Spectrum Journal of Innovation, Reforms and Development
Volume 50, April 2026 | ISSN (E): 2751-1731
Website: www.sjird.journalspark.org

ENHANCEMENT OF WALL INSULATION AND REDUCTION OF HEAT GAIN IN BUILDINGS USING A NEW MODEL BRICK: LITERATURE REVIEW

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Abstract

This paper reviews recent advancements in insulating brick technologies aimed at reducing heat gain through building walls, focusing on hollow, multi-chambered, and material-enhanced brick configurations. Given the high contribution of walls to thermal loads in hot climates, integrating insulation directly within brick units emerges as a practical and energy-efficient solution. The study highlights both numerical and experimental investigations validating the role of geometry optimization, phase change materials (PCMs), and waste-derived additives in improving thermal resistance. The analysis also considers the environmental and economic benefits of sustainable materials. Findings suggest that the integration of advanced insulation strategies within brick structures significantly enhances building energy performance, making them suitable for future climate-resilient construction.

Keywords: Thermal insulation, Hollow bricks, new model brick, Phase change materials (PCMs), Heat gain reduction, Building envelope, Sustainable construction, Numerical simulation, Material additives, Energy efficiency, Eco-friendly bricks, Thermal conductivity.

Introduction

The protection against harsh climatic conditions have always been a preoccupation of the inhabitants all over the world. The low temperatures in winter and high temperatures in summer procure thermal discomfort inside dwellings. In the context of rising global temperatures, energy consumption in buildings—particularly for cooling—has become a major concern. A significant portion of thermal gain in residential and commercial structures occurs through the building envelope, especially walls. Poorly insulated walls contribute directly to internal heat buildup, increasing reliance on air conditioning systems and leading to higher energy costs and carbon emissions (Necib, 2024; Lee et al., 2018; Vijayan et al., 2021).

The increasing global demand for energy underscores the critical need for net-zero and green buildings to address climate change. A key element of these buildings is the use of thermal insulation to control indoor temperatures and enhance thermal comfort by minimizing heat transfer. Thermal insulation has long been recognized as a key strategy in passive energy-saving techniques. Traditional wall insulation materials such as fiberglass, polyurethane foam, or mineral wool offer significant thermal resistance, but they often face challenges including high cost, installation complexity, limited durability, and, in some cases, environmental concerns. Moreover, the use of conventional solid bricks without integrated insulation properties has been shown to be inadequate in hot climates where solar radiation is intense (Dong et al., 2023; Hameed & Alwan, 2024; Shaik et al., 2023; Vijayan et al., 2021).

Recent developments in material science have led to building materials that contain integrated thermal insulation within their structure—effectively eliminating the need for additional insulating layers. These materials, often consisting of air-filled pores or lightweight aggregates, can significantly reduce heat transfer through walls (Heim & Wieprzkowicz, 2016; Kočí et al., 2014, Kočí et al., 2016; Kočí et al., 2018; Lai & Chiang, 2006).

Depending on their placement, insulation systems are typically categorized as exterior or interior. Exterior insulation systems are generally preferred for retrofitting due to advantages such as minimizing thermal bridges, protecting structural elements from thermal and hygric stress, and managing moisture more effectively. However, in cases where external modifications are restricted—such as in historical buildings or structures with architectural facades—interior insulation systems must be used. While interior systems provide a viable solution in such scenarios, they pose design challenges related to water vapor transport and condensation risk. Improper design, especially when using exterior-oriented design principles for interior applications, has historically led to failures, highlighting the need for more specialized research in this area. These limitations have made interior insulation systems a subject of extensive study in recent years, particularly in relation to moisture dynamics and hygrothermal performance (Heim & Wieprzkowicz, 2016; Kočí et al., 2016; Kočí et al., 2018).

In parallel, research is increasingly focusing on the development of novel brick designs and composite masonry units that integrate thermal insulation directly into the structural element. These include hollow bricks, multi-chambered blocks, and bricks with embedded insulating materials (e.g., phase change materials, perlite, aerogels). Such innovations aim to enhance thermal resistance while maintaining structural integrity, fire safety, and cost-effectiveness (Al-Amoudi et al., 2020).

This review aims to explore and synthesize the current state of knowledge on advanced insulating brick technologies used to reduce heat gain through building walls. It discusses material compositions, geometric innovations, experimental and numerical studies on thermal performance, and the potential of these new designs to contribute to energy-efficient and climate-resilient buildings.

3. Literature Review

3.1 Importance of Wall Insulation

Wall insulation plays a pivotal role in controlling heat transfer between indoor and outdoor environments. According to several studies, like a study conducted by Abdulsada and Salih (2022) highlighted the critical role of wall insulation in improving thermal comfort in buildings located in hot arid regions such as Kirkuk, Iraq. Their study compared two building models—one with traditional wall construction and another with thermally insulated walls designed under Passive House standards. The results showed that wall insulation contributed significantly to reducing indoor temperatures, with insulated walls maintaining an average temperature of 33°C compared to 42°C in non-insulated walls. This demonstrates how effective wall insulation can mitigate thermal gains and reduce cooling demands in harsh climates. In an earlier study, the same authors Abdulsada and Salih (2015) emphasized the importance of wall insulation in energy conservation for buildings in hot climates. Their findings indicated that integrating local insulation materials into wall systems could substantially lower the indoor temperature, maintaining it at 35°C even when external temperatures reached 45°C. The insulation also reduced the annual cooling load by approximately 6 megawatts, underscoring the potential of insulated walls to enhance energy efficiency and thermal regulation in building envelopes.

Abdullah & Aboud (2016) demonstrated the significant energy-saving potential of wall insulation. Their experimental study, comparing insulated and uninsulated brick walls in Kut, Iraq, showed that polyurethane insulation reduced air-conditioning energy consumption by 61.76%, polystyrene by 58.82%, and a newspaper-cement composite by 31.42%. This highlights the substantial role of wall insulation in reducing building energy demand.

In such settings, conventional materials often fall short in providing adequate resistance to heat flow, leading researchers to explore enhanced insulation strategies integrated into wall systems. Gao et al. (2019) emphasized that the use of thermal insulation in building envelopes plays a crucial role in reducing reliance on mechanical cooling systems such as air conditioning and cross-ventilation. This underlines the importance of passive insulation strategies in achieving energy-efficient indoor environments, particularly in regions with high thermal loads.

3.2 Conventional vs. Innovative Brick Designs

Traditional fired clay bricks, although widely used for their structural strength, have relatively high thermal conductivity (~0.7–0.9 W/m·K), which makes them poor insulators. To address this, several studies have proposed design modifications to the brick geometry and composition:

- **Hollow Bricks**: Hollow bricks are designed with air cavities that significantly enhance their thermal insulation properties by reducing both conduction and convection. The unique structure of these bricks allows for improved thermal resistance, making them an effective choice for energy-efficient construction. Alhazmy (2010) conducted a numerical study on the use of internal baffles within hollow masonry bricks to reduce natural convection and improve thermal resistance. The baffles, placed to divide the cavity into three regions, altered airflow patterns and increased insulation performance. Results showed that longer baffles achieved up to 53% improvement in thermal resistance, especially when the cavity was evenly divided. This highlights the potential of geometric modifications inside bricks as an effective passive insulation strategy in modern brick design. Also, Bachir and Taieb (2023) investigated the potential of three passive strategies—low-emissivity coatings, expanded polystyrene (EPS) infill, and phase change materials (PCMs)—to enhance thermal comfort and energy efficiency in Algerian buildings using common hollow clay bricks (HCB-8). Using Ansys-Fluent simulations, they analyzed various HCB-8 configurations incorporating these strategies. Results indicated that all three improved thermal inertia, with capric acid demonstrating superior PCM performance compared to n-Eicosane and RT-42. The combined use of PCM and EPS yielded the most significant improvements, reducing internal heat flux by approximately 73.7% and delaying the peak heat wave by about 5.5 hours compared to traditional HCB-8 bricks.

Recently, Vera et al. (2024) investigated strategies for enhancing the thermal performance of hollow clay masonry walls through detailed 3D finite element simulations and experimental validation. The study demonstrated that reducing the size of internal cavities effectively decreased the U-value to 0.761 W/m²K, and further improvements were achieved by increasing the overall brick thickness, lowering the U-value to 0.563 W/m²K. In contrast, reducing the thermal conductivity of the clay material itself had minimal impact. These findings underscore the importance of cavity geometry and wall thickness over material modification in optimizing thermal insulation in masonry construction. In recent times, Tsatsaros (2020) conducted a comprehensive investigation into the thermal insulation performance of hollow bricks by analyzing various construction configurations, ceramic materials, and mortar properties. The study utilized finite element modeling (COMSOL Multiphysics) to simulate heat transfer behaviors under different setups. Results demonstrated that the thermal efficiency of hollow bricks significantly depends on both the arrangement of internal voids and the type of ceramic composition used. Mortar properties also influenced the overall insulation, highlighting the importance of holistic material design in enhancing the energy efficiency of masonry units.

- **Multi-Chambered Bricks:** Researches indicate that multi-chambered bricks, characterized by increased vertical or horizontal cavities, significantly enhance thermal insulation while preserving structural integrity. This design effectively reduces thermal conductivity, which is crucial for energy efficiency in building materials. The following sections elaborate on the mechanisms and benefits of this approach (Hashim et al., 2020).

Cuce et al. (2022) provided a comprehensive review of thermal insulation performance of hollow bricks as a function of cavity design. The study concluded that increasing the number of voids and optimizing their geometry and distribution within the brick matrix can significantly lower thermal conductivity and U-value, thereby improving energy conservation in buildings. These findings underscore the engineering potential of multi-chambered bricks in thermal envelope design. Moreover, Bondareva and Sheremet (2023) performed a numerical study on the thermal behavior of brick walls containing multiple rectangular inserts filled with phase-change materials (PCMs). Using a finite difference method, they examined heat transfer under varying thermal conditions and found that the arrangement and melting points of PCMs had a significant effect on thermal regulation. The study highlights the effectiveness of multi-chambered bricks in enhancing passive heat storage and reducing thermal fluctuations in building envelopes. Similarly, Gianni (2010) proposed a hollow brick system designed with multiple internal channels filled with expanded plastic materials to enhance thermal insulation. The design also incorporates recesses for mortar placement, facilitating the formation of vertical joints and improving the structural cohesion of masonry walls. This configuration not only minimizes thermal bridging but also aligns with modern strategies for energy-efficient construction using multi-chambered units.

- **Material Additives**: Incorporating perlite, vermiculite, or expanded polystyrene beads into clay or cementitious matrices reduces density and improves insulation. In addition, the use of various recycled waste materials in eco-friendly unfired earth bricks, examining their impact on thermal and mechanical properties. For instance, Xie et al. (2022) demonstrated that readily available, recyclable agricultural waste, with its inherent thermal resistance, provides a cost-effective insulation solution for rural buildings. Their study, using hollow bricks filled with various agricultural materials (reed leaves and stems, rice husks and straw, wheat straw), showed that rice straw yielded the best insulation performance, reducing the overall heat transfer coefficient by 32.7% (from 1.59 to 1.07 $W/(K \cdot m^2)$). This highlights the potential of agricultural waste for improving the energy efficiency of rural construction.

A recent study by Fioretti and Principi (2014) investigated the effect of applying low-emissivity surface coatings on the internal cavities of hollow clay bricks to reduce radiative heat transfer. Using finite element modeling across multiple geometries and clay conductivities, the study found that treating the cavity surfaces with coatings of surface emissivity as low as 0.1 led to a reduction in thermal conductivity ranging between 26% and 45%. These results highlight the potential of advanced surface treatments as a material enhancement technique for improving the thermal performance of traditional hollow bricks without altering their geometry (Fioretti & Principi, 2014). Also, Liu et al. (2024) introduced a novel building insulation wall utilizing recycled polyurethane, demonstrating high thermal efficiency and energy savings while offering environmental benefits. The recycled polyurethane material exhibits a thermal conductivity of 0.023 W/(m·K), resulting in an overall wall thermal conductivity of 0.297 W/(m·K). Compared to traditional double-sided plastered porous wall tiles, this new wall design achieves an 85.4% reduction in energy consumption per square meter, showcasing improved thermal insulation and economic advantages. This approach offers a sustainable and innovative solution for building wall insulation. Moreover, Xing et al. (2018) developed a novel energy-efficient building system for cold climates, aiming to achieve a 65% energy reduction in public buildings. Their design incorporated a self-insulating concrete perforated brick with a sandwich-like EPS insulation layer integrated during manufacturing to prevent cracking. Experiments determined the optimal EPS thickness (65 mm) to meet the 65% energy savings target, resulting in a minimum heat transfer coefficient of 0.45. Comparative tests showed that the modified brick consistently outperformed unmodified bricks, reducing the heat transfer coefficient by up to 45%. The internal placement of the insulation layer effectively prevented surface cracking. Walker & Pavía (2018) highlighted the use of natural plant fibers such as straw bale, bamboo, durian, cotton stalk, and coconut fiber to introduce cellular pores into the brick matrix. This method reduces thermal conductivity and improves insulation by increasing porosity. Likewise, Kazmi et al. (2018); El Fgaier et al. (2016); Zhang et al. (2018b) reported improvements in insulation by incorporating vermiculite (32%), olive ash (17%), marble powder (60%), and rice husk ash (30%), reinforcing the role of industrial and agricultural wastes in enhancing brick thermal properties.

Abjaghou (2020) noted that while clay brick thermal conductivity is mainly linked to porosity, the concentration and type of added waste materials during production also significantly influence insulation performance. The study confirms that the incorporation of wooden furniture waste into fired clay bricks enhances thermal insulation by increasing porosity and reducing thermal conductivity. Specifically, 10 wt% wood waste resulted in a conductivity of 0.42 W/m·K. Karim et al. (2019) reviewed the use of various organic and inorganic insulation materials (paper residue, rice husk, rice husk ash, olive stone flour, wheat straw, perlite, cigarette butts, vermiculite, waste marble powder, and waste glass sludge) as additives in clay bricks to enhance thermal insulation. The review highlights the need for a comprehensive understanding of brick composition, properties, and manufacturing processes to standardize production and achieve sustainable development goals through the utilization of industrial and mining waste materials. Bakkali Yedri et al. (2022) investigated the use of industrial sludge as an additive in brick manufacturing to reduce energy consumption in buildings. Their study, employing hot plate and box methods for thermal conductivity measurement and the flash method for thermal diffusivity, examined bricks containing 10-70% sludge fired at 920 °C. Results indicated that up to 50% sludge could be incorporated, significantly reducing thermal conductivity and diffusivity, thereby enhancing the bricks' thermal insulation properties. Likewise, Binici et al. (2010) demonstrated the feasibility of producing lightweight, insulating building materials using a composite of cotton and textile ash waste. Their experimental results showed that the resulting bricks met compressive strength and thermal conductivity standards (ASTM and Turkish Standards), and that structures built with these bricks offered superior indoor temperature regulation compared to concrete brick structures. The production process is adaptable to existing brick manufacturing facilities.

El Azhary et al. (2018) found that cement- and lime-based bricks blended with cotton and paper mill waste achieved competitive thermal conductivity values (0.046–0.1 W/m·K), making them viable eco-friendly alternatives.

3.3 Integration of Phase Change Materials (PCMs)

In recent decades, the integration of phase change materials (PCMs) into building envelopes has emerged as a promising solution for enhancing thermal insulation and reducing cooling loads. PCMs operate by absorbing excess heat during the day through latent heat storage and releasing it at night as ambient temperatures drop, thus flattening the indoor temperature profile and shifting peak energy demands (Li & Wu, 2012; Soares et al., 2013).

Kenisarin and Mahkamov (2016) conducted a comprehensive review on various PCM types—such as paraffins and fatty acids—and their incorporation into building elements. Their findings confirmed that PCMs help reduce temperature fluctuations and delay energy peaks, ultimately contributing to improved thermal comfort. Similarly, Lei et al. (2016) applied numerical simulation (using EnergyPlus) to evaluate the impact of PCM layers in tropical climates. They demonstrated that adding a second PCM layer could reduce heat gain by up to 40.7% compared to traditional wall assemblies.

Experimental studies by Jin et al. (2014) revealed that the location of the PCM layer significantly influences its thermal performance. They found that positioning PCMs at 1/5th of the wall thickness from the interior side offered optimal results, achieving up to 41% reduction in peak heat flux and a time lag of around 2 hours. Additional research emphasized that when PCM melting temperature and thermal mass were increased, the optimal placement shifted closer to the interior.

Izquierdo-Barrientos et al. (2012) applied a 1D transient heat transfer model to analyze different wall orientations and PCM layer arrangements. Although notable improvements were observed in summer performance, they concluded that PCMs have limited impact on reducing winter heat losses, especially when walls are already well-insulated.

Experimental studies by Kuznik & Virgone (2009) evaluated the thermal performance of a PCM-copolymer composite wallboard across three different climates. Results consistently showed a 22-27% reduction (ratio of 0.73 to 0.78) in indoor air temperature amplitude compared to a reference cell without PCMs. Furthermore, the PCM wallboard maintained indoor temperatures within the comfort zone, reducing peak temperatures by up to 4.2 °C.

Vicente & Silva (2014) conducted experimental testing on wall elements incorporating PCM macro-encapsulation. Results indicated maximum amplitude reductions of approximately 50% and 80% for two different specimens. Furthermore, the time lag between the imposed temperature change and the response in the wall element increased from roughly one hour in the control specimen to three hours in specimens with integrated PCMs.

Evola et al (2013) proposed a full optimization methodology for PCM application in lightweight buildings. Their work focused not only on energy performance but also on thermal comfort duration and intensity, confirming that PCM selection and placement must be climate-specific.

While PCMs significantly improve wall thermal regulation, their integration into solid construction elements such as bricks remains a developing area. Embedding PCMs into the core of new model bricks offers the potential for both structural support and dynamic thermal regulation—making them suitable candidates for passive energy-efficient wall systems in climates with high cooling demands. Moreover, Mukram and Daniel (2024) developed a novel brick incorporating micro-encapsulated PCM (MEP29) within cavities offset towards the outer wall. Their numerical analysis investigated temperature variations within the brick and resulting heat flux reduction. Comparing four brick models with PCM cavity offsets of 30, 40, 50, and 75 mm towards the interior, results indicated that greater heat flux reduction and improved performance were achieved with PCMs positioned further from the exterior (heat source). The model with a 75 mm offset (mPCM75) demonstrated a maximum heat gain reduction of 32% and a 1.2 °C decrease in room temperature.

3.4 Numerical and Experimental Investigations

A comprehensive understanding of insulating brick performance requires the integration of both numerical modeling and experimental validation. These complementary approaches enable researchers to evaluate heat transfer dynamics, optimize material compositions, and assess thermal efficiency under realistic conditions.

3.4.1 Numerical Investigations

Computational modeling—using tools such as ANSYS Fluent, EnergyPlus, and COMSOL Multiphysics—plays a critical role in predicting the thermal behavior of bricks under dynamic environmental loads. Zhang et al. (2018a) employed finite element analysis to study cement-soil bricks reinforced with coir fibers, applying Fourier's law to simulate internal heat conduction. Tang et al. (2015) used a 3D finite volume method to evaluate insulation configurations within hollow bricks, finding reductions in thermal conductivity of up to 61%. Similarly, Cianfrini et al. (2017) demonstrated through 2D simulations that thermal diffusivity, rather than mass alone, governs the dynamic performance of insulated blocks. Also, Cuce et al. (2020) conducted a numerical optimization study to enhance the thermal performance of lightweight hollow concrete bricks. Using CFD simulations, they evaluated how variations in hollow cavity geometry affect thermal resistance. The study reported that optimizing the cavity design could improve thermal resistance by up to 53%, achieving a U-value of 0.43 $W/m^2 \cdot K$. This highlights the significant role of geometric modifications in increasing the insulation capacity of masonry units.

Further analysis by Söylemez (1998) provided one of the earliest computational frameworks for evaluating porous bricks, integrating all three heat transfer modes—conduction, convection, and radiation—to calculate effective thermal conductivity. Recently, Tsatsaros (2020) employed finite element modeling using COMSOL Multiphysics to analyze the thermal insulation behavior of hollow bricks under different material compositions and construction arrangements. This numerical investigation complemented experimental insights by quantifying the influence of ceramic materials and mortar properties on the overall thermal performance of masonry units.

3.4.2 Experimental Investigations

Experimental validation remains crucial for confirming numerical predictions and understanding material behavior under controlled settings. Fioretti and Principi (2014) assessed hollow clay bricks treated with low-emissivity surface coatings, achieving a 26–45% reduction in thermal conductivity. Bachir and Taieb (2023) tested hollow bricks embedded with phase change materials (PCM) and expanded polystyrene (EPS), demonstrating a 73.7% decrease in internal heat flux and a 5.5-hour time delay in peak heat penetration.

Zukowski and Haese (2010) performed laboratory measurements on perlite-filled hollow bricks, verifying simulation outcomes and confirming the material's insulation efficacy. In a recent study, Kadupu et al. (2024) compared bricks fabricated from thermoplastics (PVC, PE, PP), with PVC exhibiting superior thermal resistance. Additionally, Munir et al. (2018) experimentally validated the insulating benefits of incorporating waste-derived additives like vermiculite and marble powder into clay bricks.

These experimental findings reinforce the feasibility of enhancing thermal performance through integrated insulation strategies within the brick unit itself—an essential aspect in the design and validation of new model bricks.

3.5 Environmental and Economic Considerations

While improving thermal performance is crucial, the sustainability and economic feasibility of novel brick solutions are equally important. Shaik et al. (2023) conducted a thermo-economic analysis of porotherm blocks filled with six different recycled insulation materials (plastic, tire, cloth, leather powder, rockwool, and coconut pith) in New Delhi and Bikaner, India. Rockwool-filled porotherm bricks demonstrated superior performance, reducing unsteady transmittance (0.29 W/m²K), air conditioning costs ($0.83/m²), and payback time (0.95 years) while improving carbon mitigation (15.65 kg/kWh) in the hot-arid Bikaner climate. Also, Liu et al. (2024) introduced a novel building insulation wall utilizing recycled polyurethane, demonstrating high thermal efficiency and energy savings while offering environmental benefits. The recycled polyurethane material exhibits a thermal conductivity of 0.023 W/(m·K), resulting in an overall wall thermal conductivity of 0.297 W/(m·K). Compared to traditional double-sided plastered porous wall tiles, this new wall design achieves an 85.4% reduction in energy consumption per square meter, showcasing improved thermal insulation and economic advantages. This approach offers a sustainable and innovative solution for building wall insulation. Moreover, Abu-Jdayil et al. (2019) examined the limitations of external insulation systems, citing concerns such as limited durability, detachment over time, and safety risks. The study further addressed the impact of mortar joint width on thermal bridging, noting that increased joint sizes can exacerbate energy loss in traditional brick walls. These findings support the need for integrated insulation solutions that overcome the long-term drawbacks of surface-mounted systems.

Rashid et al. (2019) noted that the declining quality of traditional clay bricks—attributed to the scarcity of natural clay minerals and insufficient skilled labor—has prompted the construction industry to seek alternative, sustainable solutions. This has accelerated the shift toward using non-conventional, resource-efficient materials. Mandili et al. (2019) highlighted the increasing trend of incorporating low-cost and waste-derived materials in construction, offering a viable alternative to traditional brickmaking processes. These materials not only reduce production costs but also enhance environmental sustainability.

Similarly, Ozturk et al. (2019) investigated the incorporation of tea waste into clay brick mixtures and found significant changes in thermal and mechanical properties. The study demonstrated a dual benefit: addressing agricultural waste disposal and reducing environmental pollution. This aligns closely with green construction goals, where waste-derived materials contribute not only to environmental sustainability but also to the thermal efficiency of building components. Taurino et al. (2019) reported that domestic energy consumption (55%) is pushing governments to improve building thermal efficiency through insulation and CO_2 reduction policies, reinforcing the global relevance of passive wall systems. Zhou et al. (2022) investigated the microstructural properties and permeability of bricks produced using recycled ceramic waste. Their findings demonstrated that incorporating this recycled material not only reduces reliance on virgin resources but also improves thermal insulation, moisture regulation, and structural integrity. This approach offers both environmental benefits (waste diversion) and economic advantages (cost-effective material use), making it highly relevant for developing sustainable, high-performance bricks.

Recent studies have emphasized the environmental and thermal benefits of using agricultural waste materials in the production of unfired clay bricks. A comprehensive review by Lachheb et al. (2023) showed that incorporating materials such as rice husk, wheat straw, or sugarcane bagasse into brick matrices can significantly reduce thermal conductivity while preserving or even enhancing mechanical properties. This approach not only addresses waste management challenges, but also promotes eco-efficient construction solutions, aligning well with the objectives of sustainable building practices. Raut et al. (2023) developed a sustainable hybrid brick using a combination of waste glass and oil palm industry by-products. The resulting thermally efficient sustainable hybrid (TESH) brick achieved a compressive strength of 7.21 MPa, meeting the standards for non-load-bearing bricks. Its thermal conductivity was approximately 0.38 W/m·K, marking a 50% improvement over conventional red clay bricks. Moreover, a numerical conjugate heat transfer analysis showed that the thermal resistance of TESH bricks is four times higher than that of standard fired clay bricks. The study also included embodied energy analysis and environmental impact assessment, confirming the TESH brick's advantages in both sustainability and insulation performance—making it a promising solution for energy-efficient and eco-friendly construction.

4. Conclusion

The reviewed literature confirms that incorporating thermal insulation within brick structures—whether through geometric optimization, material additives, or PCM integration—offers substantial benefits in reducing indoor heat gain and improving energy efficiency. Hollow and multi-chambered designs prove particularly effective in lowering thermal conductivity, while PCM-enhanced and waste-based additives demonstrate improved dynamic thermal regulation. Numerical and experimental studies align in validating the superior performance of these new-generation bricks. The environmental and economic analyses further reinforce their value, promoting a shift toward sustainable construction practices.

5. Recommendations

1. Standardization of Testing: Future studies should adopt uniform test protocols to compare the thermal performance of various brick configurations more effectively.
2. Focus on Composite Solutions: Combining multiple strategies—such as geometric enhancement with PCM or EPS infill—should be prioritized for maximized insulation.
3. Application-Specific Designs: Insulating brick types should be customized according to regional climate conditions and structural requirements.
4. Lifecycle Assessment Integration: Environmental impacts and long-term economic benefits must be included in early design stages.
5. Scale-Up Studies: More industrial-scale pilot projects are needed to validate lab-scale innovations in real-world construction settings.

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