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Thermal Performance and Natural Ventilation in Javanese *Joglo* Architecture: A Systematic Literature Review from an Ethnophysics Perspective

Q A'yun[1], R T Lintangesukmanjaya[1]*, O Ramadhani[1], H Latifah[1], Dwikoranto[1], L N Bergsma[2]
[1]Department Physics Education, Universitas Negeri Surabaya, Surabaya, Indonesia
[2]Department TSB, Tilburg University, Tilburg, Netherland
*Corresponding Author: rahmattathoriq.20038@mhs.unesa.ac.id

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ABSTRACT

Traditional Javanese *Joglo* architecture is widely recognized for its climatic adaptability; however, systematic understanding of its thermal performance and natural ventilation mechanisms, particularly from an ethnophysics perspective, remains limited and fragmented, with existing studies addressing cultural interpretations and building-physics performance separately. This study aims to synthesize existing research on the thermal and ventilation performance of *Joglo* and *Joglo*-type Javanese architecture and to interpret the findings through the lens of ethnophysics, linking cultural architectural practices with underlying physical principles. A systematic literature review was conducted following the PRISMA framework, resulting in six Scopus-indexed open-access studies published between 2017 and 2025. The reviewed studies employed computational simulations, field measurements, and qualitative analyses to examine indoor thermal conditions, airflow behavior, architectural geometry, and material characteristics. The synthesis reveals that thermal comfort in *Joglo* and *Joglo*-type architecture is primarily achieved through passive strategies. The reviewed evidence suggests that comfort is driven more by airflow and heat exchange processes than by substantial reductions in indoor air temperature. Wind-driven horizontal ventilation dominates in *Joglo* architecture, while comparative vernacular cases demonstrate complementary buoyancy-driven and material-mediated airflow mechanisms. These findings indicate that traditional architectural forms embody empirically grounded applications of heat transfer and fluid mechanics developed through cultural adaptation. Ethnophysics bridges traditional architecture, building physics, and physics education by linking *Joglo* design with heat transfer and airflow principles. This review helps readers understand indigenous architecture as applied physics, supporting physics education, sustainable design, and interdisciplinary research on vernacular adaptation.

INTRODUCTION

Vernacular architecture is widely understood as the outcome of long-term interactions between human practices, local environmental conditions, and culturally embedded knowledge systems developed through empirical adaptation. Recent studies consistently indicate that vernacular buildings in tropical regions often demonstrate more adaptive environmental performance than conventional modern buildings, particularly in terms of thermal regulation and natural ventilation (Beccali et al., 2018; Toroxel & Silva, 2024; Yang et al., 2022). Empirical and simulation-based research reported in the literature shows that architectural form, roof geometry, opening configuration, and the use of local materials significantly influence heat transfer processes and airflow behavior, thereby shaping indoor thermal comfort (Cui, 2024; Jia et al., 2021; Kistelegdi et al., 2022). From a sustainability perspective, vernacular buildings are frequently regarded as environmentally responsive systems, as their passive design strategies are derived from accumulated local experience in responding to specific climatic contexts without intensive reliance on mechanical conditioning systems (Nie et al., 2019; Philokyprou et al., 2017).

Among Indonesia's vernacular architectural forms, the *Joglo* house is especially important because it combines environmental adaptation with culturally embedded construction knowledge, making it a valuable context for ethnophysics-based investigation. Within the Indonesian context, the Javanese *Joglo* house represents a distinctive form of vernacular architecture characterized by a multi-tiered roof structure, expansive open interior spaces, and extensive use of natural materials. These architectural characteristics are commonly associated with enhanced thermal comfort and effective natural ventilation under humid tropical conditions (Chen et al., 2017; Lau et al., 2019; Gou et al., 2018). A substantial body of research on tropical vernacular buildings has examined the relationships between building geometry, spatial configuration, material properties, and climatic variables using field measurements, numerical simulations, and comparative analyses documented in previous studies (Chen & Hong, 2018; Rajput et al., 2021). The findings reported across these studies generally suggest that inherited passive design elements—such as high-pitched roofs, unceiled spaces, layered openings, and cross-ventilation—contribute to improved air exchange rates and enhanced thermal comfort. However, the reported magnitude of these effects varies considerably across studies due to differences in climatic conditions, building configurations, surrounding environments, and methodological approaches. In some cases, passive ventilation improves thermal comfort without substantially reducing indoor air temperature, indicating that airflow enhancement may play a more significant role than temperature reduction alone. (Vangelista, 2022).

More specifically, studies focusing on traditional Javanese houses indicate that the *Joglo* roof geometry plays a critical role in promoting buoyancy-driven airflow. The tiered roof structure creates a large upper air cavity that potentially supports buoyancy-assisted airflow; however, wind-driven ventilation remains dominant because the extensive side openings and open spatial configuration of *Joglo* houses facilitate continuous cross-ventilation driven by prevailing winds, while indoor outdoor temperature differences are generally insufficient to generate a strong stack effect. (Zhang, 2024; Monghasemi & Vadiee, 2018). Previous computational fluid dynamics and field-based studies reported in the literature further corroborate this mechanism by demonstrating increased airflow velocity, reduced heat accumulation, and improved thermal stratification in the primary living zones of *Joglo* houses (Kumar & Das, 2023; Ghosh et al., 2021). In addition, the presence of a large central space with minimal internal partitions supports more uniform air distribution, reinforcing the effectiveness of passive ventilation strategies embedded in traditional architectural practice.

Beyond their physical performance, *Joglo* houses are deeply embedded in Javanese cosmological principles that emphasize harmony between humans, nature, and the built environment. Spatial hierarchy and structural organization within *Joglo* architecture reflect symbolic meanings and cultural values that guide construction practices and spatial use (Santosa & Rachmawati, 2023; Idham, 2018). However, existing studies largely address these cultural dimensions through qualitative or interpretive approaches, while analyses of thermal performance and ventilation are typically conducted using building physics frameworks in isolation. As a result, the underlying physical principles governing heat transfer and airflow—such as natural convection, thermal buoyancy, and fluid flow dynamics—are rarely examined in direct relation to the cultural logic that shapes *Joglo* architecture (Basunbul, 2023).

From an ethnophysics perspective, this separation represents a substantive limitation in the existing body of knowledge. Ethnophysics emphasizes understanding physical concepts as they are embedded in, and transmitted through, culturally situated practices. Theoretically, this perspective is grounded in constructivist and sociocultural views of learning, which posit that scientific concepts are more meaningful when connected to learners' everyday experiences and cultural knowledge systems. In physics education, ethnophysics has been applied to interpret traditional technologies, local crafts, indigenous games, and vernacular practices as contexts for teaching concepts such as mechanics, thermodynamics, waves, and electricity. Although this perspective has gained increasing attention for contextualizing abstract concepts and enhancing conceptual understanding, its application to systematic syntheses of vernacular architecture studies remains limited. (Al-Kamzari & Alias, 2025; Salimpour et al., 2021). In the context of Javanese *Joglo* architecture, insights into thermal performance and natural ventilation remain dispersed across individual empirical and simulation-based studies, with no comprehensive synthesis that interprets these findings explicitly through an ethnophysics framework. Consequently, the potential of *Joglo* architecture as a culturally grounded context for understanding fundamental physics concepts—such as heat transfer mechanisms, natural convection, and airflow dynamics—has not been fully articulated. Based on a critical examination of the existing literature, two major research gaps can be identified. First, existing reviews of thermal performance and natural ventilation in tropical vernacular architecture tend to adopt a broad perspective and rarely examine Javanese *Joglo* architecture as a primary focus (Chung-Camargo et al., 2024). Second, studies on *Joglo* architecture remain fragmented across cultural and building-physics perspectives, with considerable methodological variation that hinders systematic synthesis and limits discussion of implications for sustainable design and physics education (Li & Yu, 2025; Mavromatidis, 2018).

In response to these gaps, this study conducts a systematic literature review focusing on the thermal performance and natural ventilation of Javanese *Joglo* architecture from an ethnophysics perspective. The objectives of this study are to: (1) synthesize empirical and simulation-based findings reported in the literature related to thermal and ventilation performance in *Joglo* houses; (2) identify dominant architectural features, physical mechanisms, and methodological trends discussed across existing studies; and (3) interpret these findings through an ethnophysics lens to support a contextualized understanding of thermal physics and fluid mechanics in physics education, as contextualized learning helps students relate abstract physics concepts to real-world and culturally meaningful experiences, thereby improving conceptual understanding and learning relevance. Various studies have examined aspects related to traditional Javanese architecture, building physics, and culture-based education. Gaffara et al. (2021) explain that the *Joglo* house is a Javanese cultural heritage that represents the philosophical, cosmological, and worldview of the Javanese people. From a building physics perspective, Nugroho (2024) examines the passive cooling performance of Javanese vernacular architecture and shows that traditional design characteristics contribute to building thermal comfort. Furthermore, Muqoffa et al. (2025) examines natural ventilation strategies in Javanese vernacular houses and shows how traditional designs support air circulation, thermal comfort, and energy efficiency. More broadly, Zong et al. (2025) through a systematic literature review identified various key themes in the development of sustainable vernacular architecture, including cultural characteristics, building structures, and the architectural environment. Meanwhile, Festiyed et al. (2024) conducted a systematic literature review on ethnophysical research in various cultures in Indonesia and emphasized the importance of exploring local culture as a source for physics learning. Studies on traditional Javanese houses have also been conducted by Dewi et al. (2025) through an ethnomathematics perspective, demonstrating the potential of local culture as a source for contextual learning.However, these studies still focus on separate aspects. Studies on *Joglo* and Javanese vernacular houses generally highlight cultural values, architectural characteristics, thermal performance, or natural ventilation individually. On the other hand, ethnophysical research focuses more on integrating local culture into physics learning without specifically linking it to the physical characteristics of Javanese *Joglo* architecture. A literature search using a combination of keywords such as "*Joglo* architecture," "thermal performance," "natural ventilation," "vernacular architecture," and "ethnophysics" revealed that previous studies generally discussed the cultural aspects of *Joglo* architecture, the thermal performance of vernacular buildings, natural ventilation, sustainable vernacular architecture, or ethnophysics separately. However, until this research was conducted, no systematic literature review had been found that specifically integrated and synthesized studies of thermal performance and natural ventilation in Javanese *Joglo* architecture from an ethnophysical perspective. Therefore, this study attempts to fill this gap by integrating the study of thermal performance and natural ventilation in Javanese *Joglo* architecture into an ethnophysical framework through a systematic literature review approach. This synthesis is expected to provide a more comprehensive understanding of the relationship between local wisdom, the environmental performance of buildings, and their use as a learning context for the concepts of heat transfer and natural convection in physics education.

RESEARCH METHOD

Research Design

This study uses a Systematic Literature Review (SLR) design to synthesize existing research findings on thermal performance and natural ventilation in traditional architecture within the Indonesian and Javanese contexts, with a particular focus on Javanese *Joglo* architecture interpreted through an ethnophysical perspective. In this study, thermal performance and natural ventilation were designated as the primary analysis themes because they directly align with the research objectives. Meanwhile, related concepts, such as thermal comfort, passive cooling, and ventilation effectiveness, were treated as supporting analysis categories. Specifically, thermal comfort was viewed as an outcome of thermal performance, passive cooling was positioned as a design strategy that contributes to thermal performance, and ventilation effectiveness was used as an indicator to assess the performance of natural ventilation. This classification was applied consistently throughout the literature search, article screening, data extraction, and thematic analysis. A systematic review approach was chosen to ensure transparency, methodological rigor, and reproducibility of the research. The review process was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which include the identification, screening, eligibility assessment, and inclusion of relevant studies. This research did not involve primary data collection, field measurements, experiments, or simulations. All analyses were based on previously published literature.

Research Procedure

The literature search and selection process was conducted on January 14, 2026, using the Scopus database. Scopus was chosen as the primary database because it is one of the largest multidisciplinary indexing databases that provides extensive coverage of reputable journal articles and has undergone a peer review process in the fields of architecture, environmental studies, engineering, and education. In addition, Scopus provides a structured search feature and a consistent indexing system, thus supporting transparency, consistency, and reproducibility in the implementation of the systematic literature review. The research procedure follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework which is implemented through four sequential stages: identification, screening, eligibility assessment, and inclusion. In the first stage, potentially relevant studies are identified through a structured keyword search. The second stage is filtering by applying limitations on publication year and document type. The third stage is an eligibility assessment based on language and field of study criteria. Furthermore, only open access publications were included to ensure transparency and reproducibility of the research. The complete literature selection process is presented in Figure 1, which shows the PRISMA flowchart for this study.

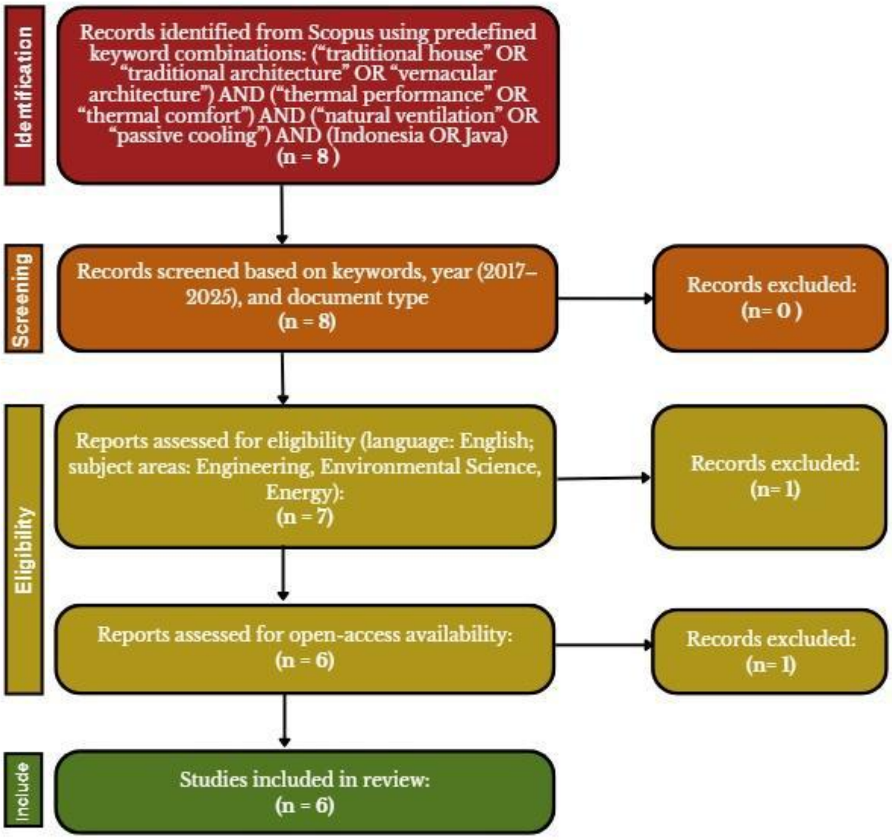

Figure 1. PRISMA flow diagram of the literature selection process.

Data Sources

The primary data source for this study was the Scopus database. Scopus was selected due to its broad coverage of peer-reviewed publications in architecture, engineering, environmental science, and energy-related fields, as well as its standardized indexing system. The use of a single, well-established database was intended to ensure consistency in document indexing and metadata quality across the reviewed studies. Scopus was preferred over platforms such as Google Scholar and Dimensions because it provides stricter journal quality control, more reliable citation indexing, and reduced risk of including non-peer-reviewed or duplicate records. In contrast, Google Scholar includes a broader but less curated set of sources, while Dimensions, although comprehensive, was not used to maintain consistency in database filtering criteria and to ensure replicability of the search strategy within a single controlled indexing system. This approach enhances transparency, reliability, and reproducibility of the review results.

Data Collection Techniques

Data collection was conducted using the Advanced Search feature in Scopus with the TITLE ABS–KEY field. The search strategy employed the following keyword combination: ("traditional house" OR "traditional architecture" OR "vernacular architecture") AND ("thermal performance" OR "thermal comfort") AND ("natural ventilation" OR "passive cooling") AND (Indonesia OR Java). The initial search yielded eight (n = 8) records. During the screening stage, the publication year was limited to 2017–2025, and the document types were restricted to journal articles and conference papers, resulting in eight (n = 8) screened records. In the eligibility stage, the language was restricted to English, and the subject areas were limited to Engineering, Environmental Science, and Energy, which reduced the number of eligible records to seven (n = 7). In the final inclusion stage, only open-access publications were retained. Thus, six (n = 6) studies met all inclusion criteria and were included in this systematic literature review. The relatively small number of studies reflects the highly specific focus of this review, which required publications to address Javanese *Joglo* architecture while also providing evidence related to thermal performance and/or natural ventilation. Most articles identified during the screening process discussed vernacular architecture, cultural values, or traditional houses in general, but did not specifically examine the thermal and ventilation characteristics of *Joglo* architecture. In addition, several studies were excluded because they did not meet the language, subject area, document type, or open-access criteria established for this review. Although only six studies met the inclusion criteria, the findings provide meaningful and reliable insights because all selected studies directly addressed the review objectives and consistently highlighted the role of architectural design elements in supporting thermal performance and natural ventilation in Javanese vernacular buildings. The consistency of findings across the included studies strengthens confidence in the identified themes and patterns. Nevertheless, the results should be interpreted within the scope of the available evidence and may serve as a foundation for future research involving broader geographical contexts, a wider range of vernacular building types, and larger datasets.

The publication period of 2017–2025 was selected to ensure that the review captures the most recent and relevant developments in building performance analysis, particularly advances in computational simulation methods, field measurement techniques, and sustainable building design approaches. This timeframe was considered appropriate because studies on thermal performance and natural ventilation in vernacular architecture have significantly increased in methodological rigor and technological accuracy within the last decade. English-language publications were selected to ensure consistency in data interpretation and to minimize translation bias during analysis. English is the dominant language in Scopus-indexed peer-reviewed journals, particularly in the fields of engineering and environmental sciences, and therefore provides the most standardized and internationally comparable scientific output. Although studies in other languages may exist, they were excluded to maintain methodological consistency, improve replicability, and ensure that all included articles could be evaluated using uniform academic and technical criteria.

Data Analysis Technique

Data analysis was conducted in two complementary stages. First, a descriptive synthesis was performed to summarize the general characteristics of the included studies, including publication year, research focus, methodological approach (field measurement, numerical simulation, or review), and reported findings related to thermal performance and natural ventilation. This stage provided an overview of research trends and methodological patterns within the selected literature.

Second, an ethnophysics-based analytical coding scheme was used to interpret the findings of the studies included in this review. The analysis was conducted by systematically identifying and grouping explicit and implicit physics concepts found in traditional architectural systems, particularly those related to heat transfer mechanisms (conduction, convection, and radiation), airflow dynamics, the stack effect, and material-based thermal behavior. Each article was manually coded using predetermined categories within a structured framework. The coded data were then synthesized to identify recurring patterns, which are then presented in the Results and Discussion section. In this study, buoyancy-driven airflow is coded as a vertical airflow mechanism that occurs due to differences in air density due to temperature variations. During the coding process, this phenomenon was identified when the study showed upward and downward air movement triggered by rising hot air and descending cold air within a building space. Thermal stratification is coded as a condition of uneven vertical temperature distribution within an interior space, characterized by the formation of a layer of warm air at the top and cooler air at the bottom due to minimal air mixing. In the coding analysis, this concept emerged as an indicator of the inhomogeneity of the space's thermal comfort. Natural ventilation effectiveness is coded as the degree of success of a natural ventilation system in improving thermal comfort without mechanical assistance. In the coding analysis, this concept was identified based on qualitative indicators such as increased airflow velocity, decreased room temperature, and the achievement of passive thermal comfort. Architectural elements such as roof geometry, spatial configuration, and opening systems were analyzed in relation to these physical principles, while cultural and contextual aspects were interpreted as factors shaping traditional design decisions. To enhance analytical rigor, the ethnophysics coding process was conducted iteratively by identifying recurring architectural features and mapping them to dominant physical mechanisms (wind-driven flow, buoyancy-driven flow, and material-mediated ventilation), followed by cross-checking interpretations across all included studies. By integrating PRISMA-based systematic synthesis with ethnophysics-oriented interpretation, this methodological approach enabled a coherent reconstruction of dispersed evidence, allowing Javanese *Joglo* architecture to be examined both as an environmentally adaptive vernacular system and as a culturally grounded context for understanding fundamental concepts of thermal physics and fluid mechanics.

RESULTS AND DISCUSSION

Scope of Reviewed Studies and Descriptive Synthesis

This systematic literature review synthesizes six Scopus-indexed open-access studies published between 2017 and 2025 that examine thermal performance and natural ventilation in Indonesian traditional and vernacular architecture. Three studies explicitly investigate Javanese traditional houses that structurally and thermally represent the *Joglo*-type system, in which roof geometry, spatial openness, and lateral openings form an integrated thermofluid system (i.e., a building system in which airflow and heat transfer are governed by the interaction between architectural form and natural driving forces such as buoyancy and pressure differences) governing indoor air movement and heat exchange (Suhendri & Koerniawan, 2017; Samodra & Irvansyah, 2021; Faisal et al., 2024). The remaining studies focus on other Indonesian vernacular houses—Rumoh Aceh, Mbaru Niang, and Bale Mangina—which are included as comparative cases to identify shared and contrasting physical mechanisms in tropical vernacular architecture, particularly in relation to passive environmental regulation strategies (i.e., design approaches that regulate indoor thermal conditions and airflow without mechanical systems) (Muslimsyah et al., 2025; Pinassang et al., 2021; Saptaningtyas et al., 2025).

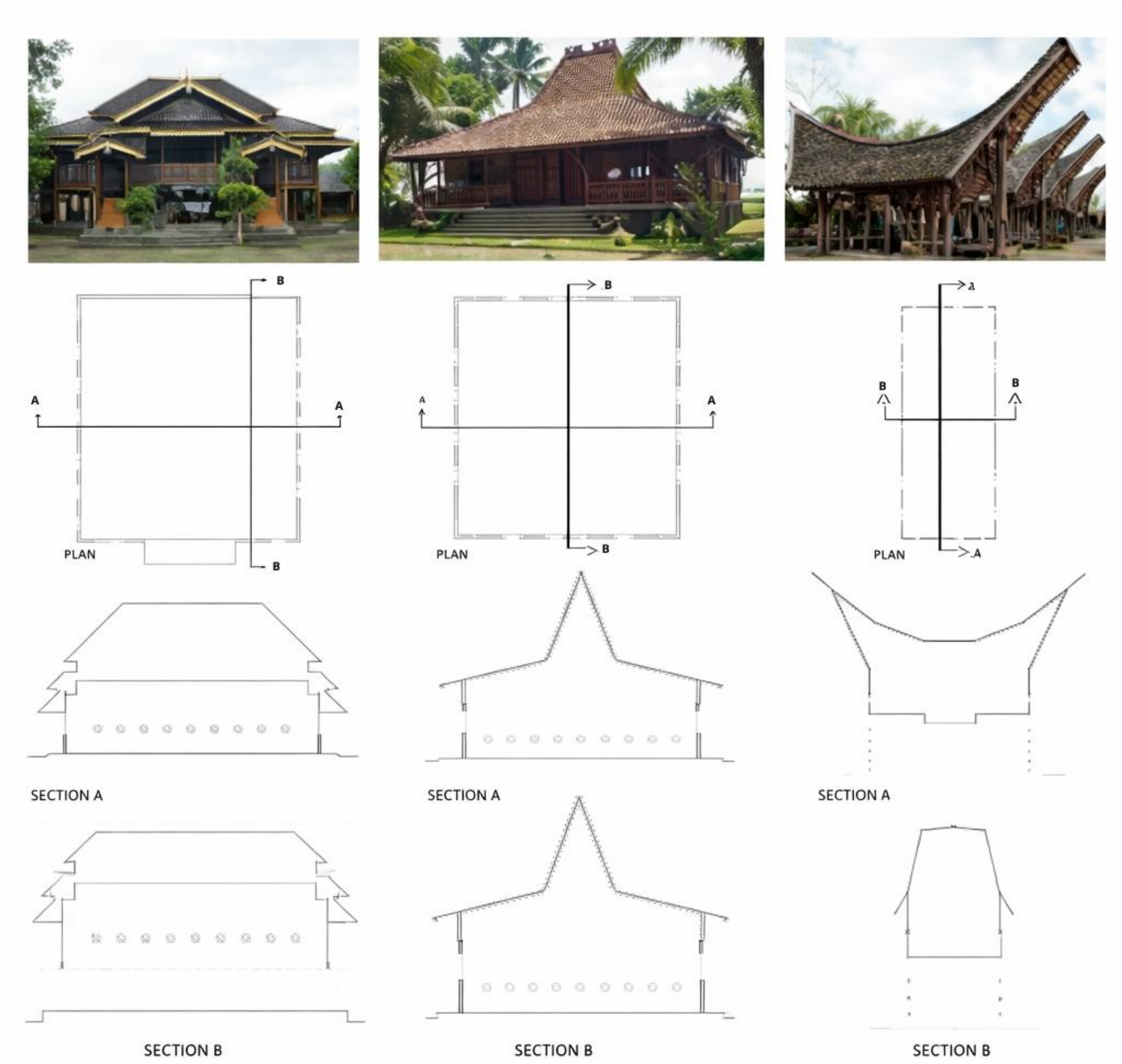

Figure 2. CFD model geometry of a *Joglo*-type house showing roof cavity and lateral openings. (Adapted from Suhendri & Koerniawan, 2017)

The computational geometry in Figure 2 defines the airflow and heat-transfer domain, where the high roof cavity acts as a thermal reservoir (i.e., a space that temporarily stores heat and moderates indoor temperature fluctuations due to its volume and reduced heat dissipation rate), while the open interior and lateral openings establish airflow pathways that regulate air movement and heat distribution. This configuration explains the performance of *Joglo* buildings as a passive thermofluid system rather than being understood solely as a cultural artifact. Methodologically, the reviewed studies employ a range of approaches, including Computational Fluid Dynamics (CFD) simulations, in-situ field measurements, numerical thermal analysis, and qualitative case studies. The primary variables investigated across the dataset include indoor air temperature, airflow velocity, opening configuration, roof geometry, and material properties, as well as passive ventilation strategies, which refer to design interventions that enhance natural air movement without mechanical assistance. A structured summary of the reviewed studies is provided in Table 1, which is presented at the end of this subsection to support the descriptive synthesis.

The descriptive synthesis indicates that existing research on Indonesian traditional architecture is predominantly performance-oriented, emphasizing environmental and thermal behavior rather than symbolic or cultural interpretation. However, substantial heterogeneity exists across studies in terms of climatic context, analytical methods, and thermal comfort indicators, including variations in measurement approaches and simulation parameters. These differences limit direct quantitative comparison and justify the use of a qualitative thematic synthesis approach. This subsection addresses the first research question by identifying and organizing the types of empirical and analytical evidence currently available regarding thermal performance and natural ventilation in *Joglo*-related and comparable vernacular architectures. Overall, the findings suggest that natural ventilation performance is strongly influenced by the interaction between architectural form, spatial configuration, and material characteristics, rather than isolated design elements.

Table 1. Characteristics of Reviewed Studies.

No	Author(s), Year	Object & Location	Method	Key Variables	Main Results	Relevance to *Joglo* & Ethnophysics	Dominant Physical Mechanism
1	Suhendri & Koerniawan, 2017	Javanese traditional house (Indonesia)	CFD simulation	Air velocity, airflow pattern, indoor temperature	Cross-ventilation effective with openings on multiple sides; ventilation improves comfort but does not significantly reduce air temperature	Core reference for *Joglo*-type wind-driven ventilation	Wind-driven cross ventilation
2	Samodra & Irvansyah, 2021	Traditional Javanese house (urban context)	Field measurement + energy simulation	Indoor temperature, MRT, cooling load	High roof delays heat gain; internal heat gain dominates thermal discomfort	Shows limits of traditional ventilation in dense urban setting	Wind-assisted thermal buffering
3	Faisal et al., 2024	Traditional house, Lampung	Field observation	Window placement, ventilation pattern	Horizontal cross ventilation dominates; window placement tied to space function & social factors	Shows vernacular ventilation logic without numerical modeling	Wind-driven cross ventilation
4	Muslimsyah et al., 2025	Rumoh Aceh	CFD + field measurement	Temperature, air velocity	Indoor temp 23–29 °C; air velocity up to 2.5 m/s; comfort ~80% of time	Quantifies passive cooling effectiveness in Indonesian vernacular	Combined wind + buoyancy

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5	Pinassang et al., 2021	Mbaru Niang, Flores	Climate analysis + CFD	Ventilation strategy, airflow	61.1% comfort strategy achieved via ventilation; void & roof enhance stack effect	Comparative model of vertical ventilation	Buoyancy-driven (stack effect)
6	Saptaningtyas et al., 2025	Bale Mangina, Lombok	Field study + qualitative analysis	Material, ventilation, indoor temp	Indoor temp 23–28 °C; porous materials enhance ventilation & cooling	Material-based thermal physics comparator	Material-mediated micro-convection

Table 2. Ethnophysics-Based Coding of Thermal and Ventilation Mechanisms in Reviewed Studies

Code	Ethnophysics Category	Physical Mechanism	Operational Definition	Representative Studies	Frequency
C1	Heat Transfer	Conduction	Heat transfer through building materials (walls, floors, wooden structures) affecting indoor thermal response	Saptaningtyas et al. (2025)	1
C2	Heat Transfer	Convection	Heat removal via air movement induced by natural ventilation and airflow exchange	Suhendri & Koerniawan (2017); Samodra & Irvansyah (2021); Faisal et al. (2024); Muslimsyah et al. (2025)	4
C3	Heat Transfer	Radiation	Solar heat gain through roof and envelope surfaces contributing to indoor thermal load	Samodra & Irvansyah (2021); Muslimsyah et al. (2025)	2
C4	Airflow Mechanism	Cross Ventilation	Horizontal airflow generated by pressure differences between opposite openings	Suhendri & Koerniawan (2017); Faisal et al. (2024); Muslimsyah et al. (2025); Saptaningtyas et al. (2025)	4
C5	Airflow Mechanism	Stack Effect (Buoyancy)	Vertical airflow driven by temperature-induced density differences and building height	Pinassang et al. (2021); Muslimsyah et al. (2025)	2
C6	Thermal Regulation	Roof Thermal Buffering	Delay of heat transfer due to high roof geometry and increased air volume	Samodra & Irvansyah (2021)	1
C7	Material-Based Cooling	Porous Material Cooling	Cooling effect produced by breathable or porous building materials enhancing airflow and evaporation	Saptaningtyas et al. (2025)	1
C8	Socio-Spatial Ventilation	Function–Airflow Coupling	Relationship between spatial function, occupant behavior, and ventilation configuration	Faisal et al. (2024)	1
C9	Combined Passive Cooling	Wind + Buoyancy Interaction	Synergistic cooling effect from combined wind-driven and buoyancy-driven ventilation systems	Muslimsyah et al. (2025); Pinassang et al. (2021)	2

The ethnophysical coding results presented in Table 2 indicate that the dominant physical mechanisms appearing in the selected studies are related to heat transfer and natural ventilation. In general, convection (C2) and cross-ventilation (C4) mechanisms appear in most studies, indicating that natural airflow is a primary strategy in the thermal performance of Indonesian vernacular architecture, including traditional Javanese houses. In addition, the stack effect (C5) and wind-drift interaction (C9) are also found in several studies, particularly in buildings with vertical space configurations or high roofs. Meanwhile, material-based mechanisms such as conduction (C1) and porous materials (C7) appear with lower frequencies, indicating that material aspects are not the dominant factor compared to air ventilation in traditional thermal systems. These findings indicate that traditional architectural systems rely more on passive airflow-based mechanisms than material heat conduction.

Thermal Performance of *Joglo* and *Joglo*-Type Vernacular Architecture

Across the reviewed literature, traditional Javanese and Indonesian vernacular houses consistently demonstrate indoor thermal conditions that are broadly aligned with adaptive comfort expectations in tropical climates. In Javanese traditional houses, Samodra and Irvansyah (2021) report that indoor air temperatures frequently exceed outdoor temperatures during daytime periods, particularly in dense urban contexts. This condition is primarily attributed to internal heat gains and limited indoor air movement. Nevertheless, the high *Joglo* roof volume functions as a thermal buffer zone that delays heat accumulation and creates vertical temperature stratification, thereby moderating peak indoor temperatures in the occupied zone (Figure 3).

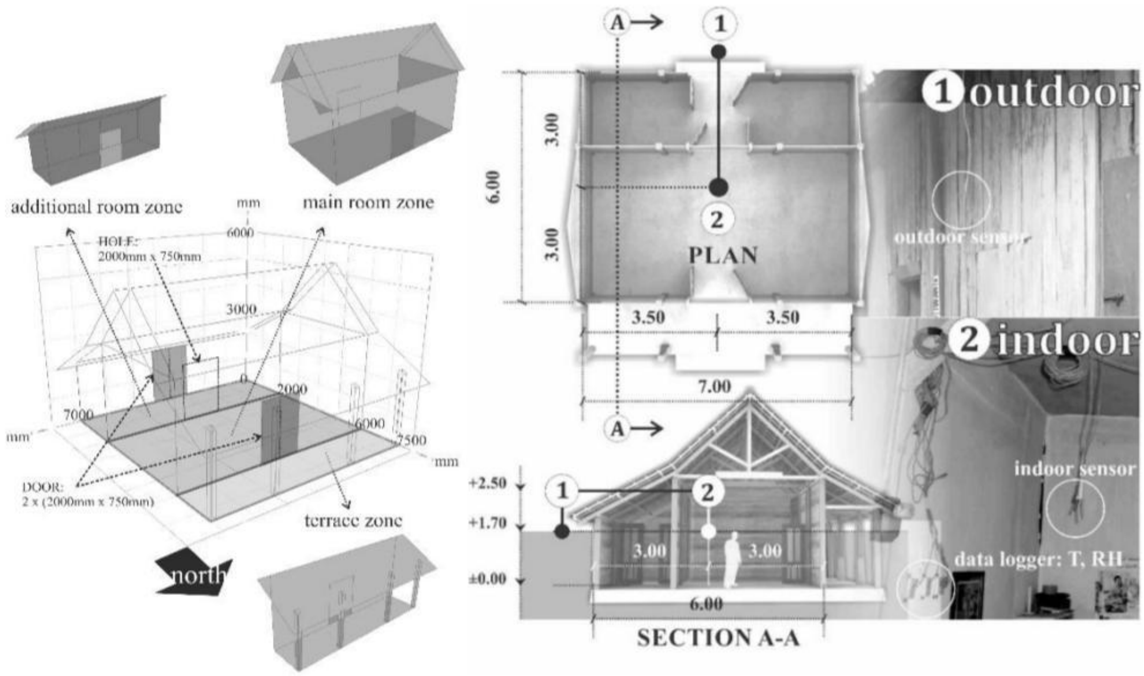

Figure 3. Section and temperature measurement layout showing stratification under the *Joglo* roof. (Adapted from Samodra & Irvansyah, 2021)

As illustrated in Figure 3, buoyancy-driven convection causes warm air to rise and accumulate in the upper roof cavity, forming a thermal reservoir that reduces radiant heat exposure in the living zone and slows downward heat transfer, which explains why thermal comfort can be achieved even without large reductions in indoor air temperature. Numerical and combined simulation–measurement studies on non-Javanese vernacular houses provide more explicit quantitative evidence and are commonly assessed using adaptive thermal comfort

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standards (based on the de Dear and Brager model as adopted in ASHRAE 55), where acceptable thermal conditions are defined by the relationship between indoor environmental conditions and occupants' adaptation to outdoor climate. A comparative synthesis of the reviewed studies reveals both similarities and differences in thermal performance mechanisms. Both Rumoh Aceh and Bale Mangina demonstrate a consistent similarity in which indoor air temperatures remain lower than outdoor conditions, indicating a shared passive cooling mechanism driven by porous envelope materials and thatched roofing systems. This similarity highlights the role of material permeability and roof construction in reducing heat gain in tropical vernacular architecture. However, differences emerge in thermal comfort outcomes. Muslimsyah et al. (2025) report indoor air temperatures ranging from approximately 23 °C to 29 °C in Rumoh Aceh, with thermal comfort conditions achieved for nearly 80% of daily hours based on adaptive comfort criteria, whereas Saptaningtyas et al. (2025) show that Bale Mangina exhibits more variable comfort conditions despite consistently lower indoor temperatures. These differences are primarily influenced by variations in material thermal properties, roof construction systems, and heat dissipation characteristics, which affect heat storage capacity and ventilation effectiveness.

When interpreted collectively, these findings suggest that thermal comfort in *Joglo* and *Joglo*-type architecture is not primarily achieved through significant reductions in indoor air temperature. Instead, comfort is attained through passive modulation of thermal perception, including delayed heat transfer, reduced radiant heat exposure, and enhanced convective heat exchange. This interpretation is consistent with CFD-based findings by Suhendri and Koerniawan (2017), who demonstrate that natural ventilation improves thermal comfort even when air temperature reductions are marginal. From an ethnophysics perspective, these strategies reflect culturally embedded understandings of heat balance between the built environment, climate, and human occupants. *Joglo* architecture, characterized by expansive roof volumes and open spatial configurations, can therefore be understood as a passive thermal system that regulates energy exchange rather than as a cooling apparatus in the mechanical sense. This synthesis directly addresses the second research question by explaining why *Joglo* architecture performs thermally as observed.

Natural Ventilation Mechanisms and Underlying Physical Principles

All six studies identify natural ventilation as the dominant mechanism influencing indoor environmental quality in traditional Indonesian houses. In Javanese traditional houses, CFD simulations reveal that lateral openings distributed on multiple façades generate pressure differentials that drive stable horizontal cross ventilation, making wind-induced airflow the dominant thermofluid mechanism in *Joglo* houses (Figure 4). However, Samodra and Irvansyah (2021) note that the effectiveness of this strategy diminishes in urban settings, where reduced wind speed and increased internal heat constrain airflow performance.

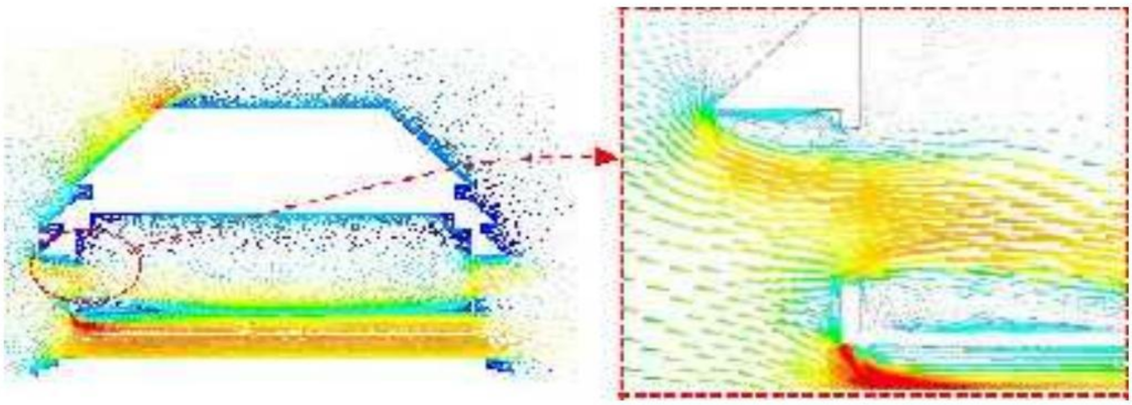

Figure 4. CFD velocity vectors showing pressure-driven cross ventilation in a *Joglo*-type house. (Adapted from Suhendri & Koerniawan, 2017)

Figure 4 visualizes airflow entering from the windward façade and exiting through the leeward side, creating continuous horizontal air movement across the interior, where increased air velocity enhances convective heat loss from occupants and thus becomes the primary contributor to perceived thermal comfort. In contrast, studies on Rumoh Aceh and Mbaru Niang report higher indoor airflow velocities, reaching approximately 1.5–2.5 m/s during peak periods, supported by vertical pressure differentials and buoyancy-driven flow (Muslimsyah et al., 2025; Pinassang et al., 2021).

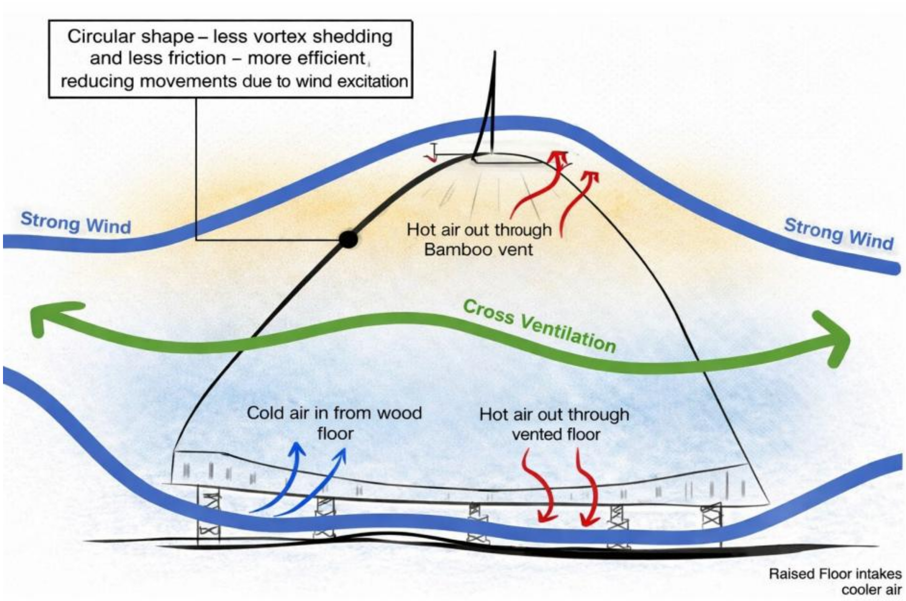

Figure 5. Stack-effect airflow in Mbaru Niang illustrating buoyancy-driven ventilation. (Adapted from Pinassang et al., 2021)

Figure 5 shows hot air rising through the conical roof apex, illustrating a stack-effect mechanism that differs fundamentally from *Joglo*’s horizontal, wind-driven flow. Bale Mangina exhibits a distinct but related mechanism, in which porous wall and roof materials enable continuous air exchange without reliance on large discrete openings (Saptaningtyas et al., 2025). Compared with Mbaru Niang and Rumoh Aceh, which exhibit indoor air velocities of up to 2.5 m/s, *Joglo* relies on lower but more widely distributed airflow combined with thermal buffering to achieve comfort.

These results indicate that the effectiveness of natural ventilation is highly contingent upon the interaction between architectural configuration and environmental context. *Joglo* architecture primarily exploits wind-driven horizontal ventilation, which provides stable airflow under favorable conditions but is sensitive to changes in surrounding urban morphology. In contrast, vernacular houses with vertical voids, conical roofs, or highly porous envelopes demonstrate stronger buoyancy-driven ventilation, which is less dependent on external wind conditions.

From a physical standpoint, this distinction reflects differences in the dominant driving forces of airflow—namely wind pressure versus thermal buoyancy. From an ethnophysical perspective, these variations also suggest that knowledge of environmental physics has been empirically transmitted through long-term observation, lived experience, and iterative construction practices within local communities. Over generations, builders have adapted architectural forms based on perceived thermal comfort and airflow behavior, allowing physical principles such as heat rise, pressure difference, and air permeability to be embedded implicitly in traditional design decisions rather than explicitly formulated as scientific theory. Rather than representing a universal solution, *Joglo* architecture therefore embodies a context-specific application of fluid mechanics adapted to Javanese climatic and social conditions.

Integrative Synthesis and Implications for Science and Physics Education

The synthesis of the reviewed studies reveals a coherent relationship between architectural form, material selection, and the physical mechanisms governing thermal and airflow behavior in traditional Indonesian houses. *Joglo* and *Joglo*-type architecture emphasizes horizontal ventilation and thermal buffering through roof geometry, while other vernacular forms prioritize vertical airflow and material porosity. Together, these findings highlight the diversity of passive strategies embedded within Indonesia's architectural heritage.

From a scientific perspective, this review reinforces the relevance of traditional architecture as a source of empirically grounded knowledge for climate-responsive building design. From an educational standpoint, the findings demonstrate the potential of ethnophysics as a pedagogical framework for contextualizing abstract concepts in heat transfer and fluid mechanics. For example, in physics learning, students can analyze *Joglo* roof structures to model buoyancy-driven convection, conduct simple experiments using scaled house models to observe airflow patterns through openings, or compare temperature distribution between different roof geometries to understand thermal buffering effects. Additionally, case-based learning activities can be designed where students relate local vernacular houses to the principles of thermodynamics and fluid dynamics, thereby linking theoretical equations to real-world architectural systems. By grounding physics instruction in culturally familiar architectural examples, ethnophysics can enhance conceptual understanding while preserving local knowledge systems.

Through a systematic synthesis of six Scopus-indexed studies published between 2017 and 2025, this review demonstrates that *Joglo* and other Indonesian vernacular architectures embody distinct, empirically verifiable thermal and ventilation mechanisms, thereby establishing ethnophysics as a rigorous conceptual bridge between traditional architectural knowledge, building physics, and physics education.

CONCLUSION

This systematic literature review examined thermal performance and natural ventilation in *Joglo* and *Joglo*-type Javanese architecture by synthesizing six Scopus-indexed studies published between 2017 and 2025. The findings indicate that thermal comfort in these traditional buildings is primarily achieved through passive mechanisms embedded in architectural form—particularly roof geometry, spatial openness, and opening configuration—rather than through substantial reductions in indoor air temperature. Natural ventilation emerges as the dominant regulatory process, with *Joglo* architecture relying mainly on wind-driven horizontal airflow, while comparative vernacular cases demonstrate stronger buoyancy-driven and material-mediated ventilation. Interpreted through an ethnophysics lens, these patterns reveal that traditional architectural practices embody empirically grounded applications of heat transfer and fluid mechanics, developed through long-term cultural adaptation to tropical environments.

The implications of this review are twofold. Scientifically, the findings suggest the potential of traditional Javanese architecture as a context-specific reference for climate-responsive and low-energy building design in tropical regions. Educationally, the results demonstrate the applicability of ethnophysics as a pedagogical framework for integrating culturally rooted architectural examples into physics education, enabling abstract concepts such as convection, airflow dynamics, and thermal balance to be taught through locally meaningful contexts. For example, ethnophysics-based learning may be implemented through activities such as analyzing *Joglo* roof structures to illustrate buoyancy-driven convection, using scaled architectural models to observe airflow behavior, and comparing thermal responses across different roof geometries to support understanding of heat transfer mechanisms. These approaches provide concrete links between theoretical physics concepts and real-world vernacular architecture. However, this study is limited by the relatively small number of eligible Scopus-indexed publications and the heterogeneity of methodologies and thermal comfort indicators across studies, which restricts direct quantitative comparison and generalization of findings. Future research is therefore recommended to expand the empirical evidence base through integrated field measurements and numerical simulations on *Joglo* and other vernacular house typologies across different climatic and spatial contexts. In addition, further studies are needed to evaluate the pedagogical effectiveness of ethnophysics-based approaches in physics education, particularly in terms of student conceptual understanding and engagement. Overall, these findings can inform the development of climate-responsive architectural strategies and provide culturally grounded case materials for teaching heat transfer and fluid mechanics in physics education.

AUTHOR CONTRIBUTIONS

Qurrota A’yun: Conceptualization, Methodology, and Validation; **Oktamia Ramadhani and Hidayatul Latifah**: Methodology, Formal Analysis, Resources, and Writing - Original Draft; and **Rahmatta Thoriq Lintangesukmanjaya, Lindsay Natalia Bergsma and Dwikoranto**: Data Curation, Project Administration, and Writing - Original Draft. All authors have read and approved the final version of this manuscript.

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Author (s):

Qurrota A'yun
Department of Physics, Faculty of Mathematics and Natural Science,
Universitas Negeri Surabaya,
Jl. Ketintang, Surabaya 60231, Indonesia
Email: qurrotaayun.22035@mhs.unesa.ac.id

* Rahmatta Thoriq Lintangesukmanjaya (Corresponding Author)
Department of Physics, Faculty of Mathematics and Natural Science,
Universitas Negeri Surabaya,
Jl. Ketintang, Surabaya 60231, Indonesia
Email: rahmattathoriq.20038@mhs.unesa.ac.id

Oktamia Ramadhani

Department of Physics, Faculty of Mathematics and Natural Science,
Universitas Negeri Surabaya,
Jl. Ketintang, Surabaya 60231, Indonesia
Email: 24030184051@mhs.unesa.ac.id

Hidayatul Latifah
Department of Physics, Faculty of Mathematics and Natural Science,
Universitas Negeri Surabaya,
Jl. Ketintang, Surabaya 60231, Indonesia
Email: 24030184049@mhs.unesa.ac.id

Dwikoranto
Department of Physics, Faculty of Mathematics and Natural Science,
Universitas Negeri Surabaya,
Jl. Ketintang, Surabaya 60231, Indonesia
Email: dwikoranto@unesa.ac.id

Lindsay Natalia Bergsma
TSB, Tilburg University
Warandelaan 2, 5037 AB, Tilburg, The Netherlands
Email: u187576@uvt.nl