

EVALUASI SUHU PADA KONFIGURASI DINDING BATU BATA MENGUNAKAN SIMULASI FEM DAN ANALISIS EKONOMI UNTUK APLIKASI BANGUNAN TROPIS

THERMAL EVALUATION OF BRICK WALL CONFIGURATIONS USING FEM SIMULATION AND ECONOMIC ANALYSIS FOR TROPICAL BUILDING APPLICATIONS

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Abstrak

Dinding merupakan komponen penting dari selubung bangunan yang berperan dalam mengendalikan perpindahan panas dan memengaruhi kondisi termal ruang pada bangunan di daerah tropis. Namun, pemilihan konfigurasi dinding bata di Indonesia umumnya masih didasarkan pada pertimbangan biaya konstruksi dan praktik konvensional, bukan pada evaluasi kuantitatif terhadap performa termalnya. Penelitian ini bertujuan untuk mengevaluasi performa termal dan efisiensi biaya dari konfigurasi dinding bata tanah liat yang umum digunakan serta menyusun rekomendasi desain berdasarkan tingkat paparan radiasi matahari. Penelitian dilakukan melalui perhitungan resistansi termal (*R-value*) dan transmitansi termal (*U-value*), simulasi *Finite Element Method* (FEM) untuk mengevaluasi distribusi temperatur dan perilaku perpindahan panas, serta estimasi biaya konstruksi melalui analisis termal-ekonomi terintegrasi. Tiga konfigurasi dinding yang dievaluasi meliputi dinding $\frac{1}{2}$ bata, dinding 1 bata, dan dinding $\frac{1}{2}$ bata dengan rongga udara. Dinding $\frac{1}{2}$ bata memiliki nilai *R-value* sebesar 0,17 m²K/W dan *U-value* sebesar 5,88 W/m²K, yang menunjukkan resistansi termal terendah, namun juga biaya konstruksi paling rendah (Rp150.000/m²). Dinding 1 bata memiliki *R-value* sebesar 0,34 m²K/W dan *U-value* sebesar 2,94 W/m²K, dengan biaya konstruksi sebesar Rp280.000/m². Sementara itu, dinding $\frac{1}{2}$ bata dengan rongga udara menunjukkan resistansi termal tertinggi (0,50 m²K/W) dan *U-value* terendah (2,00 W/m²K), namun memerlukan biaya konstruksi tertinggi (Rp320.000/m²). Hasil penelitian menunjukkan bahwa dinding 1 bata memberikan keseimbangan optimum antara kinerja termal dan efisiensi biaya, sedangkan dinding $\frac{1}{2}$ bata dengan rongga udara direkomendasikan untuk bagian bangunan yang menerima paparan radiasi matahari tinggi pada bangunan tropis.

Kata kunci: Analisa *Finite Element Method* (FEM), analisis termal-ekonomi, bangunan tropis, konfigurasi dinding bata, performa termal.

Abstract

Walls are essential components of the building envelope that regulate heat transfer and influence indoor thermal conditions in tropical buildings. However, the selection of brick wall configurations in Indonesia is generally based on construction cost and conventional practice rather than quantitative thermal performance evaluation. This study aims to evaluate the thermal performance and cost efficiency of commonly used solid clay brick wall configurations and to develop design recommendations based on different levels of solar heat exposure. The study employed thermal resistance (*R-value*) and thermal transmittance (*U-value*) calculations, Finite Element Method (FEM) simulations to evaluate temperature distribution and heat transfer behavior, and construction cost estimation through an integrated thermal-economic analysis. Three wall configurations were evaluated: half-brick wall, one-brick wall, and half-brick wall with an air cavity. The half-brick wall exhibited an *R-value* of 0.17 m²K/W and a *U-value* of 5.88 W/m²K, representing the lowest thermal resistance but the lowest construction cost (IDR 150,000/m²). The one-brick wall achieved an *R-value* of 0.34 m²K/W and a *U-value* of 2.94 W/m²K, with a

construction cost IDR 280,000/m². The half-brick wall with an air cavity demonstrated the highest thermal resistance (0.50 m²K/W) and the lowest U-value (2.00 W/m²K), however it required the highest construction cost (IDR 320,000/m²). The findings indicate that the one-brick wall provides the optimum balance between thermal performance and cost efficiency, while cavity walls are recommended for areas exposed to high solar radiation in tropical buildings.

Keywords: Finite Element Method (FEM) analysis, thermal–economic analysis, tropical buildings, brick wall configuration, thermal performance.

I. INTRODUCTION

Buildings located in tropical climates face significant thermal challenges due to high solar radiation intensity, elevated ambient temperatures, and prolonged heat exposure throughout the day. These climatic conditions substantially contribute to increased indoor temperatures, reduced thermal comfort, and increased cooling energy demand in buildings [1]. In tropical regions, passive design strategies have become increasingly important to reduce operational energy consumption while maintaining indoor thermal comfort. Among various passive approaches, optimization of the building envelope is recognized as one of the most effective strategies for controlling heat transfer from outdoor to indoor environments and improving building energy efficiency [2].

As a major component of the building envelope, walls play a crucial role in controlling heat transfer between outdoor and indoor environments. The thermal performance of wall systems is influenced by several factors, including material thickness, thermal conductivity, density, thermal mass, and layer composition. Recent studies have demonstrated that wall thermal performance can be enhanced through the use of insulated assemblies, multilayer systems, air-cavity configurations, and advanced envelope materials that reduce heat transmission and improve thermal resistance [3], [4], [5]. Passive design strategies that utilize thermal mass have been shown to moderate indoor temperature fluctuations and delay heat flow, thereby improving thermal comfort and reducing cooling energy demand in warm climates [6]. These findings highlight the importance of wall configuration in achieving energy-efficient and thermally responsive building envelopes.

Despite recent developments in advanced thermal technologies, conventional brick walls remain the dominant construction system in many tropical countries, including Indonesia, especially for residential and medium-scale buildings. Their extensive use is mainly attributed to affordability, material availability, ease of construction, and local building practices. In practical construction, commonly applied brick wall configurations include half-brick walls, one-brick walls, and cavity brick walls. However, wall selection is generally based on construction cost considerations and conventional practices rather than quantitative thermal performance evaluation. In fact, each wall configuration possesses different heat transfer characteristics that may

significantly influence indoor thermal comfort and building energy performance [2].

Recent research on building envelopes has predominantly focused on advanced insulation systems, innovative materials, phase change materials, and high-performance wall technologies to improve thermal efficiency and reduce building energy consumption [5], [6]. Nevertheless, comparative investigations of conventional brick wall configurations that are widely applied in everyday construction practice remain limited, particularly in tropical regions. Furthermore, studies that simultaneously evaluate thermal performance and construction cost efficiency within a single assessment framework are still relatively scarce. Since wall selection in practical building projects is influenced not only by thermal characteristics but also by budget constraints and construction feasibility, an integrated thermal–economic evaluation is essential to support more effective and sustainable design decisions.

Despite growing interest in building thermal performance, studies integrating thermal effectiveness and construction cost efficiency of conventional brick wall configurations in tropical climates remain limited. This gap highlights the need for a comprehensive approach that considers both thermal and economic aspects in wall design decisions. To address this issue, the present study proposes an integrated thermal–economic assessment framework that combines thermal resistance calculations, heat transfer analysis, numerical simulation, and construction cost estimation. Thermal performance is assessed through analytical evaluation of thermal resistance (R-value) and thermal transmittance (U-value), while Finite Element Method (FEM)-based simulations are employed to examine temperature distribution and heat transfer characteristics within wall assemblies [3]. Construction cost analysis is incorporated to evaluate the economic feasibility of each wall configuration and to identify solutions that balance thermal efficiency with cost effectiveness for tropical building applications.

Figure 1 illustrates the conceptual framework of the thermal performance evaluation conducted in this study. The figure presents the heat transfer mechanism through brick wall configurations under tropical climatic conditions subjected to high solar radiation exposure. Thermal boundary conditions were applied on the external wall surface with a constant outdoor temperature of 45°C, while indoor surface temperatures varied depending on wall configuration performance. Heat transfer through the

wall section was analyzed using Finite Element Method (FEM)-based thermal simulation in ANSYS to evaluate temperature distribution, and indoor heat reduction capability. The figure also demonstrates the relationship between outdoor heat exposure, wall thermal resistance, and indoor thermal response, which forms the basis of the proposed thermal-economic evaluation framework.

This study evaluates three commonly used brick wall configurations, namely half-brick walls, one-brick walls, and half-brick walls with air cavities. The objective is to identify the relationship between thermal performance and construction cost efficiency to determine the most suitable wall configuration for tropical building applications. The novelty of this study lies in integrating thermal and economic evaluations into a practical framework for conventional brick wall systems, thereby providing thermally responsive and economically feasible design recommendations for tropical buildings. This study introduces an integrated thermal-economic assessment framework for evaluating conventional brick wall configurations commonly used in tropical buildings. Unlike previous studies that emphasize advanced materials or insulation systems, this research

combines analytical thermal resistance calculations, Finite Element Method (FEM)-based numerical simulations, and construction cost evaluation to identify the optimum balance between thermal performance and economic feasibility. The findings contribute to context-based wall design strategies for tropical architecture by integrating material performance, heat transfer characteristics, and construction affordability.

Although previous studies have extensively investigated advanced insulation systems, phase change materials, and high-performance building envelope technologies, comparative studies focusing on conventional brick wall configurations commonly used in tropical construction remain limited. Moreover, the integration of thermal performance evaluation, FEM-based thermal visualization, and construction cost assessment within a unified framework has received relatively little attention. Therefore, this study contributes by developing an integrated thermal-economic evaluation of practical brick wall configurations for tropical building applications.

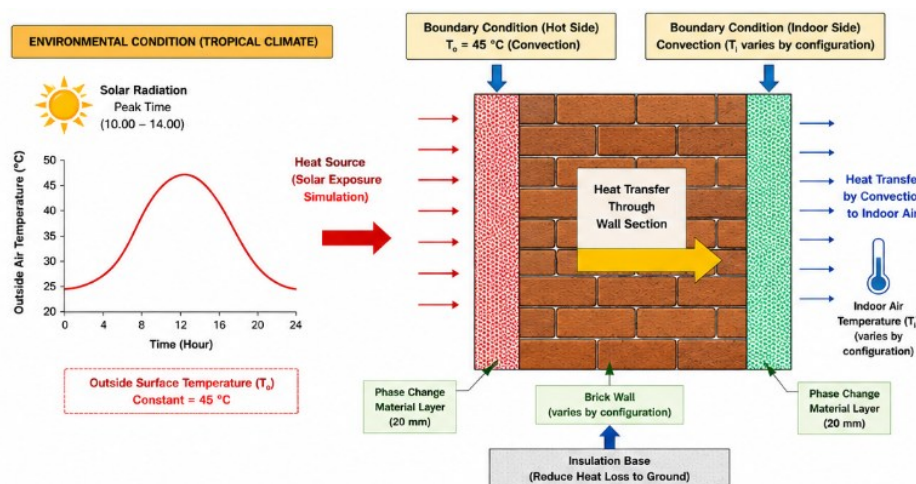


Figure 1. Illustrates the conceptual framework of the thermal performance evaluation

II. LITERATURE REVIEW

A. Thermal Performance of Building Envelope

The building envelope plays a critical role in regulating heat transfer between outdoor and indoor environments, particularly in tropical climates characterized by high solar radiation and elevated ambient temperatures. Heat transmission through building envelopes significantly affects indoor thermal comfort and building energy consumption, especially cooling demand. Consequently, improving the thermal performance of envelope components has become one of the primary passive strategies for reducing energy use in buildings [2].

Thermal performance of envelope systems is generally evaluated using thermal resistance (R-value) and thermal transmittance (U-value). The R-value represents the resistance of a material to heat transfer, whereas the U-value indicates the rate of heat transfer through a building component. Lower U-values indicate better thermal insulation performance and improved thermal efficiency of the building envelope [7]. Previous studies have demonstrated that improvements in wall insulation, material layering, and cavity systems can significantly reduce heat gain and improve thermal comfort in hot climatic regions [8].

In tropical buildings, passive thermal control strategies are particularly important because cooling loads constitute

a major proportion of operational energy demand. Appropriate envelope design can reduce indoor heat accumulation and delay heat penetration, thereby minimizing cooling energy consumption and enhancing occupant comfort [1].

B. Thermal Characteristics of Brick Wall Configurations

Brick walls continue to be widely used in tropical regions due to their affordability, material availability, durability, and ease of construction. Nevertheless, different brick wall configurations exhibit distinct thermal characteristics that affect heat transfer through the building envelope. Parameters such as wall thickness, thermal conductivity, density, thermal mass, and the presence of air cavities significantly influence thermal resistance and heat storage capacity [3], [6]. Previous studies have shown that increasing wall thickness generally enhances thermal resistance and thermal inertia by increasing the material's capacity to absorb and store heat. This thermal mass effect can delay heat transfer into indoor spaces, reduce indoor temperature fluctuations, and improve thermal comfort in warm climates [6], [9]. However, thicker wall systems may require greater material consumption and higher construction costs, highlighting the need to balance thermal performance with economic considerations during the design process.

Alternatively, cavity wall systems incorporating air gaps have been shown to provide substantial improvements in thermal insulation performance. Air cavities function as insulating layers due to the low thermal conductivity of trapped air, thereby reducing heat transfer through conduction. Studies have indicated that cavity walls may achieve lower thermal transmittance values than solid walls with comparable thickness, making them particularly suitable for buildings exposed to intense solar radiation [8].

Despite the widespread application of conventional brick walls, comparative studies assessing half-brick walls, one-brick walls, and cavity brick walls under tropical conditions remain relatively limited. Existing research predominantly focuses on advanced insulation systems and innovative wall materials rather than commonly applied brick configurations in practical construction [2].

C. Finite Element Method (FEM) in Building Thermal Analysis

Thermal performance analysis was conducted to evaluate the ability of each wall configuration to resist heat transfer from outdoor to indoor environments. The evaluation combined analytical heat transfer calculations and Finite Element Method (FEM)-based numerical simulation, allowing both quantitative comparison and thermal visualization of wall behavior [10], [11].

Numerical simulation has become an important tool in building thermal performance research. Recent studies

have employed COMSOL Multiphysics and Finite Element Method (FEM)-based approaches to investigate temperature fields, heat flux distribution, thermal storage behavior, and heat transfer mechanisms within building envelope systems. These approaches enable detailed visualization of transient thermal processes and provide reliable support for evaluating and optimizing envelope configurations under different climatic conditions [12].

The application of the Finite Element Method (FEM) has been extensively validated in engineering research through numerical and experimental investigations. It demonstrated that nonlinear FEM accurately predicted structural responses with an error of only 2.79% compared with analytical solutions, confirming its reliability for engineering simulations [13]. Another study applied FEM together with cyclic loading tests to evaluate the seismic performance of an Oval Plate Damper (OPD), showing that the numerical model successfully captured structural stiffness and energy dissipation characteristics [14]. Furthermore, another recent study reported good agreement between FEM simulations and experimental observations in evaluating structural deformation and energy dissipation, further demonstrating the capability of FEM to predict complex engineering behaviour [15]. Collectively, these studies demonstrate that FEM is a reliable and well-validated numerical approach capable of accurately simulating complex physical behavior under various engineering conditions. Although these studies focused on structural engineering applications, the same numerical principles can be extended to thermal analyses because heat conduction is also governed by differential equations that can be solved using the finite element formulation. Therefore, FEM has become a reliable approach for predicting temperature distribution and heat transfer in building components, including solid clay brick wall systems.

In the context of building envelope evaluation, FEM provides significant advantages over conventional analytical calculations because it enables detailed visualization of temperature contours, thermal gradients, and localized heat transfer phenomena within wall assemblies. While analytical methods are generally limited to one-dimensional heat conduction, FEM can represent spatial temperature distributions and interactions between different material layers more comprehensively. Therefore, integrating analytical thermal calculations with FEM-based numerical simulations provides a more robust framework for evaluating the thermal performance of conventional solid clay brick wall configurations in tropical buildings.

Compared with analytical calculations, FEM offers more detailed visualization of thermal behavior by considering spatial heat distribution and boundary interactions. In wall system analysis, FEM can effectively illustrate thermal gradients, heat flux distribution, and thermal lag characteristics that may not be fully captured using simplified one-dimensional analytical approaches [10].

D. Thermal–Economic Assessment in Building Design

Building material selection is not solely influenced by thermal performance but also by economic feasibility. In practical construction, cost considerations often determine the choice of building materials and wall systems, particularly in developing countries where affordability remains a major concern. Recent studies have emphasized that building envelope design should be evaluated using multiple criteria, including thermal performance, economic cost, and long-term sustainability impacts [16], [17]. Therefore, integrating thermal performance and construction cost into a unified assessment framework becomes increasingly important for achieving balanced and practical design decisions.

Previous studies have primarily emphasized energy efficiency and thermal optimization, whereas economic evaluation is often treated separately. As a result, practical decision-making regarding wall selection frequently lacks comprehensive assessment that simultaneously considers thermal efficiency and cost effectiveness [18].

A thermal–economic approach enables the identification of wall configurations that offer optimum thermal performance while remaining economically feasible. Such integration is particularly relevant for tropical building design, where high thermal exposure demands effective heat control strategies without significantly increasing construction costs. Therefore, evaluating the relationship between thermal resistance, heat transfer characteristics, and construction cost can provide more rational guidance for selecting wall systems suitable for tropical conditions.

III. RESEARCH METHODOLOGY

A. Research Framework

This study employed a quantitative analytical–numerical approach to evaluate the thermal performance and cost efficiency of different solid clay brick wall configurations commonly used in tropical buildings. The approach was selected to provide measurable, objective, and comparable results for evaluating thermal characteristics and economic feasibility among wall alternatives.

The research framework consisted of four integrated stages, namely: (1) identification of research objects and variables, (2) thermal performance analysis, (3) construction cost efficiency analysis, and (4) integrated thermal–economic evaluation. This methodological framework enables a comprehensive assessment by simultaneously considering thermal behavior and economic feasibility in determining appropriate wall configurations for tropical building applications.

The overall research workflow is illustrated in Figure 2, which presents the systematic relationship between thermal analysis, numerical simulation, and economic assessment leading to design recommendations.

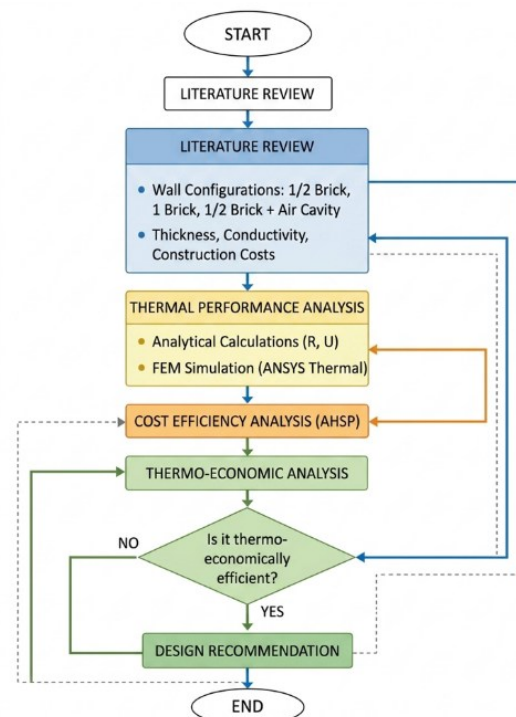


Figure 2. Research workflow

B. Research Object and Variables

The research object in this study was solid clay brick wall systems as components of the building envelope, functioning as barriers to heat transfer from the outdoor environment into indoor spaces. Since tropical buildings are exposed to high solar radiation intensity, wall performance becomes a significant factor influencing thermal comfort and building energy efficiency.

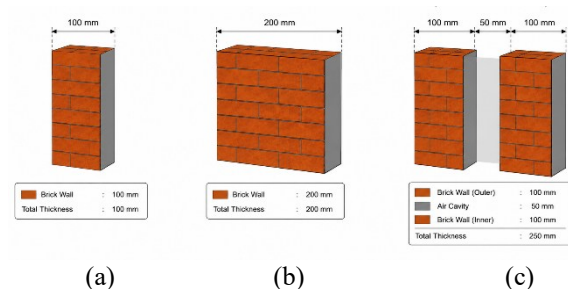


Figure 3. Brick wall configurations (a) Half-brick (b) One-brick (c) Half brick wall with an air cavity

Figure 3 presents a 3D steady-state thermal model was developed in ANSYS to represent three conventional solid clay brick wall configurations commonly used in Indonesia, namely a half-brick wall (100 mm), a one-brick wall (200 mm), and a half-brick wall incorporating a 50 mm air cavity. All wall models were represented with identical height and width to ensure consistent comparison. Three brick wall configurations commonly

applied in practical construction were evaluated in this study:

1. Half-brick wall, with an approximate thickness of 10 cm,
2. One-brick wall, with an approximate thickness of 20 cm,
3. Half-brick wall with an air cavity, consisting of two brick layers separated by an air gap.

The selection of these wall configurations was based on their widespread application in residential and medium-scale buildings in Indonesia, making the results practically relevant for tropical construction contexts. The primary variables analyzed in this study included:

1. wall thickness (t) (m),
2. thermal conductivity (k) (W/mK),
3. thermal resistance (R-value) ($\text{m}^2\text{K/W}$),
4. thermal transmittance (U-value) ($\text{W/m}^2\text{K}$), and
5. construction cost estimation (Rp/m^2).

These variables were selected to represent the two major aspects investigated in this research, namely thermal performance and economic efficiency.

C. Thermal Performance Analysis

Thermal performance analysis was conducted to evaluate the ability of each wall configuration to resist heat transfer from outdoor to indoor environments. The assessment combined analytical heat transfer calculations and Finite Element Method (FEM)-based numerical simulations, enabling both quantitative comparison and visualization of thermal behavior within wall assemblies. This integrated approach facilitates a more comprehensive understanding of temperature distribution and heat transfer mechanisms in building envelope systems [3], [16].

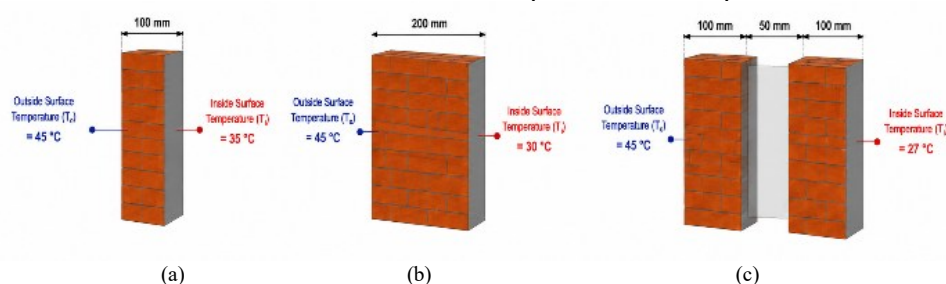


Figure 4. Thermal boundary condition (a) Half-brick (b) One-brick (c) Half brick wall with an air cavity

The ANSYS simulation focused on evaluating temperature distribution, thermal gradients, heat flux behavior, and thermal lag characteristics for each wall configuration. The numerical analysis was used as a comparative thermal assessment tool to support the analytical calculations.

3) Simulation Assumptions and Boundary Conditions

To ensure consistency among the wall configurations, several assumptions and thermal boundary conditions

1) Analytical Thermal Analysis

Thermal performance was analytically assessed using thermal resistance (R-value) and thermal transmittance (U-value) calculations. The thermal resistance of each wall material layer was determined using Equation (1).

$$R = \frac{t}{k} \quad (1)$$

Where R , t and k is thermal resistance ($\text{m}^2\text{K/W}$), material thickness (m) and thermal conductivity (W/mK), respectively. For multilayer wall systems, including cavity walls, the total thermal resistance was calculated as Equation (2).

$$R_{total} = \sum R_i \quad (2)$$

The thermal transmittance (U-value) was then determined by Equation (3).

$$U = \frac{1}{R_{total}} \quad (3)$$

The U-value was used as the primary indicator for evaluating wall thermal performance. Lower U-values indicate higher resistance to heat transfer and better thermal insulation capability.

2) Finite Element Method (FEM) Analysis

To complement the analytical evaluation, numerical thermal simulations were conducted using the Finite Element Method (FEM) in ANSYS Steady-State Thermal to visualize temperature distribution and heat transfer behavior within the wall systems. The simulation was performed under identical thermal boundary conditions with an outdoor surface temperature of 45°C representing tropical solar heat exposure.

were applied in the ANSYS FEM simulation. The analysis was conducted using a steady-state thermal analysis under stable heat-transfer conditions. The wall materials were assumed to be homogeneous and isotropic, with thermal properties uniformly distributed throughout each material layer.

A constant outdoor surface temperature of 45°C was applied to represent tropical solar heat exposure, while the indoor surface temperatures varied according to the thermal resistance of each wall configuration. Heat

transfer through the wall systems was assumed to occur primarily through one-dimensional conduction, while convection and radiation effects were neglected to maintain consistency with the analytical thermal-resistance calculations. For the cavity-wall configuration, the air layer was modeled as a low-thermal-conductivity zone representing trapped and stationary air conditions.

The numerical models were discretized using tetrahedral elements with a uniform mesh size of 15 mm for all wall configurations [13-15]. The same element type and mesh size were maintained throughout the simulations to ensure consistent numerical accuracy and a reliable comparison among the different wall systems. The ANSYS FEM simulation focused on evaluating the temperature-distribution contours, thermal-gradient behavior, heat-transfer characteristics, and thermal-lag performance of each wall configuration under identical thermal boundary conditions. Therefore, the numerical simulation was intended as a comparative thermal-assessment tool supporting the analytical calculations rather than as direct experimental validation. Further experimental verification is recommended in future studies.

D. Construction Cost Analysis

Construction cost efficiency was further evaluated to assess the economic feasibility of each wall configuration. Cost estimation was performed based on material quantities and construction work requirements per square meter (m^2) of wall area, encompassing brick materials, mortar volume, labor, and finishing work. The analysis adopted the *Analytical Unit Price Method (Analisis Harga Satuan Pekerjaan / AHSP)*, commonly employed in Indonesian construction planning, enabling a comparative assessment of construction costs across the investigated wall alternatives.

E. Thermal-Economic Analysis

The final stage of this study involved an integrated thermal-economic analysis, combining thermal performance indicators and construction cost efficiency into a single evaluation framework. At this stage, the relationship between U-value and construction cost for each wall configuration was analyzed to:

1. identify the wall configuration with the best thermal performance;
2. determine the most economically efficient alternative; and
3. establish the optimum balance between thermal performance and construction cost.

This integrated approach enables more rational and data-driven design decisions by simultaneously considering engineering performance and economic feasibility in tropical building applications.

IV. RESULT AND DISCUSSION

A. Thermal Performance of Brick Wall Configurations

The thermal performance of the evaluated wall configurations was assessed using thermal resistance (R-value) and thermal transmittance (U-value) analysis. These parameters were employed to determine the ability of wall systems to resist heat transfer under tropical environmental conditions. Lower U-values indicate lower heat transfer rates and improved thermal insulation performance, thereby contributing to enhanced indoor thermal comfort and reduced cooling energy demand (Lawrence et al., 2016).

Table 1. Analytical Calculation Results

Wall Configuration	R-value (m^2K/W)	U-value (W/m^2K)
Half-Brick	0.17	5.88
One-Brick	0.34	2.94
Half-Brick + Air Cavity	0.50	2.00

The analytical results revealed differences in thermal performance among the evaluated wall configurations due to variations in wall thickness and internal composition. (Table 1) The half-brick wall demonstrated the lowest thermal resistance because of its relatively thin section and limited thermal mass, resulting in higher thermal transmittance. Consequently, this configuration exhibited the highest susceptibility to heat penetration compared to the other alternatives.

The one-brick wall exhibited improved thermal performance due to its greater thickness and thermal mass. Increased wall thickness enhances thermal resistance, thereby reducing heat transfer rates and delaying heat penetration into indoor spaces. Previous studies have shown that masonry walls with higher thermal mass can moderate indoor temperature fluctuations and improve thermal comfort in warm climates [9]. Among the evaluated configurations, the half-brick wall with an air cavity demonstrated the best thermal performance, achieving the lowest thermal transmittance value of approximately $2.00 W/m^2K$. This improvement can be attributed to the insulating effect of the enclosed air layer, which reduces conductive heat transfer through the wall assembly. Air cavities provide additional thermal resistance because stagnant air has relatively low thermal conductivity. Similar findings have been reported in recent studies, which indicate that ventilated and cavity wall systems can significantly enhance the thermal efficiency of building envelopes by reducing heat gain and improving thermal resistance [3], [4].

Overall, the findings indicate that wall configuration significantly influences heat transfer performance. Therefore, thermal considerations should be incorporated

into wall selection strategies for tropical buildings instead of relying solely on construction traditions or economic preferences.

B. FEM-Based Thermal Simulation Results

To complement the analytical thermal assessment, Finite Element Method (FEM) simulations were conducted using ANSYS Steady-State Thermal to visualize temperature distribution and heat transfer characteristics across different wall configurations. The numerical simulation provided comparative thermal behavior under identical thermal boundary conditions, enabling a more comprehensive evaluation of wall thermal performance.

Figure 4 presents the FEM simulation results and two-dimensional temperature distribution curves for the evaluated wall configurations. The simulation results indicate that each wall system exhibited different thermal responses depending on wall thickness and cavity configuration.

The half-brick wall demonstrated the highest temperature penetration from the exterior to the interior surface. As shown in Figure 4(a), the thinner wall section resulted in a steeper thermal gradient and higher indoor surface temperature of approximately 35°C. This condition indicates relatively low thermal resistance and faster heat transfer through the wall assembly.

In contrast, the one-brick wall exhibited improved thermal performance due to its greater wall thickness. Figure 4(b) shows that the temperature reduction became more gradual compared with the half-brick wall, resulting in a lower indoor surface temperature of approximately 30°C. The increased wall thickness enhanced thermal mass and delayed heat penetration into indoor spaces.

Meanwhile, the half-brick wall with an air cavity demonstrated the best thermal performance among all evaluated configurations. Figure 4(c) indicates that the air cavity significantly reduced heat transfer through the wall system, producing the lowest indoor surface temperature of approximately 27°C. The trapped air layer functioned as an insulating barrier due to its low thermal conductivity, thereby minimizing thermal bridging and improving overall thermal resistance.

The two-dimensional temperature distribution curves further confirm the thermal behavior observed in the FEM contour results. The half-brick wall exhibited the steepest temperature decline, while the one-brick wall showed a more stable thermal gradient due to increased wall thickness. Meanwhile, the cavity wall configuration produced the most gradual temperature distribution and the slowest heat penetration rate, indicating superior thermal insulation capability.

Figure 5 presents the comparative temperature distribution behavior through wall thickness for all wall configurations under identical thermal exposure conditions. The comparison clearly shows that the half-brick wall experienced the highest temperature transfer rate, resulting in the highest indoor surface temperature.

In comparison, the one-brick wall demonstrated lower heat penetration due to its increased wall thickness and higher thermal mass. Meanwhile, the half-brick wall with an air cavity exhibited the lowest indoor surface temperature and the most stable thermal gradient profile. The presence of the air cavity effectively reduced heat transfer and delayed thermal propagation through the wall system.

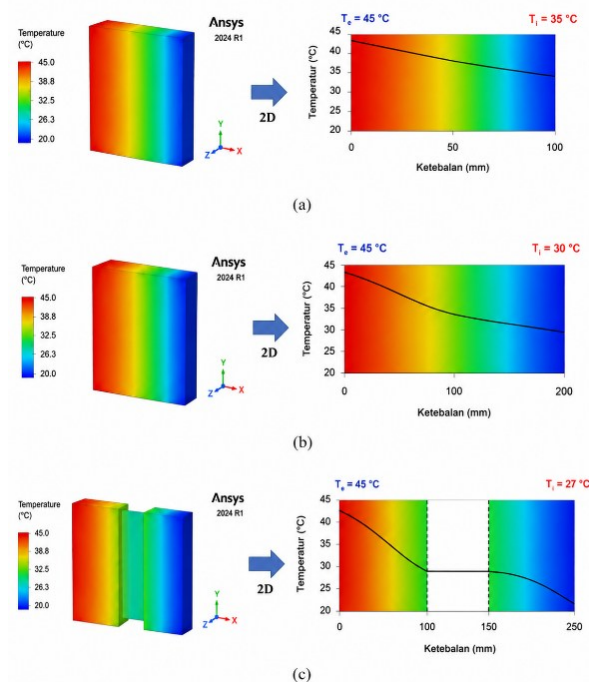


Figure 5. ANSYS FEM thermal simulation results and two-dimensional temperature distribution curves for wall configurations: (a) Half-brick wall, (b) One-brick wall, and (c) Half-brick wall with an air cavity

The comparison shown in Figure 5 indicates that increasing wall thickness improves thermal resistance; however, the incorporation of an air cavity provides a more effective reduction in heat transfer compared with increasing wall thickness alone. These results confirm that the cavity wall configuration provides the best thermal insulation performance among the evaluated wall systems for tropical building applications.

The ANSYS FEM simulation results demonstrated good agreement with the analytical thermal calculations of R-value and U-value. The numerical simulation confirmed that wall thickness and cavity configuration significantly influence thermal resistance and indoor heat transfer behavior. Although the half-brick wall represented the simplest and most economical configuration, its thermal performance remained comparatively limited due to higher heat transfer potential.

C. Comparison between Analytical and FEM Results

A comparison between the analytical calculations and Finite Element Method (FEM)-based numerical simulations was conducted to evaluate the reliability of the

analytical approach in representing heat transfer behavior for each wall configuration. The analytical method employed a simplified one-dimensional heat conduction assumption, while the FEM simulation using ANSYS provided a more detailed representation of temperature distribution and thermal gradients within the wall assemblies. The comparison between the analytical and FEM results is presented in Table 2.

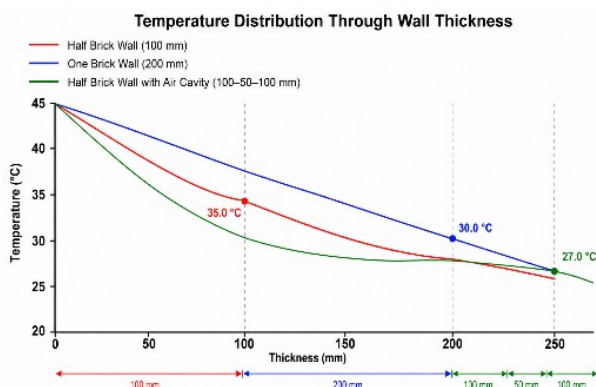


Figure 6. Comparative temperature distribution behavior through wall thickness for different wall configurations

Table 2. Comparison Between Analytical and FEM Results

Wall Configuration	U Analytical	U FEM	Difference (%)
Half-Brick	5.88	6.10	3.74%
One-Brick	2.94	3.05	3.74%
Half-Brick + Air Cavity	2.00	2.15	7.50%

To verify the reliability of the finite element model, the numerical heat transfer results obtained from ANSYS were compared with the analytical calculations based on thermal resistance (R-value) and thermal transmittance (U-value). The results indicate that both analytical and FEM approaches demonstrate consistent thermal performance tendencies, with relatively small differences of less than 10% for all wall configurations. For the half-brick wall and one-brick wall, the discrepancy of approximately 3.74% suggests that the analytical approach provides sufficiently accurate estimations for representing conductive heat transfer through homogeneous wall systems.

Meanwhile, the half-brick wall with an air cavity exhibited a slightly larger discrepancy of 7.50%, which may be attributed to the more complex thermal mechanisms occurring within the cavity layer. In cavity wall systems, heat transfer is not solely governed by conduction but may also involve localized convection effects within the enclosed air space. Such phenomena are represented more comprehensively through FEM simulation, resulting in slightly higher thermal transmittance values compared to analytical calculations.

However, the overall consistency between both methods confirms that analytical calculations remain

reliable for preliminary thermal performance assessment, particularly in practical building design applications. However, FEM provides enhanced understanding through detailed visualization of temperature distribution and heat transfer patterns, thereby functioning as a complementary validation tool for wall thermal evaluation [10].

These result demonstrate that integrating analytical and numerical approaches offers a more comprehensive framework for evaluating thermal behavior in conventional brick wall systems, particularly for tropical building applications where heat transfer performance significantly influences indoor thermal comfort.

D. Construction Cost Efficiency Analysis

The economic feasibility of each wall configuration was evaluated through construction cost analysis. Cost estimation considered material quantities, mortar consumption, labor requirements, and wall construction work per square meter of wall area.

Table 3. Estimated Construction Cost of Evaluated Wall Configurations

Wall Configuration	Construction Cost (IDR/m ²)
Half-Brick	150.000
One-Brick	280.000
Half-Brick + Air Cavity	320.000

The half-brick wall demonstrated the lowest construction cost due to reduced material usage and simpler construction requirements. This configuration represents the most economical alternative; however, its thermal performance remained comparatively limited because of higher heat transfer potential and lower thermal resistance.

Therefore, the one-brick wall required higher construction cost due to increased material volume and wall thickness. Nevertheless, the improved thermal performance obtained from greater thermal mass and lower heat penetration indicates a more balanced relationship between cost and thermal efficiency. The half-brick wall with an air cavity exhibited the highest construction cost among all configurations because of additional wall layers, increased construction complexity, and cavity installation requirements. Although this configuration demonstrated the best thermal insulation performance and the lowest indoor surface temperature, the higher construction cost may influence its practical implementation, particularly in cost-sensitive building projects.

Figure 7 illustrates the relationship between construction cost and relative cost efficiency for each wall configuration. The results indicate that increasing thermal performance generally requires additional construction cost. However, the cavity wall configuration provided superior thermal resistance and improved indoor thermal conditions compared with the conventional wall systems. The results demonstrate that economic feasibility remains

an important consideration in wall system selection, especially for tropical building applications in developing regions where affordability significantly influences construction decisions.

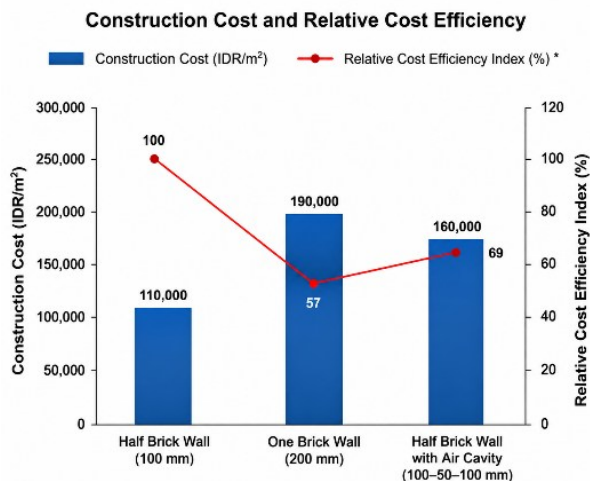


Figure 7. Construction cost and relative cost efficiency of wall configurations

E. Thermal-Economic Assessment

The integration of thermal performance and construction cost analysis revealed important trade-offs among wall configurations. Although the half-brick wall with an air cavity demonstrated the best thermal performance, its higher construction cost may limit its applicability in budget-constrained projects.

Conversely, the half-brick wall represented the most economical solution but exhibited relatively poor thermal resistance, potentially increasing indoor heat accumulation and cooling demand over time.

The one-brick wall showed the most balanced performance between thermal efficiency and economic feasibility. While not achieving the lowest U-value, this configuration provided improved thermal performance relative to the half-brick wall while maintaining more reasonable construction costs than cavity wall systems. Therefore, the one-brick wall may represent the most practical alternative for tropical building applications where both thermal performance and affordability are important considerations.

The results indicate a clear trade-off between thermal performance and construction cost. Increasing wall thickness from a half-brick wall to a one-brick wall reduced the U-value from 5.88 to 2.94 W/m²K (approximately 50%), while increasing construction cost from IDR 150,000/m² to IDR 280,000/m² (86.7%). Incorporating an air cavity further reduced the U-value to 2.00 W/m²K (32% improvement), whereas the construction cost increased by only 14.3% compared with the one-brick wall. These findings demonstrate that improvements in thermal performance are accompanied by additional construction costs; however, the magnitude of thermal improvement is not directly proportional to the

increase in cost. The findings highlight the importance of adopting a thermal-economic evaluation approach in building envelope design. Rather than emphasizing thermal performance or construction cost independently, integrated assessment enables more rational and context-responsive decision-making for tropical architecture.

V. DESIGN RECOMMENDATION FOR TROPICAL RESIDENTIAL BUILDINGS

Based on the integrated thermal-economic assessment, this study proposes a practical wall configuration recommendation for small-scale tropical residential buildings. The recommendation was developed by considering thermal performance, economic feasibility, and spatial practicality under tropical environmental conditions.

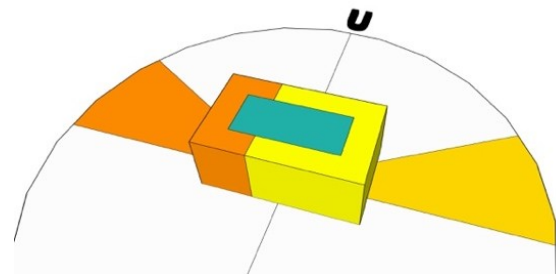


Figure 8. Recommended wall configurations according to façade orientation and relative solar heat exposure in tropical buildings.

Figure 8 illustrates the proposed application of wall configurations based on façade orientation in tropical architectural design. In tropical regions, the apparent position of the sun changes throughout the year due to seasonal variations in solar declination. As a result, north- and south-facing façades may receive considerable direct solar radiation during different periods of the year, depending on latitude and seasonal solar movement. However, east- and west-facing façades are generally considered the most thermally critical orientations because they are consistently exposed to low-angle solar radiation during the morning and afternoon. Such low-angle solar incidence increases the duration and intensity of heat gain through vertical wall surfaces, particularly on west-facing façades where afternoon solar radiation coincides with peak ambient air temperatures. Therefore, while north- and south-facing walls should not be regarded as thermally insignificant, enhanced thermal protection is generally more critical for east- and west-facing façades.

Based on the thermal and economic analyses conducted in this study, the one-brick wall is recommended for east-, north-, and south-facing façades because it provides an optimum balance between thermal performance and construction cost. In contrast, the half-brick wall with an air cavity is recommended for west-facing façades, where the thermal load is typically the highest.

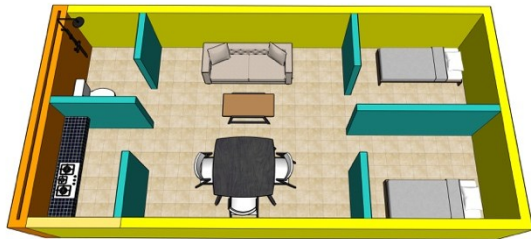


Figure 9. Conceptual building layout illustrating the recommended application of solid clay brick wall configurations based on different levels of solar heat exposure.

Figure 9 present the proposed building model represents a simple tropical dwelling consisting of a living room, dining area, kitchen, bathroom, and two bedrooms. The spatial configuration was designed to reflect commonly found residential layouts in Indonesia, thereby improving the practical relevance of the findings. Spatial zoning comprises public spaces, including the living and dining areas, service spaces such as the kitchen and bathroom, and private spaces represented by the bedrooms. The thermal-economic assessment suggests that wall configurations may be selectively applied according to thermal exposure intensity and the functional characteristics of each space.

A. Recommended Wall Configuration Strategy

Table 4. The wall recommendation framework

Wall Configuration	Azimuth Orientation	Thermal Exposure Level	Spatial Function	Thermal Role	Design Recommendation
Half-Brick + Air Cavity	Western façade (azimuth 270°–300°)	High	Service spaces (bathroom, storage, utility kitchen)	Functions as a thermal buffer by reducing and delaying heat transfer before reaching primary occupied spaces	Recommended for highly exposed western façades and combined with light-colored exterior finishes, vertical shading devices, or vegetation barriers to reduce solar heat gain before entering primary spaces
One-Brick	Eastern façade (azimuth 60°–90°)	Moderate	Bedrooms and semi-private spaces	Provides adequate thermal mass to moderate morning heat gain and reduce indoor temperature fluctuations	Recommended to be integrated with natural ventilation, cross ventilation, and operable window openings to prevent heat accumulation and improve indoor comfort
One-Brick	Central façade	Relatively Low	Primary living spaces (living and dining areas)	Maintains thermal stability through sufficient thermal mass in relatively protected areas	Recommended to be combined with neutral or high-reflectance wall finishes, open spatial planning, and stack or cross ventilation strategies to optimize thermal comfort and airflow
Half-Brick	Interior zones without direct solar exposure	Low	Interior partitions and secondary service spaces	Contributes minimally to thermal control due to negligible solar exposure	Recommended to improve construction cost efficiency while maintaining overall thermal performance; suitable for non-load-bearing interior partitions and spaces with minimal thermal demand

The half-brick wall with air cavity is recommended for envelope sections directly exposed to high solar radiation, particularly on east- and west-facing façades, due to its superior thermal resistance. Although this configuration generates higher construction costs, its ability to minimize heat transfer may contribute to improved thermal comfort and reduced cooling demand over time. However, the one-brick wall is considered the most balanced alternative for the majority of building envelope applications because it provides adequate thermal resistance while maintaining reasonable construction costs. This configuration is particularly suitable for living spaces requiring a balance between thermal comfort and affordability.

The half-brick wall remains a practical option for service areas and internal partitions where thermal exposure is relatively lower and thermal performance is less critical. Its lower material consumption and construction cost make it economically advantageous in non-critical thermal zones.

B. Conceptual Design Recommendation

The proposed conceptual design integrates wall configuration selection with spatial planning strategies suitable for tropical buildings.

The design emphasizes:

1. high-performance envelope treatment for solar-exposed façades;
2. balanced thermal-economic materials for occupied spaces;
3. cost-efficient wall application in secondary spaces; and
4. compact spatial arrangement to reduce excessive heat exposure.

This approach demonstrates that thermal performance optimization does not necessarily require the application of expensive advanced materials. Instead, performance improvements may be achieved through strategic

combinations of conventional wall systems based on environmental exposure and economic consideration.

VI. CONCLUSION

This study evaluated the thermal performance and economic feasibility of three commonly used brick wall configurations for tropical residential buildings, namely the half-brick wall, one-brick wall, and half-brick wall with an air cavity, through an integrated analytical–numerical approach. Thermal performance was assessed using R-value and U-value calculations, supported by Finite Element Method (FEM)-based simulations to visualize temperature distribution and heat transfer behavior. The results indicate that wall configuration significantly affects thermal performance. The half-brick wall with an air cavity demonstrated the best thermal performance, achieving the lowest thermal transmittance value due to the insulating effect of the trapped air layer, which effectively reduced heat penetration into indoor spaces. However, this configuration also involved the highest construction cost. In contrast, the half-brick wall provided the lowest construction cost but exhibited relatively poor thermal resistance. The one-brick wall emerged as the most balanced alternative, offering adequate thermal performance while maintaining reasonable construction costs, making it the most practical option for tropical building applications. Based on the thermal–economic assessment, this study recommends strategic wall application according to building thermal exposure, with cavity walls prioritized for highly exposed façades and one-brick walls applied in main occupied spaces. The findings contribute to practical building envelope decision-making by integrating thermal and economic considerations into a unified framework suitable for tropical architecture. Nevertheless, this study remains limited to analytical and numerical simulation approaches. Therefore, future research is recommended to conduct experimental validation through field measurements or laboratory testing to further verify the thermal performance of the proposed wall configurations under actual environmental conditions.

This study is limited to steady-state thermal analysis and numerical simulation under simplified boundary conditions. Future research should incorporate experimental validation and dynamic thermal analysis under actual climatic conditions to further improve the reliability of the proposed thermal–economic assessment framework.

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