.8 / 1.0 / 85

Table 6. Temperature, Air Velocity, and Relative Humidity in a *Limas* House with Two *Bengkilas* Tiers

Time (HH:MM)	**Season**	**Temperature (°C), Air Velocity (m/s), and Relative Humidity (%)**		
		Outdoor	***Bengkilas* 1 (Lower)**	***Bengkilas* 2 (Upper)**
Morning (06:00–08:00)	Dry	26.5 / 1.2 / 90	25.9 / 1.0 / 88	25.5 / 0.9 / 87
	Rainy	26.8 / 1.5 / 92	26.3 / 1.3 / 90	26.0 / 1.2 / 89
Midday (12:00–14:00)	Dry	34.0 / 2.3 / 68	32.5 / 1.9 / 66	30.9 / 1.7 / 65
	Rainy	32.8 / 2.6 / 72	31.2 / 2.3 / 70	29.9 / 2.1 / 69
Afternoon (16:00–18:00)	Dry	30.8 / 1.9 / 76	29.5 / 1.6 / 74	28.5 / 1.5 / 73
	Rainy	29.3 / 2.3 / 79	28.2 / 2.0 / 77	27.6 / 1.9 / 76
Night (22:00–24:00)	Dry	27.0 / 1.1 / 86	27.3 / 0.9 / 84	27.6 / 0.8 / 83
	Rainy	24.8 / 1.4 / 89	25.4 / 1.2 / 87	25.7 / 1.1 / 86

4.3 Vertical Temperature Stratification

A consistent pattern of vertical temperature stratification was identified in all case studies, especially during the daytime when solar radiation is at its peak (midday to late afternoon). Air temperature tends to decrease as the elevation of the *bengkilas* increases, with the highest tier generally exhibiting cooler conditions than the tiers below it.

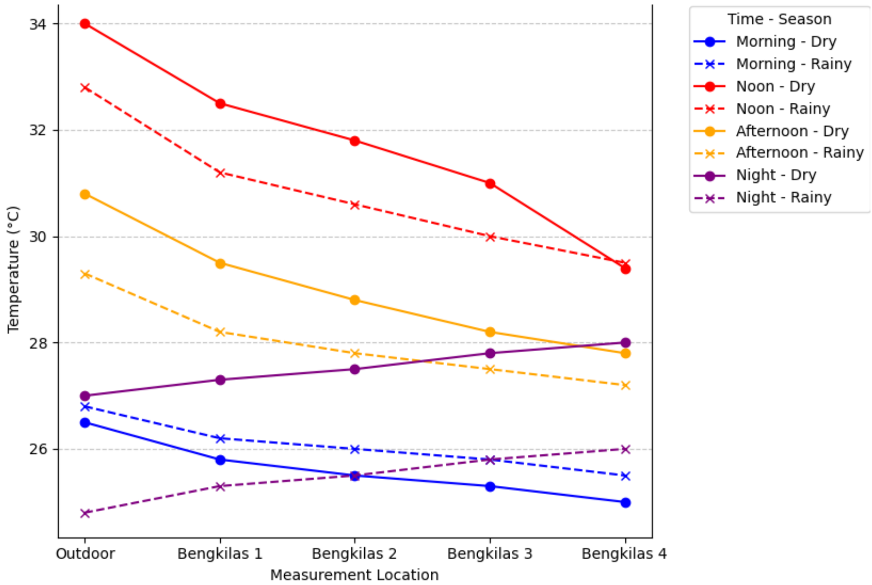
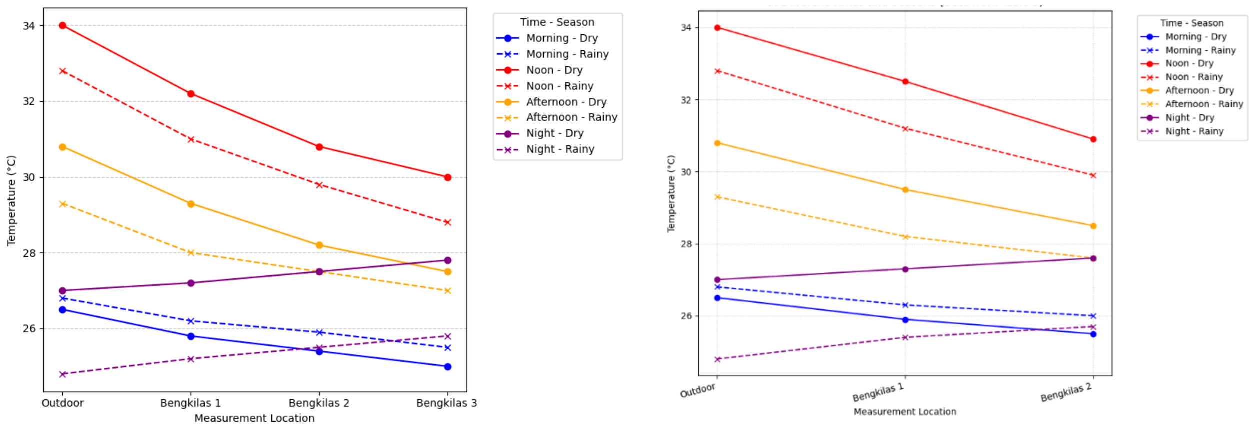


Figure 4. Temperature comparison across *bengkilas* tiers (example from a *Limas* house with four tiers).

This phenomenon is most pronounced in the house with four *bengkilas* tiers, which showed the greatest vertical temperature differences. This evidence confirms the crucial role of a multi-level spatial configuration combined with a large roof volume in facilitating vertical air movement. **Figure 5** illustrates the temperature differences between tiers in representative cases.



(a) (b)

Figure 5. Temperature Comparison Across *Bengkilas Tiers*: (a) *Limas* House with Three *Bengkilas*; (b) *Limas* House with Two *Bengkilas*

The observed stratification highlights the influence of vertical configuration and roof space as a reservoir for hot air. This pattern aligns with the principle of thermal buoyancy: warm air naturally moves upward toward high roof areas, leaving a relatively cooler layer below (Lotfabadi & Hançer, 2019; Muslimsyah et al., 2024; Wu et al., 2022). The open-plan design without interior partitions further facilitates this vertical air circulation.

These findings reinforce the hypothesis that *bengkilas* tiers serve not only as symbolic social elements but also as passive mechanisms that support vertical thermal zoning. The results are consistent with earlier research on temperature differences in open multi-level buildings, demonstrating how this principle specifically applies to *Limas* houses.

Notably, in the house with four tiers, the data show sharper temperature gradients between levels, strengthening the argument for the effectiveness of this vertical spatial system in shaping adaptive thermal environments in tropical climates. However, it should be noted that temperature measurements in this study were limited to air temperature (dry-bulb) and did not include mean radiant temperature (MRT), which is essential for a comprehensive evaluation of thermal comfort in the tropics (Nicol, 2004; Wu et al., 2022). MRT is typically estimated using globe thermometers, which were not available during this field study. Consequently, our interpretation of thermal comfort is constrained to air temperature, relative humidity, and wind speed, and does not fully capture the influence of radiant heat.

4.4 Effect of Number of *Bengkilas* and Spatial Complexity

Comparative analysis showed a positive correlation between the number of *bengkilas* tiers and the effectiveness of passive cooling. The maximum indoor–outdoor temperature differences during the day in the dry season reflect this correlation (**Table 7**). The more tiers a house has, the greater the maximum temperature difference recorded, indicating that a multi-level spatial configuration contributes to the formation of a more pronounced thermal stratification layer.

Table 7. Daytime Maximum Temperature Differences (Dry Season) by Number of *Bengkilas*

House (*Bengkilas* Tiers)	Highest Indoor Temperature (°C)	Outdoor Temperature (°C)	Max Temperature Difference (°C)	Spatial Volume (Relative)	Passive Cooling Potential
2 tiers	30.9	34.0	3.1	Low	Moderate
3 tiers	30.0	34.0	4.0	Medium	High
4 tiers	29.4	34.0	4.6	High	Very High

This finding suggests that having a more complex, multi-tiered interior space (which often implies greater internal volume and segmentation of activities) can enhance thermal layering and significantly reduce indoor temperatures relative to outdoors (Chen et al., 2020; Muslimsyah et al., 2024; Shaeri et al., 2018). However, it is important to note that we cannot confirm this relationship as a direct causal link, since many other factors (e.g., building orientation, window size and placement, local microclimate) also influence thermal performance and were not fully controlled in this study (Aziz et al., 2021; V. Rahman & Wibowo, 2021). In addition, in multi-tier houses, the increased internal surface area and spatial segmentation can affect airflow dynamics and heat transfer efficiency. Further studies, such as computational fluid dynamics (CFD) simulations, would be needed to isolate and examine these processes in detail (Chen et al., 2020; Rodriguez & Fumo, 2024).

Overall, these results reinforce the position of the *bengkilas* not only as a symbolic element in the socio-cultural structure of *Limas* houses but also as an active component of a passive climate-control system that is well-adapted to tropical conditions.

4.5 Variations in Wind Speed and Relative Humidity

Variations in wind speed and relative humidity between *bengkilas* tiers reflect the typical hygrothermal dynamics of *Limas* houses. As shown in **Figure 6**, indoor wind speeds are generally lower than outdoor wind speeds, especially during the day. This indicates a damping effect produced by the building envelope and spatial configuration, which creates a calmer and more thermally stable interior environment, conditions beneficial for occupant comfort, particularly during afternoon activities.

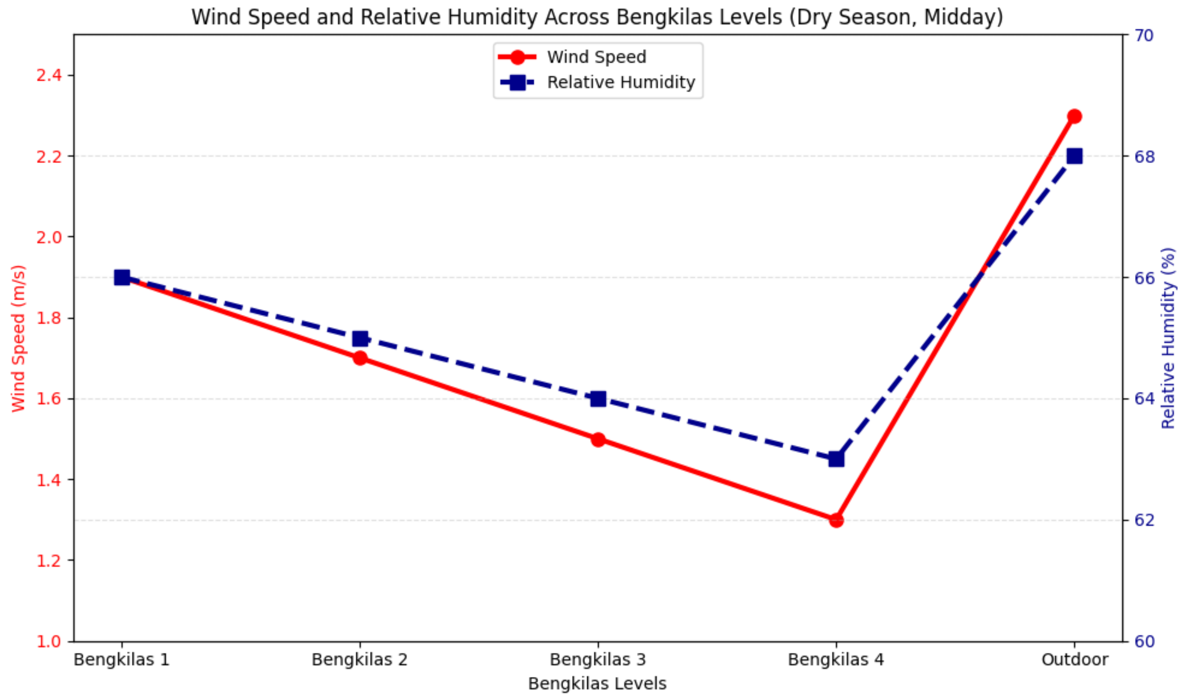


Figure 6. Wind Speed and Relative Humidity Across *Bengkilas* Tiers (Daytime, Dry Season)

Meanwhile, patterns of relative humidity (RH) showed more complex fluctuations and did not exhibit as clear a stratification as temperature. Although indoor RH was generally slightly lower than outdoor RH, differences among the tiers were inconsistent. This suggests that indoor humidity is influenced by additional factors such as the intensity of natural ventilation, the hygroscopic characteristics of building materials (particularly wood), and occupant behaviors (e.g., cooking, drying clothes) that add moisture to the air (Allouzi et al., 2022; Ramezani & Reza, 2022).

Interestingly, measurements taken at night, when windows were typically closed by occupants for security and privacy, showed indoor temperatures that were actually higher than outside. This can be attributed to reduced heat loss through convection and residual heat stored in the building materials. Such nighttime temperature stability could potentially improve comfort during sleep by preventing excessive cooling (Lotfabadi & Hançer, 2019; Muslimsyah et al., 2024; Nicol, 2004). Overall, these findings highlight the need for further research on how natural ventilation practices, window operations, and the moisture-absorbing qualities of local materials combine to create homes that adapt well to humid tropical climates.

To assess the potential for physiological thermal comfort, we compared the observed indoor airspeed range (approximately 0.7–2.3 m/s) with recommended thresholds for natural ventilation in humid climates. Nicol (2004) and Shaeri et al. (2018) suggest that air speeds around 1.3–2.4 m/s are effective in promoting evaporative cooling. In our cases, daytime wind speeds in several *bengkilas* tiers did reach this optimal range, although there was a significant drop in air movement at night. Considering relative humidity levels of about 64–68% and ambient temperatures between 25 °C and 34 °C during the day, the available ventilation can likely mitigate physiological heat stress for short periods, particularly under conditions of light activity and minimal clothing typical for the climate. However, accurately predicting comfort would require incorporating composite thermal indices (such as Predicted Mean Vote, PMV, or Standard Effective Temperature, SET), which were beyond the scope of this study.

4.6 Social Zoning and Occupant Experience

Qualitative findings from interviews and observations add layers of understanding that enrich the quantitative results, especially regarding how occupants use the space. The data show that the *bengkilas* tiers are not only spatially and thermally distinct but also carry strong social associations. Occupants consciously utilize the different tiers based on a combination of perceived thermal comfort and the social functions attached to each tier (see **Table 8**).

Each tier has a distinctive functional role and level of intimacy. The lowest tier, being relatively warmer and more open to the exterior, is used as a general reception area for casual visitors and community interactions. In contrast, the highest tier, cooler, more enclosed, and furthest from direct outdoor access, is regarded as a private and even sacred domestic space. This vertical arrangement represents a socio-spatial hierarchy consistently found in *Limas* house architecture (Aziz et al., 2021).

The harmony between thermal comfort and the symbolic value of space is exemplified by an elderly resident's comment describing the highest tier as "the coolest and most respected place." This remark underscores that comfort is not only a physiological state but is also influenced by cultural perceptions and inherited value structures.

Table 8. Integrative Spatial-Thermal-Social Analysis of a *Limas* House with Four *Bengkilas* Tiers

Tier	Guest Status / Intimacy Level	Primary Function	Roof Ceiling Distance	Orientation & Access	Occupant Perceived Comfort	Thermal & Social Interpretation
Tier 1 (lowest)	General guests	Reception, formal events	Farthest from roof	Faces front; adjacent to entrance	Warm; sometimes crowded	Representational space: heat tends to accumulate – suitable for short-term, formal use
Tier 2	Close friends / extended family	Informal gatherings, casual use	Higher than Tier 1	Central zone; near structural columns	Comfortable; semi-shaded	Transitional zone: balanced thermal conditions encourage social engagement
Tier 3	Special guests / household members	Ceremonial or meaningful interactions	Higher than Tier 2	Deeper interior; limited openings	Calm; cool	Semi-private and thermally stable – appropriate for extended use and respectful encounters
Tier 4 (highest)	Immediate family / domestic use	Daily domestic or sacred activities	Closest to roof	Deepest zone; minimal openings	Stable; enclosed	Highly private; optimal thermal comfort – functions as an introspective and ritual space

While **Table 8** presents an integrated overview of spatial and social zoning aligned with thermal characteristics, our current approach remains primarily descriptive and does not fully capture the dynamic performance of this system. In the context of tropical thermal comfort, variables such as metabolic rate and clothing insulation (clo) are critical determinants of how occupants actually feel (Nicol, 2004). Field observations indicated that residents typically engage in light activities (estimated 1.2–1.5 MET) while wearing lightweight clothing (clo ~0.4–0.5), especially during the day, conditions that theoretically align well with the recorded thermal environment on the upper tiers. However, due to the lack of quantitative measurements of these human factors, our comfort assessment remains indicative and based on perception.

To strengthen the social dimension of the analysis, we recommend incorporating additional methods such as Actual Mean Vote (AMV) surveys, which directly capture users' perceived comfort in each *bengkilas* zone. Similarly, behavior mapping could document the intensity, type, and spatial distribution of social activities across the tiers. Qualitative indicators such as frequency of use of each tier, satisfaction with the thermal ambiance, and the continuity of cultural practices (e.g., rituals, guest reception, daily family activities) are essential components that future research should expand upon. Integrating such data would enable a more robust evaluation of the relationship between thermal performance and social function in traditional zoning systems.

4.7 Integration of Thermal and Social Zoning: Thermal-Social Zoning System

The results of this study show that the *bengkilas* is not only a social zoning structure but also simultaneously forms a passive thermal comfort system inherently integrated into *Limas* house architecture. The vertical position of each tier correlates consistently with both temperature stratification and the privacy level of the space: the lowest tier is warmer and caters to more public functions, while the highest tier is cooler and supports the most private, domestic functions.

This dual layout is made possible by a combination of distinctive architectural elements: the stepped elevation between floor levels, the high volume of the roof, and the absence of full-height internal partitions. Together, these features support vertical air movement and create a thermal layering that is adaptive to the tropical climate while reinforcing the house's long-standing social hierarchy (Hariyanto et al., 2021).

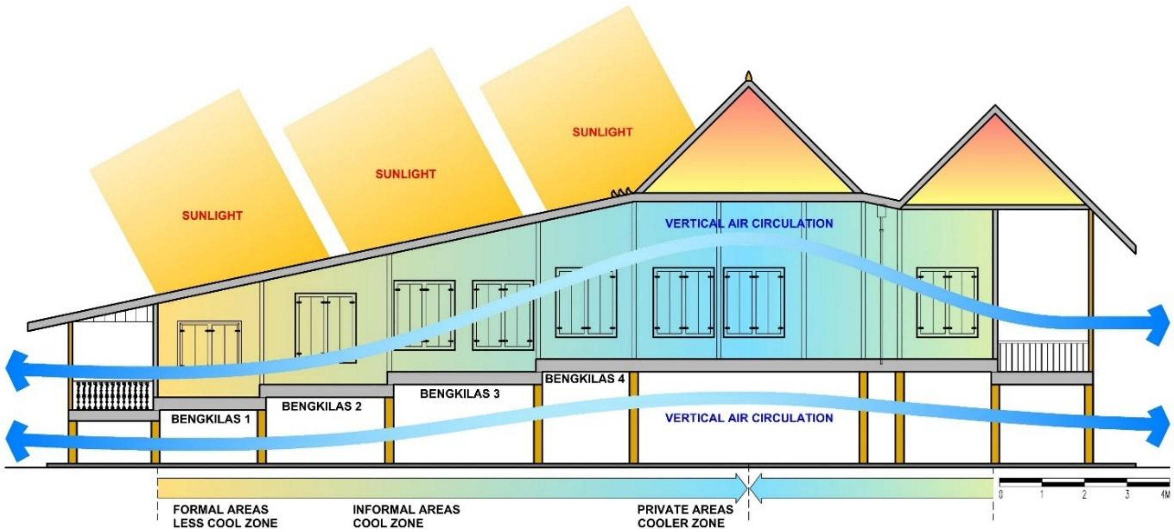


Figure 7. Thermal-Social Zoning Integration Mechanism in the *Limas* House.

Figure 7 schematically shows the relationship between the vertical position of *bengkilas* tiers, the direction of air circulation, and the social function of each zone. Although the thermal contribution of the raised floor system has not been quantitatively isolated in this study, the stilted construction of *Limas* houses is believed to help stabilize indoor temperatures by providing additional ventilation from beneath the floor.

In essence, the *bengkilas* functions both as a spatial symbol in Palembang's social value system and as an active element in a culture-based thermal comfort system. These findings enrich our understanding of vernacular architecture as a complex adaptive system, one that is not merely the result of traditional aesthetics, but a product of climatic and social logic refined over generations.

The principles observed in this thermal–social zoning system could inform both the preservation of traditional houses and the design of modern tropical buildings that need to be energy-efficient, comfortable, and legible in their layout. The primary contribution of this study lies in its integrative approach, which bridges thermal performance and socio-spatial meaning within a single vertical configuration. Most previous studies on traditional tropical houses (Allouzi et al., 2022; Lotfabadi & Hançer, 2019; V. Rahman & Wibowo, 2021) have tended to analyze thermal comfort and cultural dimensions separately. In contrast, this study positions the *bengkilas* as an architectural element that inherently unites two systems: a passive cooling mechanism and a social zoning framework. This approach expands the notion of sustainability from mere energy efficiency toward *cultural* sustainability, demonstrating that climate adaptation in traditional architecture is inseparable from embedded social values and local behavioral patterns.

Additionally, this research moves beyond the predominantly horizontal orientation that characterizes much of contemporary tropical design by proposing a culturally grounded, vertically layered zoning model. This contribution advances the discourse on contextual sustainability, an approach that integrates microclimatic features, spatial configurations, and social practices into a cohesive adaptive system, offering a viable framework for future tropical architecture (Muslimsyah et al., 2024; Rodriguez & Fumo, 2024).

4.8 Thermal-Social Zoning Conceptual Models and Design Principles

Based on this study's findings, the *bengkilas* can be seen as a design model that brings together environmental comfort and social structure in one space. Contemporary tropical architectural design can incorporate three main principles derived from this model:

1) **Vertical stratification for passive cooling:** Utilize vertical separation and stratification. Elevation differences between floor tiers create significant natural temperature gradients, reinforced by high roof volumes and open interior layouts. Studies indicate that higher elevated spaces tend to have more stable temperatures and better support passive cooling.
2) **Optimizing ventilation and vertical airflow:** Design for unobstructed vertical air circulation. A configuration without full-height partitions allows warm air to rise and escape through roof apertures, while cooler air can be drawn from underneath (in stilted structures). This creates efficient air movement without mechanical assistance, maintaining a calm, adaptive indoor climate in humid tropical conditions.
3) **Managing spatial depth and orientation:** Consider the depth of spaces from the building facade and their orientation toward openings. Areas farther from the main facade (deeper inside) are more shaded and thermally stable, making them suitable for private functions, whereas zones closer to openings are brighter, warmer, and better suited for public functions. Orienting spaces thoughtfully with respect to natural light and prevailing winds is crucial in balancing comfort and social usage.

These three principles demonstrate that vernacular architectural elements like the *bengkilas* are not only culturally significant but can also inspire conceptual strategies for sustainable design. They support the integration of thermal efficiency, climate adaptation, and clear social zoning in contemporary architecture.

4.9 Interdisciplinary Perspectives and Future Relevance

In traditional Palembang architecture, social zoning systems were not explicitly designed in response to thermal parameters but were rooted in inherited value structures and longstanding social relations (Angkasa & M. Kamil, 2024; Hasan et al., 2022). Spatial organization was primarily governed by household hierarchy, the sanctity of certain spaces, and patterns of guest reception, such that thermal comfort emerged as a passive byproduct embedded within cultural logic (Tatarestaghi et al., 2018). Paradoxically, within this historical subordination of thermal considerations to social values lies a potential insight for future design: spaces configured around social meaning can also inherently achieve adaptive and efficient environmental performance (Azmi et al., 2017; Quoc et al., 2024). Empirical findings from this study reveal that the spatial stratification created by the *bengkilas* not only governs social interaction patterns but also produces natural thermal zoning without mechanical intervention (Therán-Nieto et al., 2023). This suggests that local architectural practices embed integrative strategies that could be revitalized to meet contemporary tropical climate challenges in a more human-centered manner (Askari & Soltani, 2018; A. A. Rahman et al., 2022).

To reinforce this understanding, we propose enriching the theoretical framework with the concept of socio-ecological resilience (Latif & Kosman, 2017). Within such a framework, traditional architecture can be viewed as a socio-ecological system capable of adapting to environmental changes while preserving cultural identity. This perspective enables a reinterpretation of elements like the *bengkilas* as **trans-systemic design models**, design elements that are simultaneously ecological, social, and symbolic, supporting the development of contextual tropical architecture resilient to both climatic and socio-cultural transformations (Maharika et al., 2020; Salura et al., 2020).

5.0 CONCLUSIONS

This study demonstrates that the *bengkilas* configuration in Palembang's *Limas* houses is not merely a visual cultural element, but a spatial structure that simultaneously governs social zoning and passive thermal stratification. Through a multiple case study and mixed-methods analysis, we found consistent evidence that the more complex the tiered *bengkilas* structure, the more effectively it facilitates both natural temperature gradation and the framing of domestic social functions. These findings broaden our understanding of tropical residential typologies in Southeast Asia by emphasizing that achieving thermal comfort relies not only on technical engineering solutions but also on local value systems and social structures.

The main contribution of this research is the formulation of a vertically integrated zoning model that is both socially and environmentally responsive, offering a reference framework for context-sensitive tropical architectural design. This model bridges the longstanding disjunction between thermal performance and cultural values, which are too often treated separately in contemporary practice. By focusing on residential dwellings in the Palembang region as a representative case, the research reinforces the position of vernacular architecture as a source of adaptive design knowledge that remains ecologically and socially relevant.

Nevertheless, several limitations must be acknowledged. First, the study did not include detailed physiological measurements of occupants (such as metabolic rate, clothing insulation, or mean radiant temperature), all of which are crucial in tropical thermal environments. Second, we lacked longitudinal behavioral data, which limits insights into long-term patterns of spatial use. Third, this study did not assess dynamic conditions such as high-occupancy scenarios during communal events or large family gatherings, which could significantly alter thermal distribution and airflow patterns.

Furthermore, since our research was limited to residential *Limas* houses in the Palembang area, the generalizability of the findings to other regions with different typologies or climates is constrained. Future research should therefore focus on: (1) developing simulation models (e.g., CFD) to examine vertical airflow dynamics more precisely; (2) incorporating composite thermal comfort indices such as PMV and SET for a more holistic comfort assessment; and (3) integrating behavioral mapping and Actual Mean Vote (AMV) surveys to evaluate user experiences across different zones and social layers over time.

By expanding our interdisciplinary approach to include socio-cultural resilience and micro-ecological adaptation, future studies are expected to produce tropical housing prototypes that are not only energy-efficient but also deeply rooted in local values and highly adaptive to both climatic challenges and evolving lifestyles.

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