

2025

## Numerical Comparative Study of the Thermal Performance and Load-Bearing Capacity of Hollow Clay Bricks Used in Construction in Libya

Osama Lawej

*Sabratha University, Faculty of Engineering, Department of Mechanical Engineering, Sabratha 26.27.151, Libya*

Mahmoud Ahmed

*Sabratha University, Faculty of Engineering, Department of Architecture and Urban Planning, Sabratha 26.27.151, Libya*

Ismael Ehtiawesh

*Sabratha University, Faculty of Engineering, Department of Mechanical Engineering, Sabratha 26.27.151, Libya, ehtiawesh@gmail.com*

Follow this and additional works at: <https://commons.yildiz.edu.tr/jscmt>



Part of the [Biomaterials Commons](#), [Chemical Engineering Commons](#), [Civil and Environmental Engineering Commons](#), [Engineering Science and Materials Commons](#), [Materials Science and Engineering Commons](#), [Mechanical Engineering Commons](#), and the [Molecular, Cellular, and Tissue Engineering Commons](#)

---

### Recommended Citation

Lawej, Osama; Ahmed, Mahmoud; and Ehtiawesh, Ismael (2025) "Numerical Comparative Study of the Thermal Performance and Load-Bearing Capacity of Hollow Clay Bricks Used in Construction in Libya," *Journal of Sustainable Construction Materials and Technologies*: Vol. 10: Iss. 3, Article 6.

<https://doi.org/10.29187/2458-973X.1195>

Available at: <https://commons.yildiz.edu.tr/jscmt/vol10/iss3/6>

This Research Article is brought to you for free and open access by YTU Press. It has been accepted for inclusion in Journal of Sustainable Construction Materials and Technologies by an authorized editor of YTU Press.



## RESEARCH ARTICLE

# Numerical Comparative Study of the Thermal Performance and Load-Bearing Capacity of Hollow Clay Bricks Used in Construction in Libya

Osama Lawej<sup>a</sup>, Mahmoud Ahmed<sup>b</sup>, Ismael Ehtiwesh<sup>a,\*</sup>

<sup>a</sup> Sabratha University, Faculty of Engineering, Department of Mechanical Engineering, Sabratha 26.27.151, Libya

<sup>b</sup> Sabratha University, Faculty of Engineering, Department of Architecture and Urban Planning, Sabratha 26.27.151, Libya

## ABSTRACT

The optimization of structural and thermal performance in building components remains a key challenge in sustainable construction, particularly in hot climate regions like Libya. Hollow clay bricks are widely used due to their local availability and affordability; however, their internal geometry is rarely optimized for thermal resistance or mechanical integrity. This study addresses this gap through a numerical investigation considering the effect of cavity geometry on the load-bearing capacity and thermal insulation performance of hollow clay bricks. Three configurations were analyzed, including two commercial designs from the Libyan market and a newly proposed arched cavity design. Finite Element Method (FEM) simulations were performed using ANSYS to evaluate both structural and thermal behavior under realistic boundary conditions. The results showed that the arched cavity design significantly reduced stress concentrations and improved mechanical performance compared to traditional models. Thermally, the optimized design achieved lower heat transfer rates, especially when combined with insulation materials such as polyisocyanurate (PIR). The proposed design improved both structural efficiency and energy performance. These findings contribute to the development of energy-efficient, structurally sound wall systems using local materials, and offer practical insights for sustainable building design in arid climates.

**Keywords:** Hollow clay bricks, Finite element analysis, Load-bearing capacity, Arched cavity design, Thermal performance, Thermal insulation, Sustainable construction

## 1. Introduction

Hollow clay bricks are among the most widely used construction materials due to their favorable combination of mechanical strength, thermal insulation, and sustainability. Produced from natural clay and fired at high temperatures, these bricks contain internal cavities that reduce weight and enhance energy performance. Their use lowers structural loads and minimizes the consumption of complementary materials such as concrete and steel, particularly in floor systems [1]. In addition to their mechanical and economic benefits hollow clay bricks

are cost-effective and environmentally friendly, making them a practical solution for construction in both hot and cold climates, including Libya. Owing to these advantages, their structural and thermal performance has been extensively studied, especially in the context of sustainable building construction. Recent research highlights the importance of material selection and design parameters in reducing the energy demand of residential buildings through the use of innovative materials, advanced technologies, and modern construction techniques [2]. While one such study was conducted in Nigeria, its conclusions underline a broader principle: the adoption of

Received 18 May 2025; revised 20 August 2025; accepted 20 August 2025.  
Available online 17 September 2025

\* Corresponding author.  
E-mail address: [ehitiwesh@gmail.com](mailto:ehitiwesh@gmail.com) (I. Ehtiwesh).

<https://doi.org/10.29187/2458-973X.1195>

2458-973X/© 2025 Published by Yıldız Technical University Press, İstanbul, Türkiye. This is an open access article under the CC BY-NC 4.0 Licence (<https://creativecommons.org/licenses/by-nc/4.0/>).

sustainable and optimized materials—such as the hollow clay bricks investigated in the present work—can significantly reduce building energy consumption, particularly in hot-climate regions facing acute energy challenges. In response to increasing energy demands and sustainability concerns, several studies have investigated methods to enhance the thermal and structural performance of hollow masonry units [3–11]. A recent study [3] employed finite element analysis to investigate the mechanical behavior of functionally graded material (FGM) plates under various loading and boundary conditions. The study used ANSYS Mechanical APDL, and demonstrated that both material gradation and mesh resolution significantly affect stress distribution and deflection behavior in functionally graded plates. These results emphasize the importance of accurate geometric and material modeling in finite element-based structural assessments. While the focus of the study was on functionally graded material plates under mechanical loading, their work demonstrates the versatility of finite element modeling in analyzing the performance of complex building materials. This modeling approach is similarly employed in the current study to assess hollow clay bricks with varying cavity configurations.

As shown in the study by Al-Tamimi et al. [4], it explored optimal cavity configurations in concrete blocks using numerical simulation to minimize heat transfer, emphasizing the role of cavity ratio and thermal bridges. Similarly, Sassine et al. [5] analyzed ten cavity arrangements in clay bricks and found that longitudinal barriers improve thermal performance, while transverse barriers may form unwanted thermal bridges. Other researchers, such as del Coz Díaz et al. [6] have optimized lightweight floor blocks by adjusting the number and orientation of internal walls, showing that increased partitioning and lower material conductivity improved thermal efficiency. Sustainable material integration has also been a focus. For example, the study by Sutcu et al. [7] demonstrated that incorporating paper waste into clay bricks significantly reduces thermal conductivity, while Ahmadi et al. [8] showed that filling hollow bricks with compressed wheat straw enhances insulation by reducing heat flow. From a mechanical perspective, the work of Cavaco et al. [9] validated the feasibility of recycling aluminum sludge into clay bricks without compromising structural performance. Likewise, the study [10] showed that firing and introducing cavities into clay bricks markedly improve both strength and thermal resistance. These studies collectively highlight the importance of cavity geometry, material innovation, and thermal design in improving brick performance. In a related numerical

investigation, Kumar et al. [11] analyzed the dynamic response of hollow and cavity-type clay brick masonry infill panels subjected to blast loading using nonlinear finite element methods. Their study demonstrated that cavity design significantly influences the energy absorption and failure mechanisms of masonry systems under high-strain-rate conditions. Although their study addressed dynamic loading scenarios such as blast impacts, their findings emphasize the critical role of internal cavity geometry in influencing structural performance. The current study explores this same principle under static compressive and thermal conditions representative of conventional building applications. Recent research has increasingly focused on improving the performance and sustainability of hollow masonry units. As shown in [12], investigated the use of superabsorbent polymer (SAP) waste as an admixture in hollow concrete blocks. The study demonstrated that optimized mixtures significantly enhanced compressive strength (up to 8.20 MPa), reduced water absorption (5.28%), and achieved suitable density ( $1900 \text{ kg/m}^3$ ), thereby exceeding international standards for non-loadbearing concrete blocks. While their research emphasizes concrete-based units and the benefits of chemical admixtures, it underscores a broader trend of enhancing the performance and sustainability of hollow masonry systems. Building on this direction, the present study shifts the focus to hollow clay bricks used in Libya, aiming to evaluate their thermal performance and load-bearing capacity, aspects that remain less explored in comparison to the mechanical improvements observed in hollow concrete blocks. In line with growing interest in material efficiency and sustainability, Şenay Atabay [13] applied the Value Engineering (VE) method to determine the most suitable exterior wall material based on Leadership in Energy and Environmental Design (LEED) criteria. The study evaluated eight alternative cladding materials using functional performance metrics such as thermal insulation, recyclability, and local sourcing. Although the focus was not on numerical simulation, the structured approach toward material optimization demonstrates the interdisciplinary link between engineering functionality and environmental design. This aligns with the current study's objective to enhance both structural integrity and thermal insulation in hollow clay bricks through cavity redesign and material treatment.

Despite significant advancements in the global analysis of hollow masonry units, there remains a lack of focused research on the structural and thermal performance of hollow clay bricks specifically used in Libya—particularly under the country's unique climatic conditions, construction practices, and

locally available materials. In this context, the present study evaluates two hollow clay block configurations commonly used in the Libyan market and introduces a novel arched-cavity design aimed at improving both mechanical and thermal performance. Accordingly, this study aims to conduct a finite element-based numerical investigation to optimize the mechanical strength and thermal efficiency of hollow clay bricks used in Libyan buildings, by redesigning cavity structures and exploring insulation strategies tailored to regional needs. The scope is limited to clay-based hollow bricks manufactured from locally available raw materials, excluding other types such as solid or aerated bricks. The investigated bricks are primarily used in residential and commercial buildings across Libya. The study particularly emphasizes the impact of internal cavity geometry, material composition, and insulation strategies on both load-bearing capacity and thermal performance. Numerical simulations using the free student version of ANSYS platform [14] are employed to analyze heat transfer and mechanical stress under conditions representative of real-world applications. While the primary analysis relies on numerical modeling, limited experimental data are incorporated for validation purposes. Environmental degradation factors such as corrosion or seismic effects are not considered; the focus remains on performance under Libyan environmental conditions.

Sustainable construction practices are gaining momentum in response to increasing environmental concerns, energy demands, and cost-efficiency needs. Hollow clay bricks, particularly those produced locally in Libya, offer significant potential due to their low-carbon footprint, affordability, and thermal mass. However, their structural and thermal performance varies greatly dependent on internal cavity geometry and material composition. The present study contributes to advancing sustainable masonry systems by introducing an optimized hollow clay brick design tailored to hot climate conditions. This research holds scientific, economic, and environmental relevance. Scientifically, it employs validated finite element modeling to assess and optimize stress distribution and thermal conductivity in masonry units. Economically, improved insulation can reduce operational energy demands and construction costs. Environmentally, the use of locally sourced materials and passive insulation strategies supports carbon reduction and aligns with the UN Sustainable Development Goals—particularly Goal 11 (Sustainable Cities) and Goal 13 (Climate Action).

Finally, a comparative summary of key recent studies is presented in Table 1, highlighting the methodologies, research focus, outcomes, and their alignment with the current work.

**Table 1.** Comparative summary of related studies and current work.

| Reference | Methodology                       | Main Focus                                                  | Key Findings                                                                                    | Relation to Current Study                                       |
|-----------|-----------------------------------|-------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|
| [4]       | FEM + Experimental                | Optimizing cavity and insulation in concrete blocks         | Optimized geometry improved insulation by 71%; insulation materials reduced conductivity by 40% | Supports cavity redesign and insulation impact                  |
| [5]       | Numerical (FEM)                   | Effect of bulkhead layout on thermal/mechanical performance | Longitudinal bulkheads improved thermal resistance; transversal ones enhanced lateral strength  | Relates to cavity geometry influence                            |
| [6]       | FEM + Topological Optimization    | Reducing block weight while preserving strength             | New hollow shapes-maintained strength while reducing weight for better handling                 | Supports FEM use and geometry impact                            |
| [7]       | Experimental + FEM                | Paper waste in clay bricks to improve insulation            | Conductivity reduced from 0.68 to 0.39 W/m·K                                                    | Demonstrates material modification benefits                     |
| [8]       | Experimental (Wall Models)        | Wheat straw insulation in fired bricks                      | Heat flow reduced by up to 69.2%; U-value decreased, R-value increased                          | Aligns with insulation strategy                                 |
| [9]       | Experimental (Mechanical Testing) | Aluminum sludge in clay bricks                              | No significant strength loss; improved thermal performance                                      | Validates eco-friendly additives without compromising structure |
| [10]      | Experimental                      | Fly ash and silica fume in clay bricks                      | Up to 27.6% strength gain; reduced absorption and weight                                        | Shows additive impact on strength and durability                |
| [11]      | FEM (Dynamic)                     | Blast response of hollow bricks                             | Reinforced bricks enhanced blast resistance; validated numerically                              | Reinforces FEM use and hollow configuration relevance           |
| [12]      | Value Engineering + LEED          | Sustainable material selection                              | LEED-based evaluation yielded optimal exterior material via VE method                           | Supports sustainability and material efficiency framework       |



2. Methodology

The aim of this study is to improve the structural and thermal performance of hollow clay bricks used in Libyan buildings by optimizing internal cavity geometry and evaluating the impact of insulation strategies. The research is guided by three core questions:

- (i) How does cavity geometry influence thermal insulation?
- (ii) What is the load-bearing capacity of current market bricks versus optimized designs?
- (iii) How can insulation and geometric modifications be combined to enhance overall performance?

To address these questions, finite element simulations were conducted using ANSYS platform to assess the mechanical and thermal behavior of three hollow clay brick models: two commonly available designs from the Libyan market, and a newly proposed arched-cavity design. Each model was analyzed under consistent loading and boundary conditions. The simulation results were then used to develop design recommendations for energy-efficient and structurally robust masonry components tailored to hot climates conditions.

The structural load-bearing analysis focused on hollow clay blocks used in floor slab systems, while the thermal performance assessment targeted blocks intended for wall applications. This division reflects their respective roles in structural stability and thermal insulation within typical Libyan building systems.

Numerical modeling is a powerful computational technique for simulating complex physical and mechanical behaviors through numerical methods. It is particularly useful when analytical solutions are impractical or unattainable, as it leverages advanced computing systems to approximate responses under varying conditions. In this study, numerical modeling was employed to simulate the structural and thermal performance of hollow clay blocks under different loading and environmental conditions. This method approach enables extensive parametric studies by varying cavity geometry, material properties, and load distributions, thereby generating valuable insights without the need for costly and time-intensive

laboratory experiments. Furthermore, it supports early-stage design decisions by facilitating the evaluation and optimization of both mechanical strength and thermal insulation performance. The material properties assigned in the simulations were based on experimentally validated data and literature relevant to construction materials used in Libya. For the structural analysis, the hollow clay bricks were modeled with a density of 2000 kg/m<sup>3</sup>, Young’s modulus of 2300 MPa, Poisson’s ratio of 0.2, and a compressive strength of 2.256 MPa. These parameters were applied uniformly across all structural models.

In the thermal analysis, key properties included thermal conductivity, specific heat capacity, and density for each material used (clay brick, concrete, PIR insulation, and air). These values are summarized in Table 2.

Boundary conditions for the structural simulations included a uniform vertical load of 4000 N applied on the upper surface of the block, while the base surface was fixed to prevent displacement, simulating floor system behavior. For thermal simulations, a temperature difference of 30°C was applied between the exterior (50°C) and interior (20°C) surfaces of the wall blocks. The internal face was thermally insulated to prevent heat loss, and only conductive heat transfer was considered, neglecting convection and radiation. The inner side was thermally insulated to prevent heat exchange with the surrounding environment. The total simulation time was set to 5400 seconds, sufficient to capture full thermal equilibrium while remaining within realistic operational ranges for building energy simulations. Meshing for the thermal analysis followed similar strategies as in the mechanical case, ensuring refinement in critical areas. Mesh generation was performed using ANSYS automatic meshing with advanced element control to ensure accuracy and efficiency. The models were discretized using SOLID186 3D high-order elements, suitable for capturing nonlinear structural and thermal gradients. Mesh smoothing and refinement were applied particularly at internal cavity interfaces. The element quality remained above 0.75, and convergence was achieved at a residual of 1e-4. The number of nodes and elements per model, ranging from 5484 to 6020 elements, and 15682 to 40338 nodes, depending on cavity complexity and insulation layout.

Table 2. Thermal properties of materials used in the study.

| Material                      | Thermal Conductivity<br>(W/m-K) | Specific Heat Capacity<br>(J/kg-K) | Density<br>(kg/m <sup>3</sup> ) |
|-------------------------------|---------------------------------|------------------------------------|---------------------------------|
| Hollow Clay Brick             | 1.26                            | 800                                | 2000                            |
| Hollow Cement Brick           | 1.40                            | 880                                | 2300                            |
| Polyurethane Insulation (PIR) | 0.019                           | 1500                               | 40                              |
| Air                           | 0.029                           | 1005                               | 1.2                             |

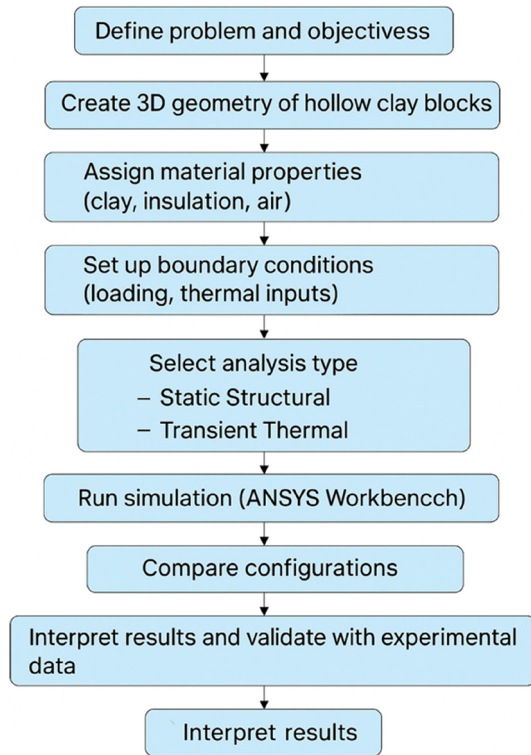


Fig. 1. Simulation workflow overview.

Overall, the adopted methodology enabled a comprehensive evaluation of hollow clay brick performance under both structural and thermal considerations. The combined use of validated finite element simulations and optimized geometrical and material configurations provides a robust basis for practical design recommendations in sustainable construction.

Flowchart summarizing the simulation workflow for evaluating the structural and thermal performance of hollow clay blocks using ANSYS is provided in Fig. 1. This diagram summarizes the key steps of the finite element analysis, including geometry creation, material assignment, meshing, boundary conditions, simulation setup, and post-processing.

## 2.1. Structural modeling of floor hollow clay blocks

To ensure the reliability of the numerical simulations, a calibration process was carried out by comparing simulation results with conducted experimental data. These experiments involved compressive strength tests on five cubic clay block samples of varying dimensions. A uniform vertical load was applied to the top surface while the bottom surface remained fixed. The setup includes a universal testing machine with vertical loading applied to the specimens under fixed bottom support conditions. The results of this experimental are demonstrated in Table 3.

The comparison showed a high level of agreement between numerical predictions and experimental observations. The calibration results across all five samples showed less than 1% deviation between simulation and experimental results, confirming the reliability of the numerical model for structural simulations. For instance, the fifth sample recorded a maximum principal stress of approximately  $21.15 \text{ N/mm}^2$  in the simulation, whereas the measured experimental value was  $21.04 \text{ N/mm}^2$ . This close alignment confirms the validity and accuracy of the numerical models used in this study.

Hollow clay blocks commonly used in flooring systems were selected from the local market in Libya. All samples had consistent external dimensions:  $400 \text{ mm} \times 250 \text{ mm} \times 160 \text{ mm}$  (length  $\times$  width  $\times$  height). However, internal cavity configurations varied among three distinct designs:

- Model 1: Internal cavities with square cross-sections.
- Model 2: Hexagonal-shaped cavities with an internal wall thickness of 8 mm.
- Model 3: Arched cavity design aimed at more uniform load distribution and reduced stress concentration.

These variations allowed for a comparative analysis of how cavity geometry affects structural and thermal performance. The geometric configurations and dimensions of the four analyzed models—including

Table 3. Experimental and predictions of calibration tests data.

| Sample | Length<br>(mm) | Width<br>(mm) | Height<br>(mm) | Mass<br>(g) | Load<br>(N) | Air-dry-compressive strength<br>( $\text{N/mm}^2$ ) |             | Net density<br>( $\text{g/cm}^3$ ) |
|--------|----------------|---------------|----------------|-------------|-------------|-----------------------------------------------------|-------------|------------------------------------|
|        |                |               |                |             |             | Experimental                                        | Predictions |                                    |
| 1      | 46.01          | 46.01         | 45.00          | 194.58      | 53180       | 25.12                                               | 25.10       | 2.00                               |
| 2      | 45.64          | 45.83         | 46.52          | 194.4       | 39025       | 18.66                                               | 18.70       | 2.00                               |
| 3      | 46.01          | 45.81         | 46.34          | 194.40      | 51727       | 24.54                                               | 27.70       | 1.99                               |
| 4      | 47.88          | 47.34         | 48.11          | 216.23      | 50961       | 22.48                                               | 22.50       | 1.98                               |
| 5      | 47.88          | 48.01         | 48.11          | 220.04      | 48357       | 21.04                                               | 21.15       | 1.99                               |

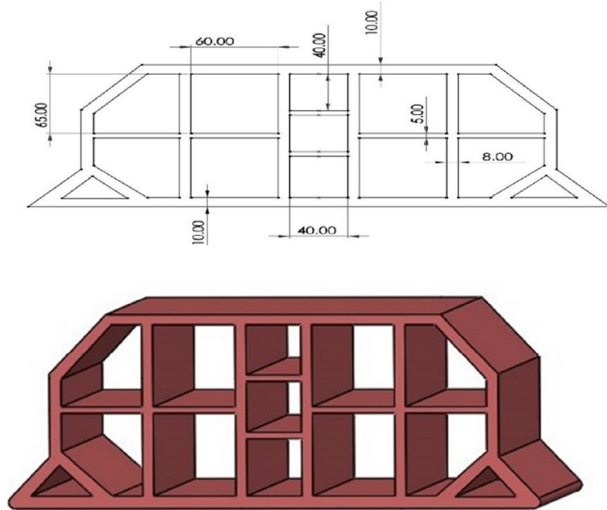


Fig. 2. Model 1 dimensions.

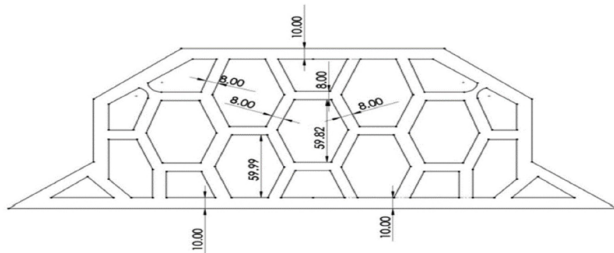


Fig. 3. Model 2 dimensions.

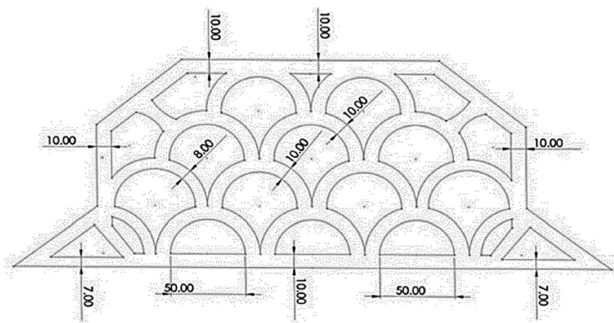


Fig. 4. Model 3 dimensions.

the two commercial types, the modified variant, and the newly proposed arched-cavity design—are illustrated in Figs. 2 to 4, which present a comparative view of their internal cavity layouts and overall block dimensions. The developed model was designed with arched-shaped cavities, based on the principle that arches distribute loads more evenly across all supporting walls and edges, thereby reducing stress concentration at any single point and enhancing overall structural stability. The arch geometry enables materials to effectively withstand

compressive forces—an advantage that is not easily achieved with conventional cavity configurations.

The base of each block was constrained to prevent displacement, mimicking fixed boundary conditions. Finite element meshing was performed using ANSYS Meshing tools. Automatic mesh generation was utilized, focusing on regions with sharp edges and high curvature to enhance accuracy. The number of elements and nodes varied depending on the complexity of the cavity shape, ranging from approximately 2145 elements and 14,699 nodes for the simplest model to 3685 elements and 22,705 nodes for the most complex configuration.

The structural analysis focused on three key outputs: Equivalent Stress (von Mises), Equivalent Strain, and Total Deformation. These indicators were used to evaluate the effect of cavity geometry on mechanical integrity and overall stability.

## 2.2. Thermal modeling of wall hollow clay blocks

Key thermal outputs included:

- Heat Transfer Rate: Indicates how quickly heat moves through the block.
- Heat Flux: Measures the amount of thermal energy passing through a unit area.
- Surface Temperature Probes: Used to monitor temperature changes across predefined points on the block's surface during the simulation.

These results enabled a comprehensive evaluation of the thermal efficiency of different cavity configurations and insulation strategies. A comparative thermal analysis was conducted between hollow clay blocks and conventional concrete blocks used in building walls. Based on previous findings, hollow clay blocks demonstrated superior thermal insulation capabilities due to their lower thermal conductivity. Therefore, further improvements focused exclusively on enhancing the thermal properties of clay blocks. Sample dimensions were standardized to a thickness of 150 mm. The outer dimensions for hollow clay blocks were set at 300 mm × 150 mm × 200 mm, while those for concrete blocks (hollow cement blocks) were 400 mm × 150 mm × 200 mm as shown in the Fig. 5.

Heat tends to transfer through building elements along the path of least thermal resistance. This path typically corresponds to regions with higher thermal conductivity compared to surrounding materials. When such high-conductivity paths exist—commonly referred to as thermal bridges—they facilitate undesirable heat transfer through structural components. As illustrated in the previously presented hollow clay block configuration, the internal cavity design

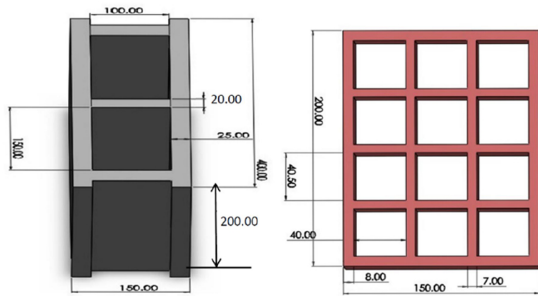


Fig. 5. Standard concrete blocks and hollow bricks dimensions.

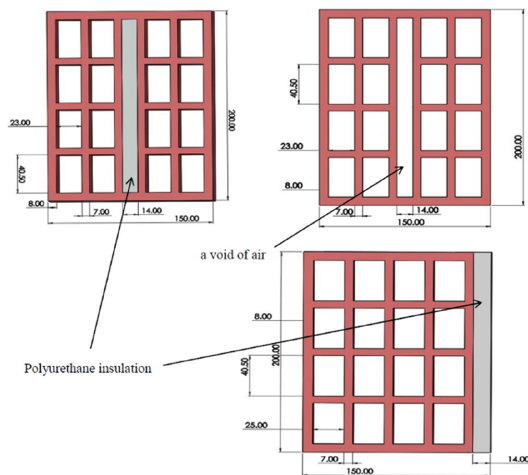


Fig. 6. Hollow bricks air gap configurations.

was modified to minimize the formation of horizontal thermal bridges. The new design introduces a central air gap that acts as a thermal break, effectively interrupting direct heat flow and enhancing overall thermal resistance and insulation performance, consistent with findings reported in prior studies. In addition to the geometric modification, a 14 mm thick layer of insulation was applied both inside the cavity and on the external surface of the block as shown in Fig. 6. The material used was polyurethane/polyisocyanurate (PUR/PIR). Polyurethane (PUR) is an organic polymer composed of repeating urethane (carbamate) linkages, while polyisocyanurate (PIR), a thermoset plastic typically manufactured as rigid foam, is widely used as a high-performance thermal insulator in roofs and wall assemblies across the construction industry.

In all three configurations, the clay blocks were modeled with a uniform width of 150 mm. For the case involving external PIR insulation, a 14 mm thick insulation layer was added to the outer surface of the block. As a result, the centrally located air gap used in earlier configurations was eliminated in this model, since the external PIR layer provided superior

thermal resistance. Although this slightly increases the total wall thickness, the trade-off is offset by the enhanced thermal performance and the simplification of internal cavity geometry. From a construction standpoint, this approach is logistically feasible and does not require significant changes to conventional masonry workflows. Furthermore, external insulation can be applied post-structurally, offering flexibility in phased construction or retrofitting scenarios.

### 3. Results and discussion

This section presents the outcomes obtained from numerical simulations conducted on hollow clay blocks used in floor and wall systems. The analysis focused on both structural behavior—such as stress distribution, strain, and deformation—and thermal performance, including heat transfer and thermal flux across different block configurations. All results were visualized using color gradient maps, where red indicates maximum values (high stress or temperature), and blue represents minimum values.

#### 3.1. Structural performance of floor blocks

Three cavity geometries were analyzed under a uniform vertical compressive load. Three hollow clay block configurations were analyzed under a uniform vertical compressive load of 4000 N using ANSYS. In the Libyan construction context, the use of manual wheelbarrows for transporting and pouring fresh concrete—particularly during slab casting—is still widely practiced on building sites. This common construction method informed the selection of the applied load in the structural simulations, ensuring the numerical model reflects realistic operational stresses encountered during conventional building activities. A uniform compressive load of approximately 4000 N was applied to the top surface of each brick model in the structural simulation. This value is based on the estimated weight of a wheelbarrow carrying 0.15 m<sup>3</sup> of fresh concrete, with a total static weight of about 4700 N. Since the load is typically distributed over two wheels, each brick beneath a single wheel supports approximately 2350 N. To account for dynamic construction effects—such as vibration, impact, and movement—a Dynamic Amplification Factor (DAF) of 1.7 was applied to the per-wheel load. This value was rounded to 4000 N to serve as a conservative and practical estimate of the transient loads experienced by hollow bricks during real-world construction operations. The base was fixed to simulate real-world boundary conditions in floor applications. It is important to note that Model 1 and Model 2 represent



commercially available hollow clay blocks widely used in the Libyan construction market, featuring square and hexagonal cavities, respectively. Model 3, by contrast, is a novel design proposed in this study, featuring arched internal cavities aimed at optimizing stress distribution and enhancing load-bearing capacity.

#### • Stress Distribution

Figs. 7 and 8 demonstrate the equivalent von Mises stress distribution for Models 1 and 2, respectively, under a 4000 N compressive load. The color scale ranges from the minimum stress that occurs at the base edges (dark blue) to the maximum stress that is observed at the upper load application points (dark red) in MPa.

Fig. 9 presents images of damaged hollow clay floor blocks, highlighting actual failure zones observed in real-world conditions. Notably, the failure patterns observed in these blocks closely align with the numer-

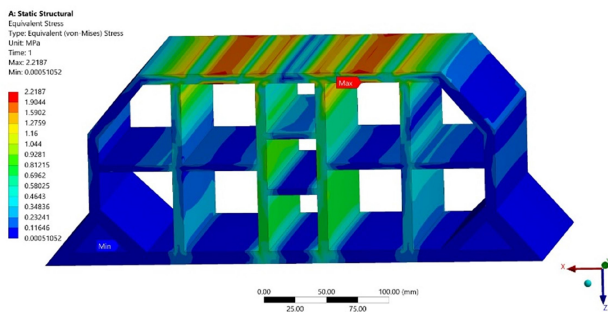


Fig. 7. Stress distribution - Model 1.

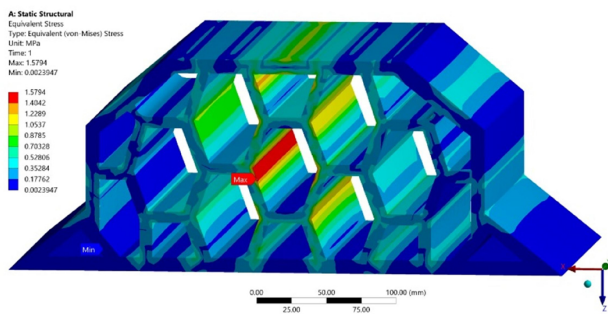


Fig. 8. Stress distribution - Model 2.



Fig. 9. Damaged hollow clay floor blocks.

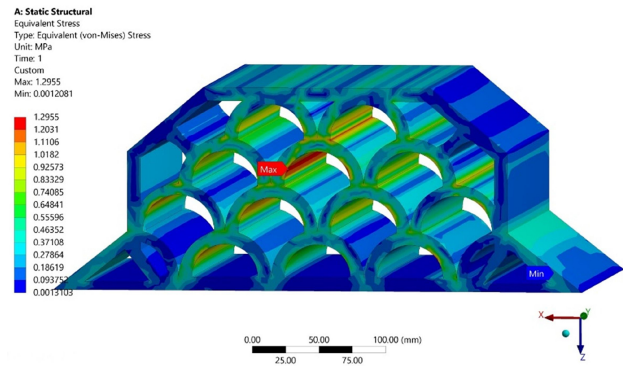


Fig. 10. Stress distribution - Model 3.

ical results presented in the preceding figures. This observation motivated the development of a new design, represented by Model 3, as shown in Fig. 10. In this modified model, the internal cavity geometry was redesigned using arched shapes, which are known to distribute stresses more efficiently. This configuration aims to reduce peak stress concentrations compared to the previous models, thereby enhancing structural performance.

Compared to Model 1, which experienced the highest stress concentration at 2.22 MPa, Model 2 exhibited a 29% reduction in peak stress. Model 3 further improved performance, reducing peak stress by over 41.7% relative to the commercial baseline as demonstrated in Fig. 10.

The figures clearly show a transition from concentrated stress zones in square and hexagonal cavities toward a more uniform distribution in the arched cavity design, validating the structural advantage of arch geometry. These results confirm that the arched cavity configuration offers a clear structural advantage by effectively distributing applied loads and limiting stress concentration zones, thereby improving the load-bearing performance of the block.

#### • Strain and Deformation Analysis

Strain and total deformation results are presented in Figs. 11 to 16; strain results followed the stress trends, model 1 recorded the highest strain value at

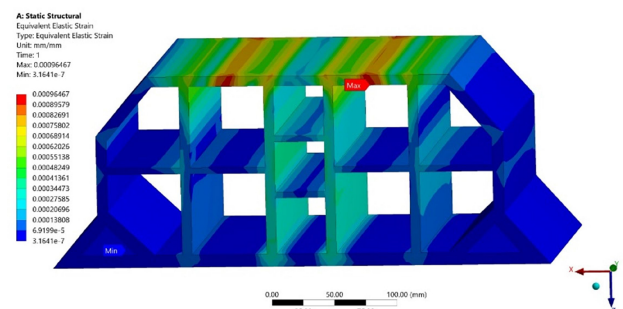


Fig. 11. Strain distribution - Model 1.

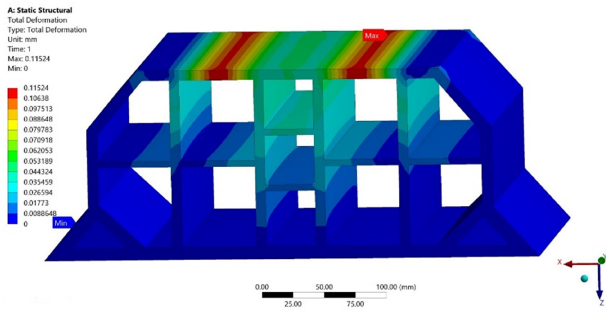


Fig. 12. Total deformation distribution - Model 1.

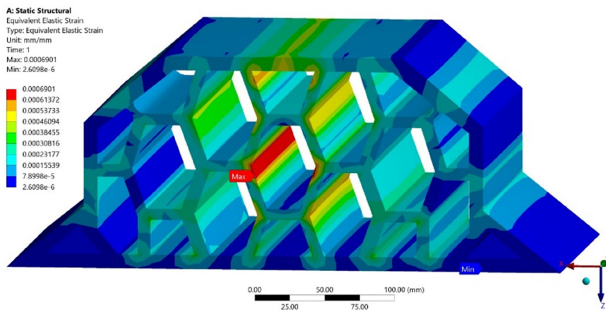


Fig. 13. Strain distribution - Model 2.

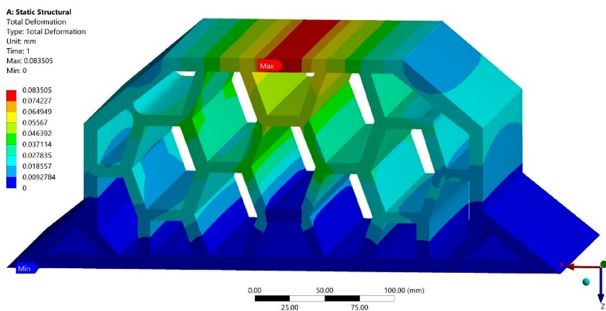


Fig. 14. Total deformation distribution - Model 2.

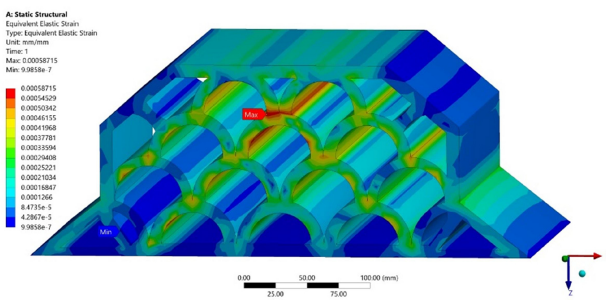


Fig. 15. Strain distribution - Model 3.

0.000964. Model 2 (8 mm and 10 mm), nearly identical strains (0.0006901 and 0.0006893, respectively). Model 3 presents lowest strain (0.000587), confirming improved resistance to deformation. The strain and deformation gradient at the color scale ranges from the minimum value that occurs at the base edges

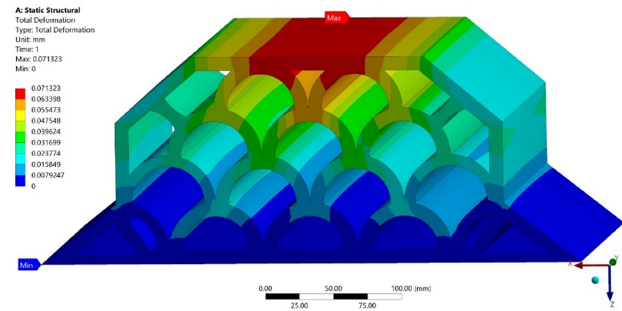


Fig. 16. Total deformation distribution - Model 3.

(dark blue) to the maximum value that is observed at the upper load application points (dark red).

Deformation patterns also favored Model 3, which exhibited the least total displacement, indicating better stability and stiffness. These findings were consistent with real-world observations of damaged floor blocks, lending credibility to the numerical approach.

From a practical perspective, the arched cavity design proposed in this study not only enhances structural stress distribution but also remains feasible for real-world application. The Libyan clay brick manufacturing sector has witnessed rapid advancements in recent years, with increasing interest in innovative and energy-efficient designs. Several local producers are already exploring alternative cavity configurations using flexible extrusion molds and automated forming machines. Thus, adopting the arched cavity structure would require minimal adaptation to current production systems and can serve as a competitive, structurally efficient, and thermally superior alternative in the local market.

### 3.2. Thermal performance of wall blocks

Thermal simulations evaluated the effect of block material and cavity modifications on heat transfer under Libyan climate conditions. Figs. 17 to 20 illustrate the heat transfer in Celsius and heat flux in W/m<sup>2</sup> for standard concert blocks and hollow clay

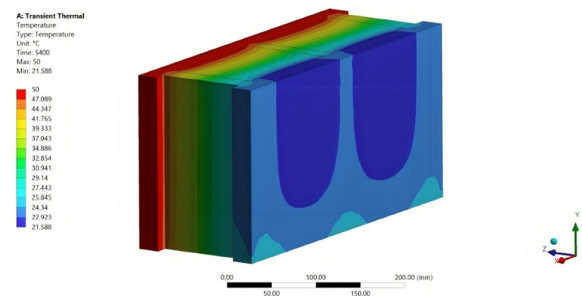


Fig. 17. Concrete blocks heat transfer results.



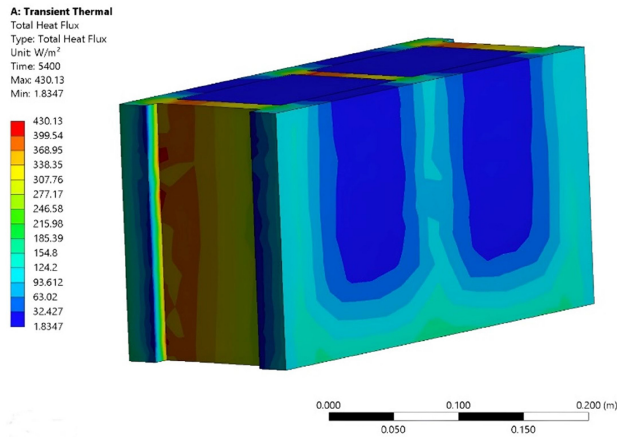


Fig. 18. Concrete blocks heat flux results.

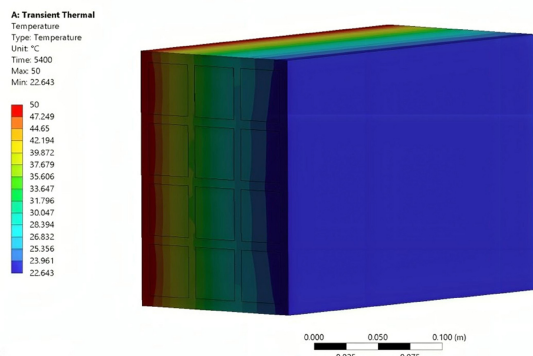


Fig. 19. Hollow bricks heat transfer results.

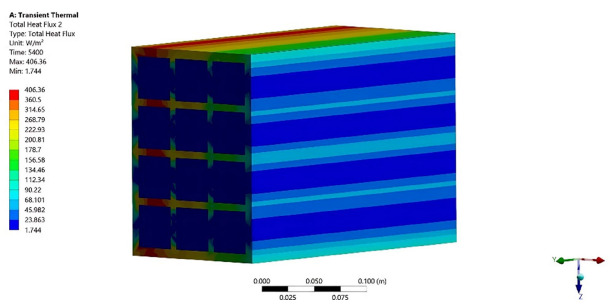


Fig. 20. Hollow bricks heat flux results.

bricks, respectively. The color scale ranges from the minimum value that occurs at the base edges (dark blue) to the maximum stress that is observed at the upper point (dark red)”.

Concrete blocks displayed the highest heat flux due to their high thermal conductivity ( $\sim 1.4$  W/m-K). Standard hollow clay blocks showed better insulation ( $\sim 1.26$  W/m-K), making them more suitable for energy-efficient applications.

As previously observed, horizontal thermal bridges significantly contribute to heat transfer and thermal flux through the block. To mitigate this effect, the

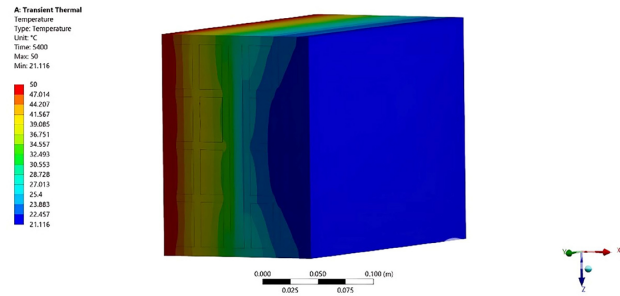


Fig. 21. Hollow bricks' air gap heat transfer results.

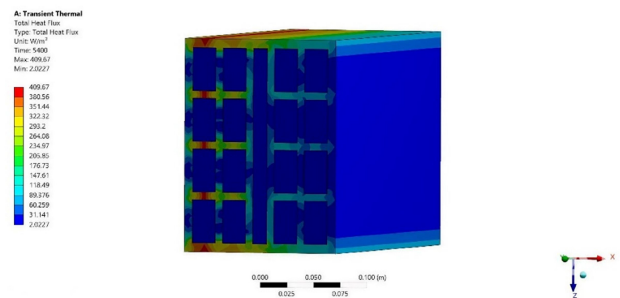


Fig. 22. Hollow bricks' air gap heat flux results.

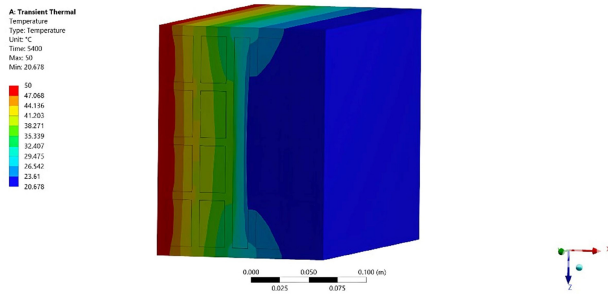
internal cavity of the clay block was redesigned to include a central air gap as shown in Figs. 21 and 22. This air-filled void acts as a natural insulator, effectively interrupting the direct path of heat flow through the block and enhancing its overall thermal resistance.

Furthermore, by incorporating polyurethane (PIR) insulation within the central air gap, the results indicated a reduction in interior surface temperature rise by approximately 43%–57% compared to concrete blocks. This improvement highlights the effectiveness of PIR as a low-conductivity thermal barrier in clay masonry units.

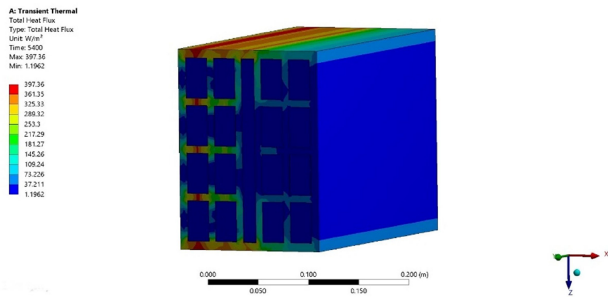
This enhancement is attributed to the very low thermal conductivity of the insulation material, as illustrated in Fig. 23. Additionally, the thermal flux across the insulated block was significantly reduced compared to the block with only an air gap, as shown in Fig. 24.

The final configuration shown in Figs. 25 and 26 involved the application of a 14 mm thick insulation layer on the exterior surface of the clay block, in order to obtain results for comparison with the previously analyzed cases.

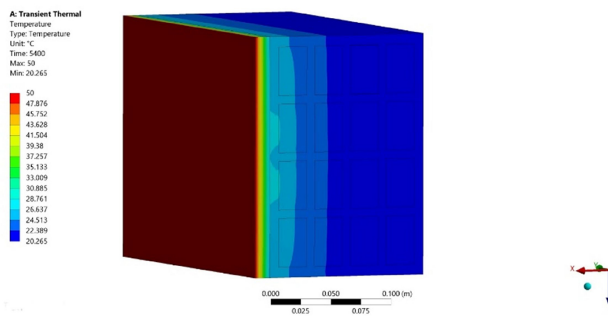
**Air Gap Integration:** Introducing an internal air layer disrupted conductive pathways and reduced thermal bridging. **Internal PIR Insulation:** Filling the cavities with polyisocyanurate (PIR) significantly enhanced resistance due to its low conductivity ( $\sim 0.019$  W/m-K). **External PIR Insulation:** Applying a 14 mm PIR layer externally achieved the



**Fig. 23.** Hollow bricks' internal polyurethane (PIR) insulation heat transfer results.

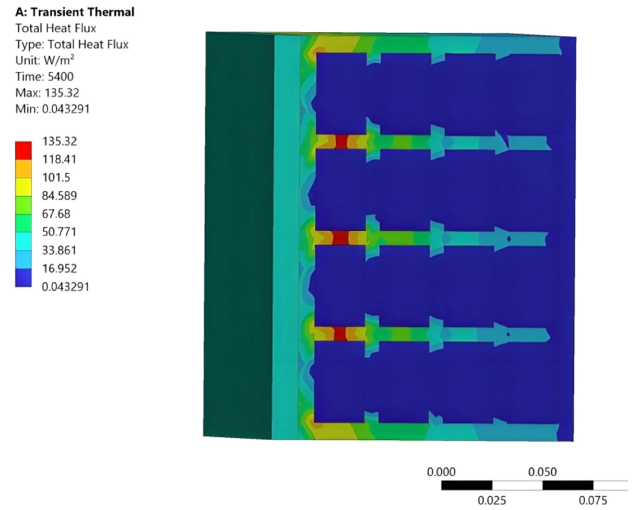


**Fig. 24.** Hollow bricks' internal polyurethane (PIR) insulation heat flux results.

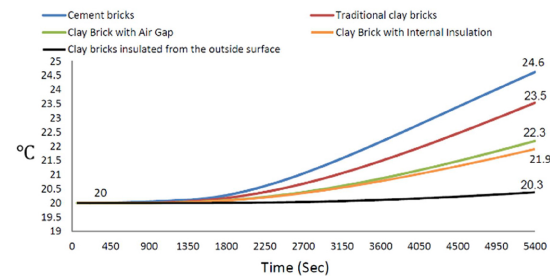


**Fig. 25.** Hollow bricks' external polyurethane (PIR) insulation heat transfer results.

best thermal insulation and minimized indoor surface temperatures. The external insulation approach not only offered the best thermal performance but also allowed for the removal of the internal air gap, optimizing both heat transfer resistance and constructability. The resulting system maintained the standard block width of 150 mm, with insulation integrated externally. The Fig. 27 illustrates the variation in the interior surface temperature of the wall over a period of ninety minutes for the five previously discussed cases. Thus, blocks with insulation demonstrated markedly lower heat fluxes. In addition, surface temperature probes showed that external insulation was most effective in reducing inner wall heating, which contributes to better thermal



**Fig. 26.** Hollow bricks' external polyurethane (PIR) insulation heat transfer results.



**Fig. 27.** Temperature over time for the internal surfaces of the different brick configurations.

comfort and lower HVAC loads. Thermal performance findings are reported in Table 4.

Time-dependent temperature rise on the internal surface of different wall configurations over a 90-minute simulation period. The externally insulated clay brick exhibited the lowest temperature increase (from 20°C to 20.3°C), demonstrating superior thermal resistance. In contrast, cement bricks showed the highest temperature rise (up to 24.6°C), indicating the least insulation performance.

The results indicate that modifying the cavity geometry and integrating insulation materials—particularly on the outer surface—can significantly enhance the thermal efficiency of hollow clay blocks. Among the tested configurations, the arched cavity design (Model 3) demonstrated the best structural performance, exhibiting the lowest stress concentrations, strain, and total deformation. While increasing wall thickness showed a marginal improvement in mechanical strength, it was less effective than optimizing cavity geometry. Observations from damaged floor blocks in actual buildings further supported the simulation results, particularly in

**Table 4.** Summary of thermal performance results.

| Block type                   | Thermal conductivity (W/m-K) | Observations                      |
|------------------------------|------------------------------|-----------------------------------|
| Concrete Block               | 1.4                          | Highest heat transfer             |
| Standard Clay Block          | 1.26                         | Moderate thermal resistance       |
| Clay Block with Air Gap      | ~0.029 (air effect)          | Reduced thermal bridging          |
| Clay Block with Internal PIR | ~0.019                       | Significantly improved insulation |
| Clay Block with External PIR | ~0.019 (surface)             | Best thermal performance          |

terms of stress distribution and deformation patterns. In terms of thermal behavior, hollow clay bricks outperformed conventional concrete blocks due to their lower thermal conductivity. Moreover, the introduction of air gaps and the application of polyisocyanurate (PIR) insulation—especially when applied externally—substantially reduced heat transfer. These findings collectively underscore the potential of using optimized cavity geometries in combination with passive insulation strategies to develop building units that enhance both structural integrity and energy efficiency, particularly in hot climate regions such as Libya.

4. Conclusion and recommendations

4.1. Conclusions

To validate the numerical model, compressive strength tests were performed on five hollow clay block samples with varying geometries. The experimental setup, loading conditions, and boundary constraints were replicated in the finite element simulations using ANSYS. The results showed strong agreement between the experimental and numerical predictions, confirming the reliability of the model for further parametric studies. Therefore, only the baseline geometry was physically tested, while optimized designs was evaluated numerically.

This study presented a numerical investigation into the structural and thermal performance of three hollow clay brick configurations under Libyan climatic conditions. Two of the models (Model 1 and Model 2) represent commercially available clay bricks in the local construction market, while Model 3 introduces a novel arched-cavity geometry designed specifically for this research. The arched cavity design (Model 3) demonstrated superior structural performance compared to the existing market options. Model 1 exhibited the highest stress concentration at 2.22 MPa, Model 2 showed a 29% reduction. Model 3 further enhanced performance, achieving a 41.7% reduction. Similarly, Model 3 recorded the lowest strain value (0.000587), representing a 39.1% reduction relative to Model 1, while Model 2 achieved a 28.5% reduction. These findings confirm that optimizing cavity geometry—particularly

through an arched configuration—has a greater influence on structural efficiency than simply increasing wall thickness.

From a thermal perspective, hollow clay bricks exhibited approximately 10% lower thermal conductivity than hollow concrete blocks. Modifying cavity layout to include an air gap reduced heat transfer, while the incorporation of PIR insulation further enhanced thermal resistance. Internal PIR integration decreased heat flux, whereas external application of PIR insulation yielded the most significant improvement, minimizing overall heat transmission.

Overall, the results highlight the effectiveness of combining cavity geometry optimization with targeted insulation strategies to improve both structural integrity and energy efficiency. This approach contributes to the development of sustainable masonry systems suitable for hot-climate regions such as Libya.

4.2. Recommendations

To build upon the findings of this study and improve its practical relevance, several technical, experimental, and sustainability-oriented recommendations are proposed:

•Enhanced Numerical Resolution:

Future studies should employ finer mesh configurations to increase the accuracy of finite element simulations and better capture localized stress and heat transfer phenomena.

•Experimental Validation:

Laboratory testing of both structural and thermal behavior is essential to validate simulation outcomes and confirm their applicability in real-world construction.

•Material Property Characterization:

Precise measurement of the physical and thermal properties of locally produced clay bricks—including thermal conductivity, density, and specific heat—is crucial to refine simulation models and ensuring realism.

•Advanced Heat Transfer Modeling:

Incorporating radiative and convective heat transfer mechanisms into thermal simulations would provide a more holistic understanding of energy dynamics within and around hollow brick systems.

#### •Field Trials and Environmental Exposure Testing:

Future work should test optimized block designs under real climatic conditions (e.g., solar radiation, wind, humidity) to evaluate long-term durability, structural integrity and thermal efficiency.

#### •Full-Scale Wall Application Studies:

Applying the proposed block configurations to full-scale wall systems would enable assessment of thermal bridging, overall structural stability, and constructability at the building envelope level.

#### •Life-Cycle Assessment (LCA):

To fully capture the environmental benefits of optimized clay bricks, future work should include a life-cycle analysis comparing embodied energy, emissions, and operational energy savings with conventional masonry materials.

## Acknowledgements

The authors would like to express their sincere appreciation to **Al-Zawiya Brick Factory** for providing access to their laboratory facilities and supporting the experimental testing. Their technical assistance and cooperation were essential for the successful calibration of the numerical models.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## Author's contributions

All of the authors have contributed equally to the article. Further, all of the authors have validated and approved the final manuscript.

## Ethics

There are no ethical issues with the publication of this manuscript.

## Dataset

The dataset generated and analyzed during the current study is not publicly available but is available from the corresponding author upon reasonable request.

## References

1. Yüksek İ, Öztas SK, Tahtalı G. The evaluation of fired clay brick production in terms of energy efficiency: a case study in Turkey. *Energy Efficiency*. 2020;13:1473–1483. <https://doi.org/10.1007/s12053-020-09896-y>.
2. Akande O, Emechebe C, Lembi J, Nwokorie J. Energy demand reduction for nigerian housing stock through innovative materials, methods and technologies. *Journal of Sustainable Construction Materials and Technologies*. 2023;8(3):216–232. <https://doi.org/10.47481/jscmt.1184338>.
3. Noori M, Bilgin A, Diallo H, Al Rousan M, Noori A. A study on the influence of material gradient index on bending and stress responses of FGM rectangular plates using the Finite Element Method. *Journal of Sustainable Construction Materials and Technologies*. 2024;9(3):239–254. <https://doi.org/10.47481/jscmt.1555157>.
4. Al-Tamimi A, Al-Amoudi O, Al-Osta M, Ali M, Ahmad A. Effect of insulation materials and cavity layout on heat transfer of concrete masonry hollow blocks. *Construction and Building Materials*. 2020;154:119300. <https://doi.org/10.1016/j.conbuildmat.2020.119300>.
5. Sassine E, Cherif Y, Dgheim J, Antczak A. Investigation of the mechanical and thermal performances of concrete hollow blocks. *SN Applied Sciences*. 2020;2(2006). <https://doi.org/10.1007/s42452-020-03881-x>.
6. del Coz Díaz J, Nieto P, Rabanal F, Martínez-Luengas A. Design and shape optimization of a new type of hollow concrete masonry block using the finite element method. *Engineering Structures*. 2011;33(1):1–9. <https://doi.org/10.1016/j.engstruct.2010.09.012>.
7. Sutcu M, del Coz Díaz J, Rabanal F, Gencel O, Akkurt S. Thermal performance optimization of hollow clay bricks made up of paper waste. *Energy and Buildings*. 2014;75:96–108. <https://doi.org/10.1016/j.enbuild.2014.02.006>.
8. Ahmadi R, Sourı B, Ebrahimi M. Evaluation of wheat straw to insulate fired clay hollow bricks as a construction material. *Journal of Cleaner Production*. 2020;254:120043. <https://doi.org/10.1016/j.jclepro.2020.120043>.
9. Cavaco E, Grilo I, Gouveia J, Júlío E, Neves L. Mechanical performance of eco-efficient hollow clay bricks incorporating industrial nano-crystalline aluminium sludge. *European Journal of Environmental and Civil Engineering*. 2018;24(12):1921–1938. <https://doi.org/10.1080/19648189.2018.1492974>.
10. Kumar A, Kumar R, Das V, Jhatial A, Ali T. Assessing the structural efficiency and durability of burnt clay bricks incorporating fly ash and silica fume as additives. *Construction and Building Materials*. 2021;310:125233. <http://doi.org/10.1016/j.conbuildmat.2021.125233>.
11. Shamim S, Ahmad S, Khan R. Numerical study on dynamic response of hollow and cavity type clay brick masonry infill



- panels subjected to blast loading. *Engineering Failure Analysis*. 2023;146:107104. <https://doi.org/10.1016/j.engfailanal.2023.107104>.
12. Candano L, Elorde R, Mejos A, Cabada J, *et al*. Performance of superabsorbent polymer as admixture in hollow concrete blocks. *Journal of Sustainable Construction Materials and Technologies*. 2023;8(3):153–167. <https://doi.org/10.47481/jscmt.1348426>.
  13. Atabay S. Determination of exterior material in sustainable buildings by value engineering method according to LEED criteria. *Journal of Sustainable Construction Materials and Technologies*. 2023;8(1):1–11. <https://doi.org/10.47481/jscmt.1246202>.
  14. ANSYS®Academic Research. Retrieved from <https://www.ansys.com>.