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Thermally Efficient Clay Bricks Incorporating Mushroom Cultivation Waste for Sustainable Construction in Hot-Arid Climates

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Keywords
Mushroom Cultivation Waste (MCW), Thermal conductivity, Energy-efficient bricks, Hot-arid climate, Sustainable construction

Abstract : This investigation examines the integration of Mushroom Cultivation Waste (MCW) as a sustainable additive in clay brick manufacturing for hot-arid climate applications, with New Aswan, Egypt, serving as the case study location. Comprehensive laboratory analyses evaluated the mechanical, physical, and thermal characteristics of MCW-incorporated bricks across varying concentrations (0–15% by weight). Results demonstrated that optimal MCW content of 15% achieved substantial thermal conductivity reduction of 62%, decreasing from 0.77 to 0.293 W/m·K, while preserving sufficient compressive strength (8.6 MPa) suitable for non-structural applications. Energy performance modeling through parametric simulations indicated that north-facing building facades constructed with 15% MCW-enhanced bricks exhibited 14.3% decreased annual cooling energy requirements relative to conventional brick systems. The findings establish that MCW-modified bricks enhance thermal performance, contribute to agricultural waste valorization, and advance circular economy implementation in construction practices. This research provides evidence-based recommendations for sustainable building material development in hot-arid environmental conditions, demonstrating practical waste-to-resource conversion applications.

1. Introduction

The built environment faces critical challenges amid climate change and rising energy requirements. The construction industry is responsible for approximately 40% of global energy usage and contributes 30% of greenhouse gas emissions worldwide [1]. In hot-arid climates, cooling systems account for up to 70% of a building's total energy expenditure,

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intensifying resource depletion, urban heat island effects, and climate change [2 - 3]. Therefore, a critical challenge arises from the widespread use of traditional building materials, such as conventional fired clay bricks, which possess high thermal conductivity. This inherent property allows for significant heat transfer from the scorching exterior to the interior spaces, leading to substantial indoor heat gain. Consequently, buildings constructed with these materials become heavily dependent on mechanical cooling systems. This reliance not only inflates operational costs but also exacerbates environmental issues through increased greenhouse gas emissions, further contributing to climate change. Therefore, there is an urgent need for sustainable and thermally efficient building materials that can mitigate these issues and enhance thermal comfort in hot-arid environments. In response to international efforts such as the Paris Agreement, there is a pressing need to develop advanced, thermally efficient construction materials that reduce the environmental footprint of buildings while ensuring thermal comfort under extreme climate conditions [4]. One promising strategy is the integration of agricultural waste materials into brick production. These bio-based construction elements offer multiple environmental advantages, including mitigating pollution from conventional waste disposal methods like incineration and landfilling, and reducing the depletion of natural resources associated with traditional brick manufacturing [5 - 6]. Agricultural residues such as sugarcane bagasse ash (SBA), rice husk ash (RHA), and sugarcane trash have demonstrated significant potential as sustainable brick constituents [5 - 6]. Research shows that incorporating these by-products can improve thermal insulation, acoustic absorption, hydro-stability, fire resistance, and the mechanical properties of composite materials [7]. Additionally, bio-bricks made from such materials may serve as carbon-negative building components while maintaining economic viability, offering a comprehensive solution to environmental challenges in the construction sector. This approach addresses waste management needs and contributes to atmospheric pollution reduction, which is particularly relevant in developing economies facing urban air quality issues [5, 8 - 9].

Recent investigations have systematically explored the use of agricultural by-products in clay bricks, demonstrating that adding materials like RHA and SBA at 5–15% by weight can yield structurally sound bricks with improved thermal performance and reduced production costs [10]. Numerous investigations have explored various agricultural residues, including RHA, sugarcane bagasse, and coconut fibers as potential additives [11 - 14]. Comprehensive analysis examining the integration of agricultural wastes in fired clay brick production demonstrates that incorporating materials such as RHA and SBA at proportions ranging from 5-15% by weight can produce structurally viable bricks while addressing environmental sustainability concerns [15]. Further studies testing up to 30% waste content have identified optimal results with 20% SBA and 10% RHA, balancing compressive strength, water absorption, and energy consumption during production [16 - 18]. Agricultural waste holds significant promise as a sustainable additive in brick production, offering both environmental and economic benefits. Their incorporation into clay bricks, such as RHA, SBA, and wheat straw ash (WSA), can significantly reduce environmental impact and lead to more economical construction [19 - 20]. These additives generally decrease brick density and compressive strength but improve properties like sulphate attack resistance and efflorescence [20 - 22]. Optimal inclusion rates are typically 5-10% by weight [19, 23]. Agricultural waste can also act as pore-forming agents and provide energy during firing [23]. Further studies testing up to 30% waste content have identified optimal results with 20% SBA and 10% RHA, balancing compressive strength, water absorption, and energy consumption during production [6, 24 - 26].

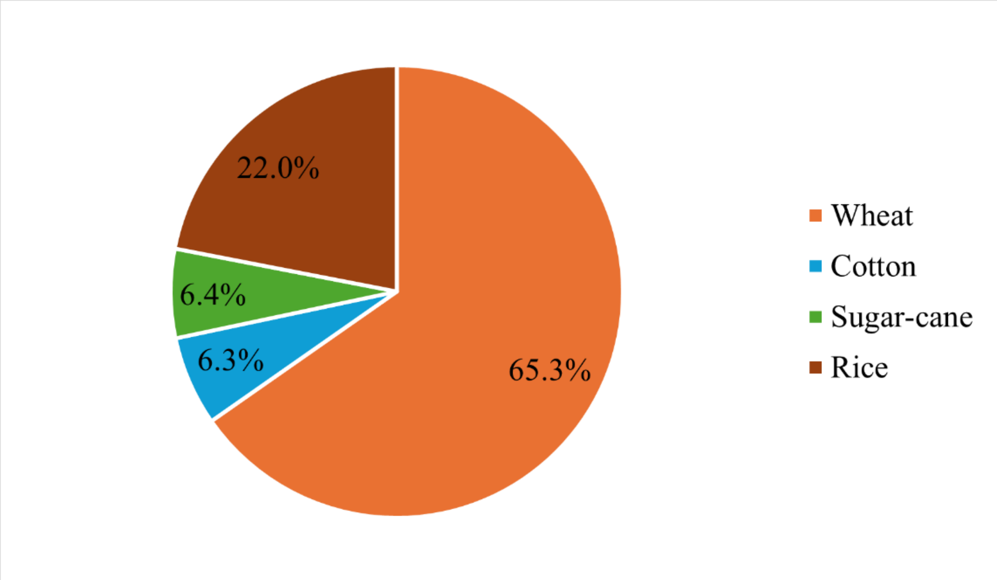


Fig. 1: Annual only major agricultural crops in Egypt (modified by authors) [28].

Rice husk, generated at approximately 4.4 million tons annually through rice cultivation as shown in Figure 1 [27 - 28], presents environmental challenges due to its resistance to natural decomposition [27, 29 - 30]. However, its high carbon and silicon content make it suitable for mushroom cultivation and as a valuable resource for sustainable building materials. The thermal insulation properties of mycelium-derived composites from rice husk vary with substrate and fungal species [31 - 32], influencing both economic and material performance. Thus, rice husk represents both a waste management challenge and a resource for sustainable construction, offering opportunities for environmental and economic optimization [33 - 35]. Recent studies have evaluated the thermal efficiency of bricks modified with different proportions of mushroom waste, focusing on cooling load requirements and long-term costs. Despite these advancements, the use of MCW as an additive in clay bricks for hot-arid regions such as Aswan, Egypt, remains underexplored. Aswan's extreme temperatures and intense solar radiation result in high energy demands for cooling, underscoring the need for energy-efficient building materials in the region [33 - 34, 36 - 37].

However, the use of MCW as an additive in clay bricks, especially for hot-arid regions such as Aswan, Egypt, has not been fully explored. Aswan experiences extremely high temperatures and intense solar radiation [18], which leads to high energy consumption for cooling buildings. Therefore, creating energy-efficient building materials is crucial for reducing energy use and promoting sustainability in this region [9, 18, 38 - 40]. Accordingly, this research systematically evaluates the thermal and energy performance of clay bricks incorporating MCW at varying concentrations (0–15% by weight) for different residential building orientations in hot-arid climates. Through comprehensive material characterization and computational energy simulations, the study aims to enhance cooling load reduction while ensuring structural integrity.

2. Methods and tools

This investigation examines the thermal impact of clay bricks modified with MCW in residential buildings, using a dwelling in New Aswan City as a case study for hot-arid climates. The methodology includes three phases:

1. Fabrication and characterization of various specimens: incorporating predetermined percentages of MCW into clay brick with thermal processing at 900°C. These specimens undergo a comprehensive assessment of their physical, chemical, mechanical, and thermal properties following international standardization protocols.
2. Build Energy Model: using Rhino 6 and Grasshopper to build a simulation model as the real building and using Open Studio and Energy Plus engines. And validate this model with the real building.
3. Analytical comparison of cooling load energy consumption: Simulating thermal performance across main building orientations with varying MCW incorporation percentages to quantify relative energy efficiency metrics.

2.1. The Investigated Building and Climatic Context

This research focuses on hot, arid climates, using New Aswan as a representative case study where substantial energy is consumed for cooling. In Egypt, standardized residential designs are often implemented without adaptation to local climates, leading to high energy demand, especially in hotter regions. This study evaluates how integrating MCW into clay bricks can enhance thermal performance compared to conventional materials. New Aswan is classified as a hot, arid climatic zone by both Köppen-Geiger and Egyptian national classifications [41 - 42]. The study analyses a social housing structure in New Aswan [43], chosen for its lack of climate-responsive design and minimal thermal insulation. The building has six stories with four 86-square-meter units per floor. It features standard 3-meter ceiling heights and a 10% window-to-wall ratio. This study examines the thermal and energy performance of clay bricks enhanced with MCW (0–15%) across various building orientations in hot-arid climates.

(a) (b)

Fig. 2: The investigated residential building in New Aswan City: a) The exterior facades; b) The horizontal architectural drawing [43].

2.2. Material preparation and fabrication

2.2.1. Raw materials and sources

This study used indigenous clay from Aswan, selected for its proximity to the site and representative composition. The MCW was obtained from the Agricultural Research Centre in Giza, Egypt. This material selection ensures that findings are transferable to regional construction and waste management practices. Using local clay minimizes the environmental impact of transportation, while incorporating MCW promotes circular economy principles by valorising agricultural waste.

2.2.2. Sample preparation protocols

This investigation examines the thermal performance implications of integrating mushroom cultivation by-products into traditional clay construction elements designed for implementation in the extreme environmental conditions of New Aswan's urban development. In the experimental procedure, clay was substituted with MCW at concentrations from 0% to 15% by mass. The materials were mixed mechanically for 10 minutes, with 18% water content added to ensure plasticity. The mixtures were pressed in 50 mm×50 mm×50 mm steel molds at 10 MPa. The specimens were first cured in direct sunlight for 12 hours, then dried at 120°C for 12 hours. Final firing occurred at 700°C, 800°C, and 900°C for 4 hours at each temperature, as shown in Figure 3. Firing at 700, 800, and 900°C is considerably lower than traditional brick firing temperatures, which can reach up to 1300°C. Lower firing temperatures directly translate to reduced energy requirements and, consequently, lower greenhouse gas emissions during the manufacturing process.

Rigorous analytical assessment of the resultant specimens encompassed multidimensional characterization of physical attributes, structural integrity parameters, and thermal transfer properties, with testing methodologies conforming to internationally recognized standardization protocols. This systematic research framework seeks to quantify the potential efficacy of biologically modified construction materials for optimizing building envelope performance under challenging climatic conditions, simultaneously addressing intersecting challenges in agricultural waste valorization and sustainable infrastructure development within Egypt's expanding urban settlement initiatives.

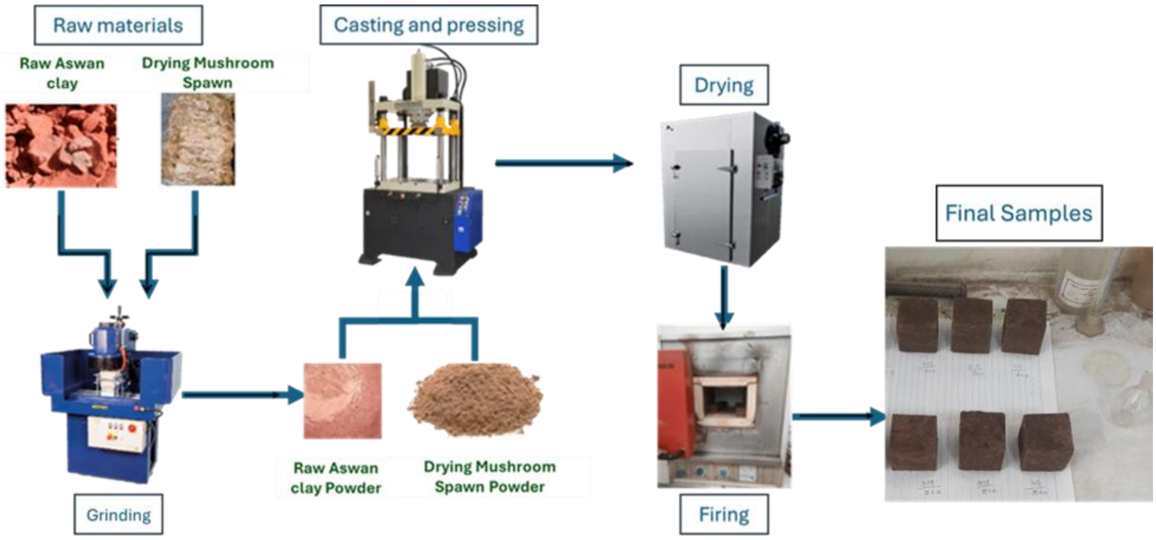


Fig. 3: A diagram illustrating the workflow of the material fabrication process (By author).

2.3. Laboratory Experiments

The specimens' mechanical, physical, and thermodynamic properties were assessed using standardized laboratory protocols.

2.3.1. Mechanical and Physical Properties

Compressive strength was evaluated per ASTM C26. Physical characterization included water absorption, bulk density, and apparent porosity, following ASTM C26 procedures. These properties are significant, as higher porosity often correlates with better thermal resistance [44 - 48].

2.3.2. Thermal Properties

Thermal conductivity was measured using a KD2 Pro analyzer, which complies with ASTM D5334. Lower thermal conductivity indicates greater insulating efficiency and is critical for evaluating the material's performance. Adherence to ASTM standards ensures that results are rigorous and reproducible.

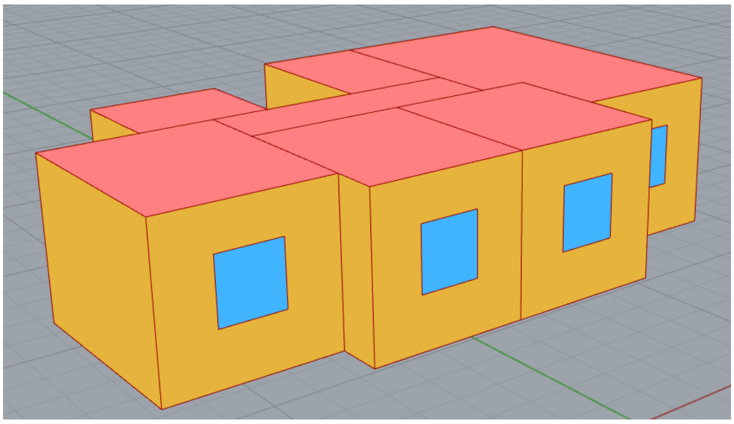
2.4. Computational simulation framework

2.4.1. Energy modelling approach

A 3D residential model was created in Rhino 6 and integrated with Grasshopper to find the optimal wall assembly using MCW bricks. A computational script defined input parameters, including conditioned zones, thermal loads, and material specifications. A residential heat pump was modelled with cooling and heating setpoints at 22°C and 25°C, respectively. The environmental simulation plugins Ladybug, Honeybee, and Climate Studio were used as interfaces for the EnergyPlus, OpenStudio, and Radiance simulation engines to analyze thermal performance, as shown in Figure 4 [35].

2.4.2. Data Collection

Household demographic parameters were established based on contemporary statistical data from Egypt's Central Agency for Public Mobilization and Statistics, which documents a mean residential occupancy of five individuals per domestic unit [49]. The spatial allocation framework was subsequently formulated in accordance with characteristic behavioral patterns observed in Egyptian family structures. Regarding meteorological conditions, climatological data incorporated into the simulation model was acquired from the Aswan International Airport meteorological monitoring station as shown in Figure 5-b, encompassing an extensive temporal range from 1940 through 2023. This comprehensive climatic dataset, accessible in Energy Plus Weather (EPW) format through the Ladybug mapping interface as shown in Figure 5-a [50], reveals distinctive temperature distribution patterns: peak thermal conditions were documented between July 20–26 during summer months, while minimum temperature values were recorded between January 13–19 in the winter period. Additionally, representative seasonal thermal profiles were identified for analytical purposes: summer (August 10–16), winter (January 6–12), autumn (October 20–26), and spring (April 26–May 2).



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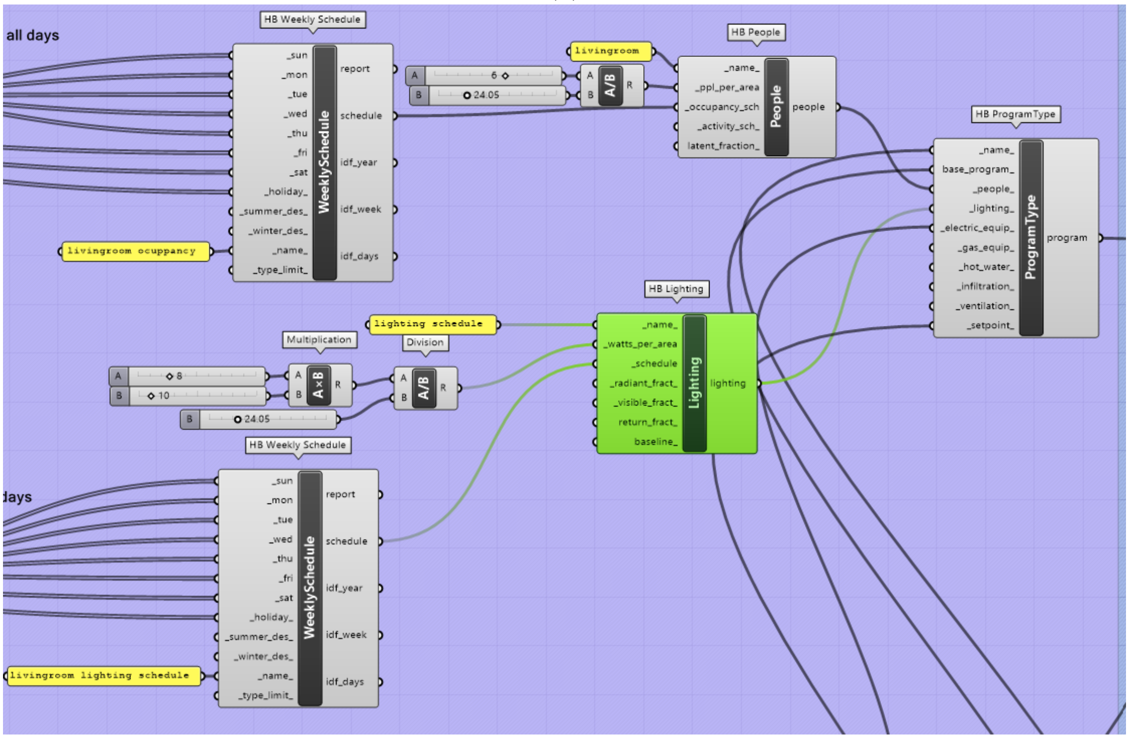
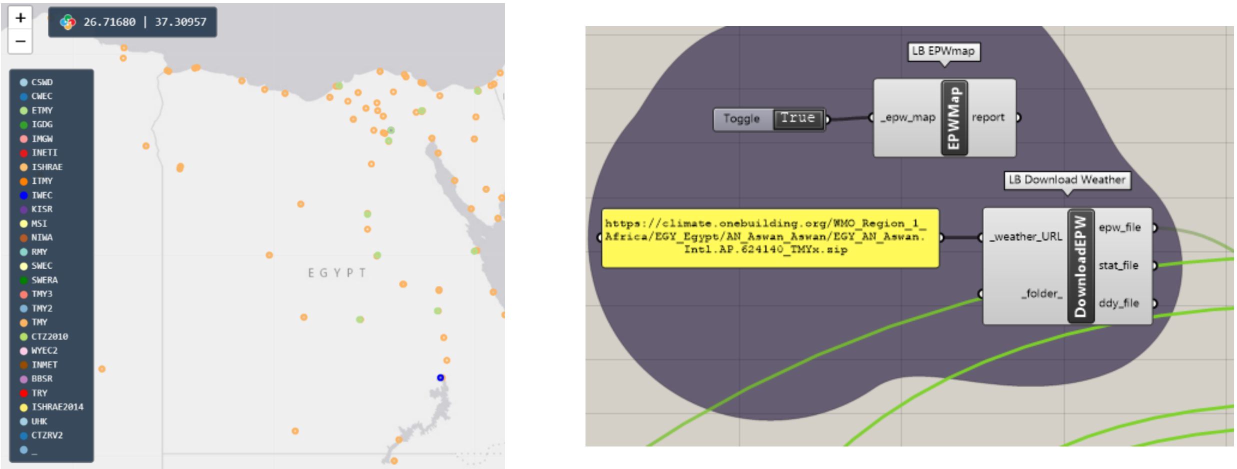


(b)

Fig. 4: Simulation model in Rhino 6 and Grasshopper software, a) 3D modeling for a case study apartment in Rhino 6 software, b) Occupancy and lighting designed space program in Grasshopper software.



(a) (b)

Fig. 5: a) Ladybug weather mapping in Egypt, b) Energy plus weather file (EPW) for Aswan City which used in simulation code.

2.4.3. Proposed various scenario

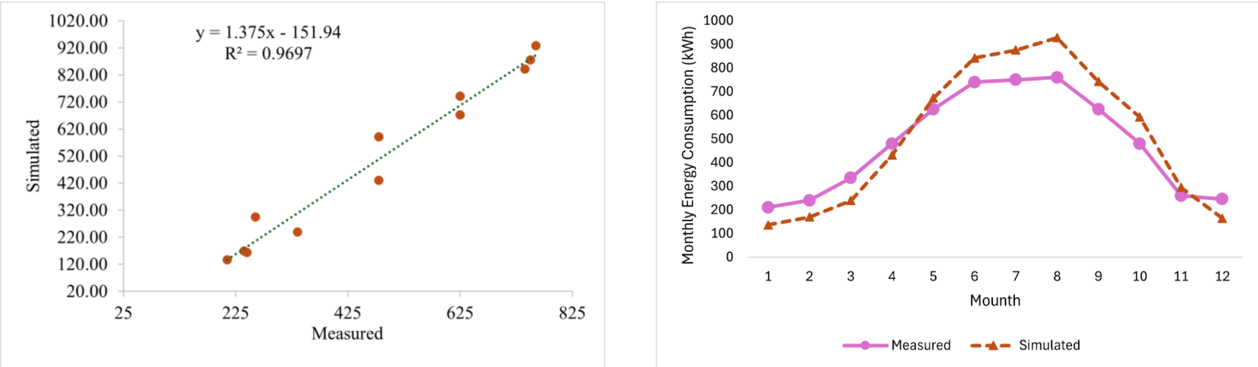
This research explores the thermodynamic performance characteristics resulting from the integration of MCW in graduated concentrations (0%-15% by mass) within construction composite materials as shown in Table 1. The analytical framework examines thermal behavior across standardized wall assemblies with an aggregate thickness of 0.35 meters, comprising a tripartite structure: exterior cementitious coating (0.03 m), primary brick matrix (0.30 m), and interior plaster finish (0.02 m) in different orientations.

Table 1: MCW percentages in different scenarios

Scenarios	MCW %	Clay %
MCW – 0	0%	100%
MCW – 5	5%	95%
MCW – 7.5	7.5%	92.5%
MCW – 10	10%	90%
MCW – 12.5	12.5%	87.5%
MCW – 15	15%	85%

2.4.4. Model validation

Computational simulation results underwent rigorous validation procedures in accordance with ASHRAE Standard 90.2-2024 protocols [51], through precise parametric modeling of the residential unit's critical characteristics, encompassing thermal comfort boundary conditions, illumination parameters, building envelope material specifications, and heating, ventilation, and air conditioning (HVAC) system configuration and operational attributes. Statistical analysis reveals a robust correlation coefficient (R^2 = 0.9697) between computational projections and empirically measured values, as demonstrated in the graphical representation in Figure 6. This pronounced positive statistical relationship indicates exceptional predictive accuracy within the simulation framework, with deviation metrics below 4% between anticipated and documented energy utilization patterns. The substantial congruence between theoretical projections and empirical observations confirms the methodological reliability of the simulation architecture, validating its efficacy as an analytical instrument for energy performance evaluation. Comparative examination of the linear data distributions demonstrates remarkable concordance between simulated and measured energy consumption trajectories across a complete annual cycle. The regression analysis exhibits notable temporal synchronization, with maximum energy demand consistently manifesting during the summer period spanning June through August in both computational and empirical datasets. This alignment of seasonal variation patterns holds particular significance, as it substantiates the model's capacity to accurately forecast energy utilization fluctuations across diverse meteorological conditions.



(a) **(b)**

Fig. 6: Validation analysis: a) Correlation between simulated and measured data; b) Comparative deviation between actual and predicted energy consumption values.

3. Results

Firing bricks at 900°C, as examined in the referenced study, yields several important environmental benefits, especially when MCW materials are used to partially replace clay. The inclusion of MCW in the brick mixture enhances thermal insulation and contributes to the overall sustainability of the product. Notably, the choice of a 900°C firing temperature achieves an optimal balance between mechanical strength, durability, and energy efficiency [9, 36]. This section presents findings in two parts. First, it examines the material property changes from MCW incorporation. Second, it provides an annual cooling demand assessment across different MCW concentrations and building orientation.

3.1. Material properties

The analysis showed clear correlations between the physical, mechanical, and thermal properties of the MCW-clay brick composites. Optimal consolidation occurred at a firing temperature of 900°C.

3.1.1. Compressive Strength and Bulk Density

Compressive strength was inversely proportional to MCW content, reaching 8.6 MPa at 15% MCW, which meets the requirements for non-load-bearing applications. Bulk density decreased from 1922 kg/m^3 (control) to 1419 kg/m^3 (15% MCW) more than this percentage will cause failure in mechanical properties, classifying the bricks as lightweight under ASTM C90 standards.

3.1.2. Porosity and Water Absorption

Porosity increased with MCW concentration, leading to higher moisture absorption. Cold water absorption rose from 13.9% to 23.6%, and boiling water absorption rose from 17.2% to 25.3% at 15% MCW.

3.1.3. Thermal Conductivity

The incorporation of 15% MCW into bricks resulted in a significant reduction in thermal conductivity, decreasing from 0.77 W/m·K in the control bricks to 0.293 W/m·K. This change represents an improvement of approximately 61.95%, highlighting the effectiveness of MCW as an additive for enhancing the thermal insulation properties of construction materials. The considerable reduction in thermal conductivity underscores the potential of these modified bricks to contribute to energy efficiency, particularly in hot-arid climates where minimizing heat transfer is essential for maintaining indoor thermal comfort and reducing energy consumption for cooling.

3.2. Cooling loads simulation results

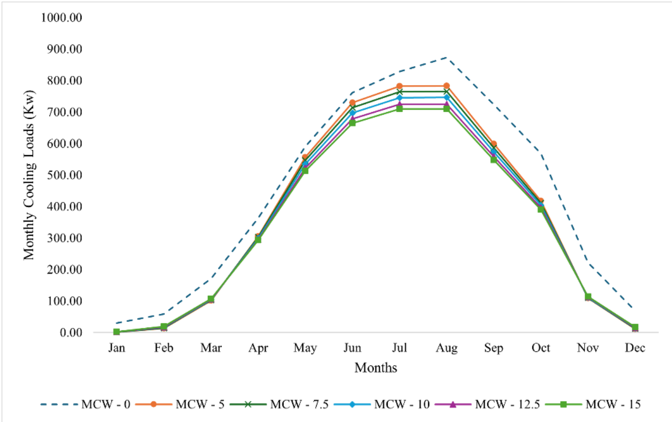
Parametric simulations using Ladybug and Honeybee quantified the thermal performance of bricks with different MCW concentrations for various building orientations.

3.2.1. Northern Orientation

In northern-facing applications, all MCW-modified bricks showed better thermal efficiency than control samples. The MCW-15 sample, for instance, recorded a cooling load of 710 kW in August. All modified compositions had similar cooling load needs from January to April and in November and December. 5% and 7.5% of the MCW samples performed similarly, with average cooling load reductions of 12.25 kW from May to October. The 12.5% and 15% samples also performed in parallel, with reductions of 10.5 kW during the same period (Figure 7a).

3.2.2. Eastern Orientation

In eastern orientations, all MCW bricks performed better than the control bricks, which recorded a cooling load of 761 kW for the MCW-15 sample in August. Load requirements were similar for all samples from January to March and in November and December. The 5%, 7.5%, and 10% MCW bricks showed cooling load reductions of about 11 kW from April to October, while the 12.5% and 15% MCW bricks showed reductions of 9 kW (Figure 7b).



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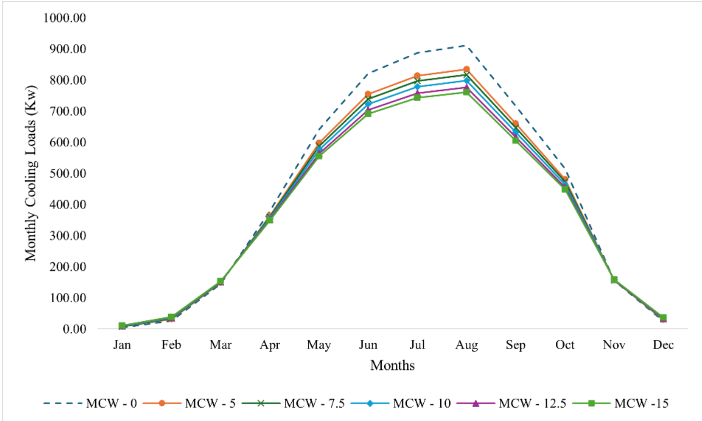

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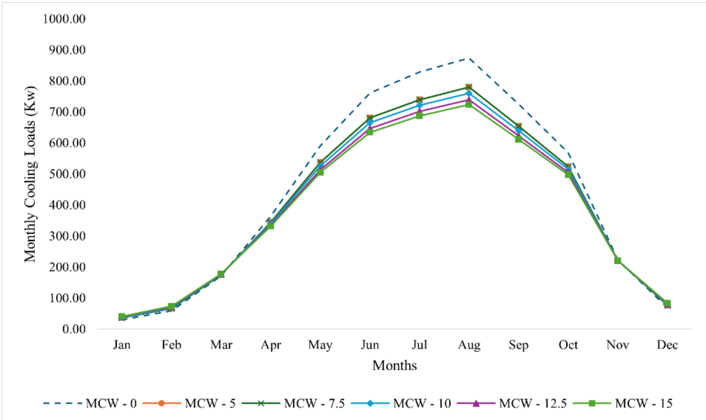

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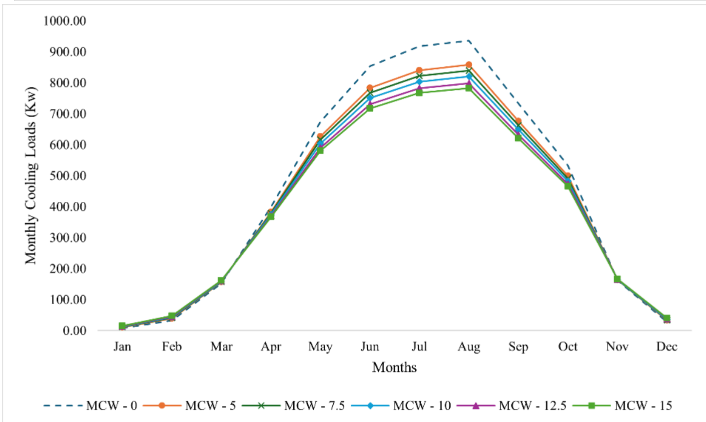

(d)

Fig. 7: Monthly Cooling Loads (Kw) in various orientations: a) Northern orientation; b) Eastern orientation; c) Southern orientation; d) Western orientation.

3.2.3. Southern Orientation

For southern orientations, all MCW bricks were more efficient than control bricks, except from December to March, when control samples had slightly lower cooling needs. The cooling load for the MCW-15 sample in August was 723 kW. The 12.5% and 15% MCW samples showed parallel performance, with average cooling load reductions of around 7 kW from April to November (Figure 7c).

3.2.4. Western Orientation

In western-facing applications, all modified bricks outperformed control bricks, except from November to March. The cooling load for the MCW-15 sample was 783 kW in August. All MCW concentrations (5-15%) showed similar thermal responses from April to October, with a maximum difference of approximately 18 kW in August (Figure 7d).

4. Discussion

The integration of MCW into clay bricks results in a notable enhancement of thermal insulation properties. A 15% incorporation of MCW achieved a 62% reduction in thermal conductivity (from 0.77 to 0.293 W/m·K), a performance that surpasses efficiencies reported for other agricultural additives like rice husk ash (RHA), which typically yield reductions of 40–50% [16, 20]. The advanced thermal performance of the MCW composite was modeled using a computational framework that integrated Honeybee, Open Studio, and Energy Plus to predict energy performance with high precision. The integration of MCW significantly enhanced the thermodynamic properties of clay brick composites, as evidenced by the reduction in thermal conductivity from 0.77 W/m.K to 0.293 W/m.K at 15% waste concentration. This improvement exceeds the thermal performance of other bio-based bricks, such as those incorporating wheat straw (WS) (0.45 W/m·K at 10% content [44 - 46]) or coconut fibers (CF) (0.52 W/m·K [11 - 13]), likely due to MCW's unique microporous structure. The integration of MCW into clay bricks demonstrates significant advancements in thermal performance and sustainability, particularly when compared to conventional bricks and other bio-based alternatives. Table 2. provides a comprehensive summary of key material properties and energy performance metrics, highlighting the unique advantages of MCW-enhanced bricks in hot-arid climates.

The enhanced thermal resistance is attributed to microstructural modifications within the brick. The organic waste particles create a more porous internal structure while reducing the overall bulk density of the composite, which curtails heat transfer. Crucially, these improvements do not compromise the material's structural integrity for its intended use. The compressive strength of bricks with 15% MCW was 8.6 MPa, a value comparable to other agro-waste composites and sufficient for non-load-bearing applications. This balance of improved insulation and adequate strength validates the material's suitability for sustainable construction remains comparable to other agro-waste composites (e.g., 7–9 MPa for RHA bricks [16]), validating their suitability for non-load-bearing applications.

Beyond material properties, the study highlights the critical role of building orientation in maximizing energy efficiency, a factor previously emphasized in studies of hot-arid climates [2, 41 - 42]. The analysis revealed that northern-oriented facades consistently achieved the highest performance, with a 15% MCW brick wall yielding a 14.3% reduction in annual cooling demand. This level of energy savings is not only a significant improvement over conventional insulated walls (8–12% [3]) but also rivals the performance of high-efficiency bio-composites like mycelium-based panels (12–15%) [31 - 32].

The economic analysis indicates that MCW-enhanced bricks are a financially viable solution, despite a marginal increase in initial construction costs of approximately 2%. This upfront cost is offset by significant long-term savings on cooling energy; for instance, a 0.35 m wall with MCW demonstrated a 17.2% reduction in energy expenditures over a ten-year period [35]. This demonstrates a clear path to cost-effectiveness, positioning the material as a sound long-term investment that utilizes a low-cost agricultural waste stream. These findings provide a strong case for adopting this technology in new construction projects within hot-arid regions, addressing the dual challenges of high energy demand and agricultural waste management.

Table 2: Comparative performance of MCW bricks with conventional and other agro-waste bricks.

Property	**Conventional Bricks** [21]	**MCW Bricks**	**RHA Bricks** [3,16, 20]	**Wheat Straw Bricks** [44 - 46]	**Coconut Fiber Bricks** [11 - 13, 31 - 32]
Thermal Conductivity (W/m·K)	0.77	0.293	0.462-0.385 (40-50% reduction from conventional)	0.45 (10% content)	0.52
Compressive Strength (MPa)	N/A (implied higher)	8.6 (for non-load bearing)	7-9 (for non-load bearing)	N/A	N/A
Bulk Density (kg/m³)	1922 (control)	1419	N/A	N/A	N/A
Water Absorption (Cold) (%)	13.9 (control)	23.6	N/A	N/A	N/A
Water Absorption (Boiling) (%)	17.2 (control)	25.3	N/A	N/A	N/A
Annual Cooling Demand Reduction (Northern Orientation)	N/A (baseline)	14.3%	8-12% (conventional insulated walls)	N/A	12-15% (mycelium-based panels)
Economic Feasibility	Baseline	Marginal 2% increase in initial cost, 17.2% reduction in energy expenditure over 10 years	N/A	N/A	N/A

5. Conclusions

This study presents a comprehensive investigation of mushroom cultivation waste (MCW) as a sustainable additive in clay brick production for hot-arid climates. The optimal 15% MCW formulation achieved a significant 62% reduction in thermal conductivity (0.293 W/m·K) while maintaining adequate compressive strength (8.6 MPa) for non-load-bearing applications. Microstructural analysis revealed that the enhanced thermal insulation properties resulted from increased porosity (23.6% water absorption) and reduced bulk density (1419 kg/m^3), consistent with pore-formation mechanisms observed in similar bio-composites. Energy simulations demonstrated the material's climate-responsive functionality, with northern facades showing maximum efficacy (14.3% annual cooling load reduction) and peak performance aligning with Aswan's cooling demand period (May-October, ambient temperatures >35°C).

While these results demonstrate promising potential, several limitations must be acknowledged. The current formulations remain restricted to non-structural applications due to strength limitations, and the increased porosity raises concerns about moisture susceptibility in humid subtropical applications. Furthermore, practical implementation would require optimization of MCW collection and supply chain logistics for industrial-scale production. Technology nevertheless offers significant environmental benefits by addressing two UN Sustainable Development Goals simultaneously: SDG 11 (sustainable cities) through energy-efficient construction and SDG 12 (responsible consumption) via agricultural waste valorization, with life-cycle analysis suggesting potential for 17.2% operational energy savings compared to conventional systems.

Future research should focus on developing hybrid material systems that combine MCW with rice husk ash or geopolymers to enhance mechanical properties for structural applications. Additional work is needed to characterize long-term durability under thermal cycling and moisture exposure conditions. Implementation studies should also develop region-specific frameworks that consider local construction practices and economic factors. This research establishes a scientifically grounded pathway for transforming agricultural waste into high-performance building materials, contributing to both materials’ science and sustainable construction engineering. The findings offer particular value for developing regions facing the dual challenges of energy-intensive cooling demands and agricultural waste management needs, providing a practical solution that aligns with circular economy principles.

List of abbreviations

Abbreviations

MCW	Mushroom Cultivation Waste
WS	wheat straw
RHA	Rice husk ash
CF	coconut fibers
SBA	sugarcane bagasse ash

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