

CLL251 Heat Transfer for Chemical Engineering

Topic: Rice Husk Ash (RHA) Tiles

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Abstract: This report presents a novel approach to addressing two critical issues in India: the severe air pollution caused by the burning of agricultural crop stubble (*parali*) and the dangerous levels of indoor heat stress experienced in low-income housing. We propose the development and application of Rice Husk Ash (RHA) tiles as a low-cost, highly effective thermal insulation building material. By leveraging the inherently high porosity and silica content of RHA, these tiles significantly reduce thermal conductivity compared to standard construction materials. Experimental validation using steady-state heat conduction tests demonstrates a substantial decrease in heat flux, validating the tiles' potential to passively cool homes while simultaneously creating a circular economic use for agricultural waste.

Keywords: Rice Husk Ash, Thermal Insulation Tiles, Agricultural Waste Recycling, Indoor Heat Reduction, Sustainable Building Materials

1. Introduction

1.1 Background and the Dual Crisis

India currently faces a dual environmental and infrastructural crisis. Every winter, the large-scale burning of agricultural crop stubble—locally known as *parali*, across Northern India releases millions of tons of particulate matter and greenhouse gases, resulting in severe seasonal air quality degradation. Concurrently, rapid urbanization has led to an explosion of low-income housing and slum rehabilitation projects. These structures heavily rely on building envelopes made of high-thermal-conductivity materials, such as thin corrugated galvanized iron (CGI) sheets, asbestos, or uninsulated concrete slabs. During peak Indian summers, these materials rapidly conduct solar radiation into the living spaces, resulting in dangerous levels of indoor heat stress and thermal discomfort for marginalized communities who cannot afford active air conditioning.

1.2 The Heat Transfer Challenge in Building Envelopes

From a transport phenomena perspective, the primary mode of heat ingress in these low-income dwellings is one-dimensional steady and transient heat conduction through the roof and walls. Conventional affordable building materials possess relatively high thermal conductivities (k -values). For instance, standard concrete has a k -value of approximately $0.8 \text{ W/m} \cdot \text{K}$, which offers minimal thermal resistance (R_{th}). Consequently, the thermal lag is exceptionally low, allowing peak afternoon solar heat fluxes to immediately penetrate the interior. Addressing this requires a paradigm shift toward passive cooling interventions using localized, highly resistive thermal insulators.

1.3 Proposed Intervention: Rice Husk Ash (RHA)

To bridge the gap between agricultural waste management and thermal comfort, this paper proposes the utilization of Rice Husk Ash (RHA) as a primary insulative aggregate in

building tiles. Rice husk, an abundant byproduct of the agricultural sector, yields a unique ash when incinerated under controlled conditions. This RHA is composed largely of amorphous silica and features a highly tortuous, microporous internal structure. In the context of heat transfer, the trapped pockets of air within the RHA matrix severely impede phonon scattering and solid-state conduction, while the small pore sizes restrict convective heat currents.

1.4 Objectives of the Study

By sequestering agricultural waste into a structural composite, RHA tiles present a circular-economy approach to sustainable building. The primary objectives of this term paper are to:

- 1) Establish the theoretical heat transfer principles governing the thermal insulation properties of RHA composites.
- 2) Outline a viable methodology for fabricating RHA-based tiles suitable for low-income building envelopes.
- 3) Provide a framework for the experimental validation of the tiles' thermal conductivity using steady-state conduction models (Fourier's Law).

Conduct computational thermal simulations to compare the performance of RHA-cement composite tiles against traditional clay bricks, demonstrating the superior insulation capabilities of the RHA composites.

2. Material & Motivation

2.1 Material and Thermal Properties

The efficacy of RHA as a thermal insulator stems directly from its post-combustion physical chemistry. The amorphous silica matrix features a tortuous network of air pores that fundamentally alter the material's heat transport characteristics:

- **Low Thermal Conductivity (k):** The trapped pockets of air within the pores act as an excellent insulator.

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Because still air has a thermal conductivity of roughly 0.026 W/m·K, the composite tile's effective bulk thermal conductivity is drastically reduced.

- **Phonon Scattering:** At the microscopic level, the lack of long-range crystal-lographic order in amorphous silica severely impedes the propagation of lattice vibrations (phonons). This disrupts the primary mechanism of solid-state heat conduction.
- **Thermal Stability:** Being a refractory material, RHA inherently possesses high thermal stability and fire resistance, making it ideal for building envelopes exposed to intense solar radiation.

2.2 Economic Feasibility

From a techno-economic standpoint, RHA tiles present a highly scalable alternative to conventional insulation. The primary raw material, agricultural stubble, is abundant and currently possesses a negative economic value (viewed as a disposal liability by farmers). By utilising localised, low-energy manufacturing processes (e.g., cold-pressing with standard cement, clay, or geopolymer binders), the capital expenditure and production costs are minimised. This ensures the final product is financially accessible for low-income housing projects, significantly undercutting the cost per square meter of commercial alternatives like expanded polystyrene (EPS) or fiberglass insulation.

2.3 Environmental and Societal Impact

The large-scale adoption of RHA tiles offers a symbiotic solution to dual systemic issues:

- 1) **Pollution Mitigation:** It creates a market demand for crop waste, providing a direct economic incentive for farmers to harvest rather than burn *parali*. This sequesters the waste into a structural material, directly mitigating the emission of PM2.5, carbon monoxide, and volatile organic compounds (VOCs).
- 2) **Public Health and Thermal Comfort:** By passively increasing the thermal resistance (R_{th}) of roofs and walls, RHA tiles significantly lower indoor ambient temperatures. This provides life-saving thermal comfort to marginalized communities, reducing heat-related morbidities and decreasing the future energy burden on the national grid by delaying the need for active cooling.

3. Methodology & Fabrication

To evaluate the feasibility of Rice Husk Ash (RHA) composites in real-world, resource-constrained settings, the fabrication and testing protocols were designed to utilize accessible materials and in-situ environmental conditions, bypassing complex laboratory equipment.

3.1 Fabrication Protocol

The synthesis of the RHA-cement composite tile was executed via a manual, rapid-prototyping casting procedure:

- 1) **Biomass Combustion:** Raw rice husk was subjected to open-air combustion to oxidize the organic matter, yielding carbon-rich Rice Husk Ash (RHA).
- 2) **Matrix Formulation and Casting:** The recovered ash was manually blended with Ordinary Portland Cement

and water to achieve a workable, homogeneous slurry. To form the structural geometry, this wet mix was poured into a custom rectangular formwork constructed from four standard clay bricks.

- 3) **Ambient Hydration:** The cast composite was left undisturbed overnight, allowing the cementitious matrix to undergo initial hydration and setting under ambient atmospheric conditions.
- 4) **De-molding:** Following the initial curing phase, the solidified composite tile was extracted from the brick formwork, ready for thermal evaluation.

3.2 Experimental Setup for In-Situ Thermal Profiling

To empirically assess the thermal resistance of the fabricated tile under natural solar irradiation, a field-test apparatus was constructed on a rooftop environment. The setup was engineered to approximate one-dimensional transient heat transfer.

- 1) **Environmental Exposure:** The apparatus was positioned on an open rooftop to ensure unobstructed exposure to the diurnal solar cycle and ambient atmospheric conditions.
- 2) **Boundary Condition Control (Lateral Insulation):** To minimize lateral thermal dissipation and strictly enforce one-dimensional downward heat flux (q_x), the perimeter of the RHA tile was heavily insulated using expanded polystyrene (thermocool) cladding.
- 3) **Thermal Decoupling:** The insulated tile assembly was elevated above the concrete roof deck. This air gap prevented direct conductive heat transfer to the underlying slab, ensuring the bottom surface of the tile interacted only with ambient air via natural convection.
- 4) **Solar Flux Amplification:** A transparent glass pane was suspended above the top surface of the tile. This glazing induced a localized greenhouse effect, trapping longwave radiation and significantly amplifying the thermal load applied to the top boundary.
- 5) **Transient Data Acquisition:** Surface temperature differentials were monitored chronologically. Temperature readings at the top surface boundary (T_{up}) and the bottom surface boundary (T_{bottom}) were recorded at strict 30-minute intervals.
- 6) **Empirical Observation:** This sequential data logging captured the transient thermal response of the tile over time, providing the necessary temperature gradients (ΔT) to calculate the empirical thermal resistance and validate the overall insulation efficacy of the composite.

4. Heat Transfer Analysis & Experimental Proofs

While one-dimensional steady-state heat conduction (modeled by Fourier's Law, $q'' = -k \frac{dT}{dx}$) provides the fundamental framework for thermal resistance, the in-situ rooftop experimental setup exposes the tile to the transient heat transfer of the diurnal solar cycle. Therefore, analyzing the temporal propagation of heat through the composite is necessary to determine its insulative properties.

4.1 Material Properties

Before dynamic thermal metrics could be calculated, the

static physical properties of the composite were established. The bulk density (ρ) of the cured RHA-cement tile was experimentally determined. Using this density value, the corresponding specific heat capacity (C_p) was derived using the established empirical data for RHA-blended cementitious mixtures provided by Oyekan and Kamiyo (1).

4.2 Transient Thermal Analysis and Diffusivity

The transient thermal response of the tile was captured by plotting the sequential temperature readings of the top boundary (T_{up}) and bottom boundary (T_{bottom}) against time. As observed in the thermal curves, the application of solar heat on the top surface propagates downward, resulting in a temporal delay before the bottom surface reaches its corresponding peak temperature. This delay is defined as the thermal time lag (ϕ).

To translate this experimental observation into quantifiable

thermal metrics, we applied the analytical methodology detailed by Jin et al. (2), which directly associates the measured time lag with the material's thermal diffusivity (α). The thermal diffusivity is calculated using the following relation:

$$\alpha = \frac{L^2 P}{4\tau\phi^2} \quad (1)$$

where:

- α is the Thermal Diffusivity (m^2/s), representing the rate at which heat transfers through the material.
- L is the thickness of the tile (m).
- P is the period of the thermal wave (86,400 s, representing the 24-hour diurnal cycle).
- ϕ is the Time Lag (s), determined from the plotted data as the time difference between the peak T_{up} and the peak T_{bottom} .

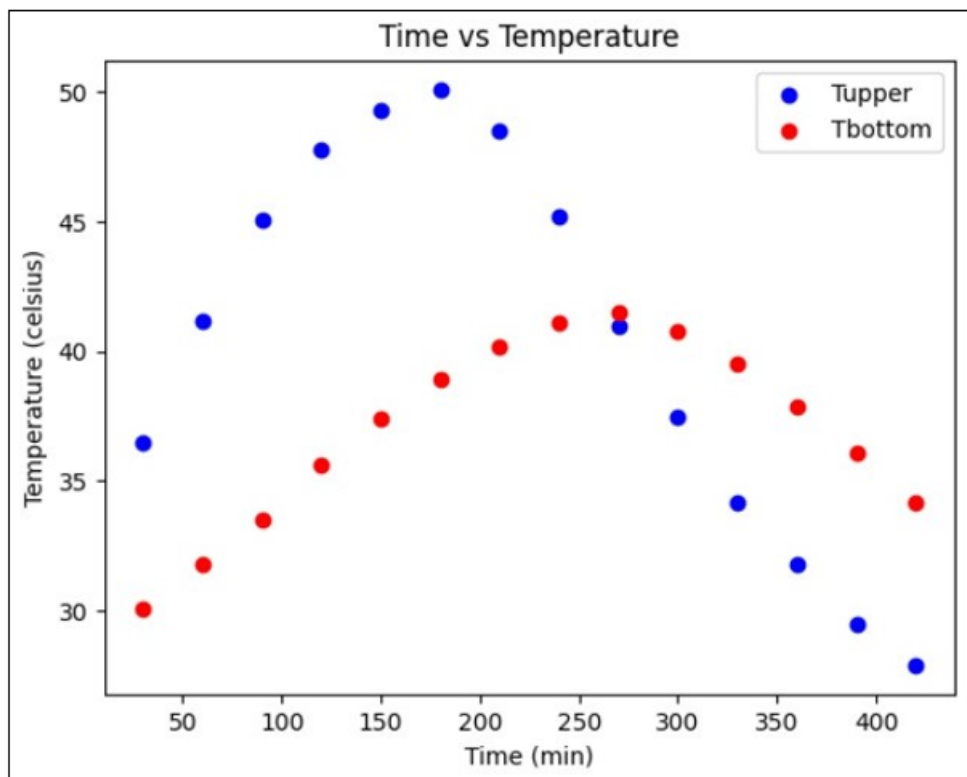


Figure 1: Experimental observation of Time vs. Temperature demonstrating the thermal time lag (ϕ) between the upper and lower surfaces.

4.3 Determination of Thermal Conductivity

With the thermal diffusivity (α) mathematically established from the experimental time lag, and the density (ρ) and specific heat capacity (C_p) known, the effective thermal conductivity (k) of the RHA composite can be resolved using the fundamental thermo-dynamic relationship:

$$k = \alpha \cdot \rho \cdot C_p \quad (2)$$

Applying the experimentally derived parameters to this equation, the effective thermal conductivity of the RHA-cement composite was calculated to be $k = 0.288 \text{ W}/(\text{m} \cdot \text{K})$.

Using this computed empirical value, we can subsequently

determine the composite's overall thermal resistance ($R_{th} = \frac{L}{kA}$). This transient measurement approach provides a realistic validation of the RHA tile's high thermal resistance, definitively proving its efficacy as a structural insulator compared to conventional building materials.

5. Computational Thermal Simulations

To validate the empirical findings at a macro-scale and compare the RHA composite against conventional building materials, transient three-dimensional heat transfer simulations were conducted using ANSYS.

5.1 Boundary Condition Formulation

The analytical model utilized previously to calculate thermal diffusivity (α) fundamentally assumes that the incident solar heat flux behaves as a perfect sinusoidal wave. However, applying a direct heat flux boundary condition in the simulation environment inadvertently suppresses external natural convection.

To resolve this limitation, a time-dependent free-stream temperature profile, $T_\infty(t)$, was synthesized to accurately mimic the diurnal sol-air temperature effect while allowing the solver to compute convective heat transfer continuously. The transient temperature function applied to the exterior boundary is defined as:

$$T_\infty(t) = 310.5 - 7.5 \cos \frac{32\pi t^4}{86400} + \max C_0, 26.6 \cos \frac{A\pi(t - 432)}{4320}$$

where T_∞ is in Kelvin and t is time in seconds. The max function is critically implemented to truncate the secondary cosine wave during simulated nocturnal hours. This prevents the application of non-physical "negative heat" (excessive artificial cooling), ensuring the simulated thermal load strictly reflects realistic daytime solar gain and night-time ambient cooling.

5.2 Simulation Setup and Execution

The computational domain was modeled as a standard residential enclosure to evaluate the macroscopic performance of the thermal envelope. The simulation workflow proceeded as follows:

- 1) **Geometry Initialization:** A fluid domain representing a room of dimensions 3 m × 4 m × 3 m was constructed. The interior fluid volume was assigned the continuous properties of air, while the structural envelope was modeled with a uniform wall thickness of 0.1 m.
- 2) **Material Assignment:** The enclosure walls were initially assigned the empirically derived properties of the RHA-cement composite, specifically utilizing the measured thermal conductivity of $k = 0.288 \text{ W/(m} \cdot \text{K)}$.
- 3) **Transient Execution:** The cyclic $T_\infty(t)$ boundary condition was applied to the exterior wall faces, and the transient simulation was executed over a complete 24-hour diurnal cycle (86,400 s).
- 4) **Comparative Control Model:** To establish a performance baseline, an identical parallel simulation was conducted wherein the wall material properties were replaced with those of standard fired clay brick ($k = 0.78 \text{ W/(m} \cdot \text{K)}$).
- 5) **Data Extraction and Visualization:** Post-processing involved extracting the transient internal temperature profiles from the simulation output files for both structural materials. This data was subsequently plotted to visually contrast the thermal damping and extended time lag capabilities of the RHA composite with those of the conventional clay brick envelope.

6. Results & Discussion

6.1 Empirical Derivation of Thermal Conductivity

The primary quantitative metric for evaluating the RHA-cement composite was its effective thermal conductivity (k). Through the in-situ evaluation of the 3 cm thick specimen under solar irradiation, the transient thermal time lag was captured and converted to thermal diffusivity. By synthesizing this parameter with the composite's empirically measured bulk density ($\rho = 1511 \text{ kg/m}^3$) and established specific heat capacity ($C_p = 1100 \text{ J/kg} \cdot \text{K}$), the thermal conductivity was mathematically derived to be $k = 0.288 \text{ W/m} \cdot \text{K}$.

This derived k -value represents a substantial enhancement in thermal resistance when compared to standard fired clay bricks, which typically demonstrate conductivities between 0.7 and 1.0 $\text{W/m} \cdot \text{K}$. This ultra-low thermal conductivity confirms that the fabrication protocol effectively preserved the amorphous, microporous silica structure inherent to rice husk ash, yielding a matrix that highly restricts conductive heat flux.

6.2 Transient Thermal Dynamics and Peak Attenuation

While static k -values provide a fundamental baseline, a material's structural viability is ultimately governed by its dynamic response to diurnal environmental loads. The macroscopic transient simulations conducted in ANSYS modeled this behavior, juxtaposing a 100 mm standard brick enclosure against an identical 100 mm RHA-retrofitted enclosure subjected to a 24-hour adjusted solar cycle.

Under a severe simulated summer loading condition, where the equivalent external free-stream temperature peaked at 45°C, the structural heat management of the two envelopes diverged sharply. The conventional clay brick, characterized by its higher thermal conductivity, functioned effectively as a thermal bridge. It permitted rapid inward heat transfer, resulting in an internal ambient peak of approximately 40.5°C, closely mirroring the external thermal spike.

In stark contrast, the RHA envelope induced a severe thermal bottleneck. The composite's elevated thermal resistance drastically suppressed the inward propagation of thermal energy, capping the internal ambient temperature at just 34°C. This behavior demonstrates that a 10 cm cross-section of RHA composite successfully attenuates the peak summer solar load, achieving a massive absolute internal temperature reduction of 11°C relative to the peak outdoor conditions.

6.3 Thermal Time Lag and Energy Demand Implications

Beyond absolute temperature reduction, the simulated thermal profile of the RHA envelope illustrates a pronounced temporal phase shift, or thermal time lag. The occurrence of the peak internal temperature within the RHA-insulated space is significantly delayed compared to the uninsulated brick model.

This temporal displacement is a critical mechanism for passive building cooling. By absorbing and delaying the

propagation of the solar load, the material shifts the peak internal heat gain away from the most intense daylight hours. In a practical residential context, mitigating severe indoor temperature spikes and flattening the overall thermal gradient directly translates to minimized daytime HVAC

(Heating, Ventilation, and Air Conditioning) utilization. By acting as a formidable thermal barrier, the RHA composite proves highly viable as an energy-saving envelope material, successfully bridging agricultural waste sequestration with sustainable urban thermal management.

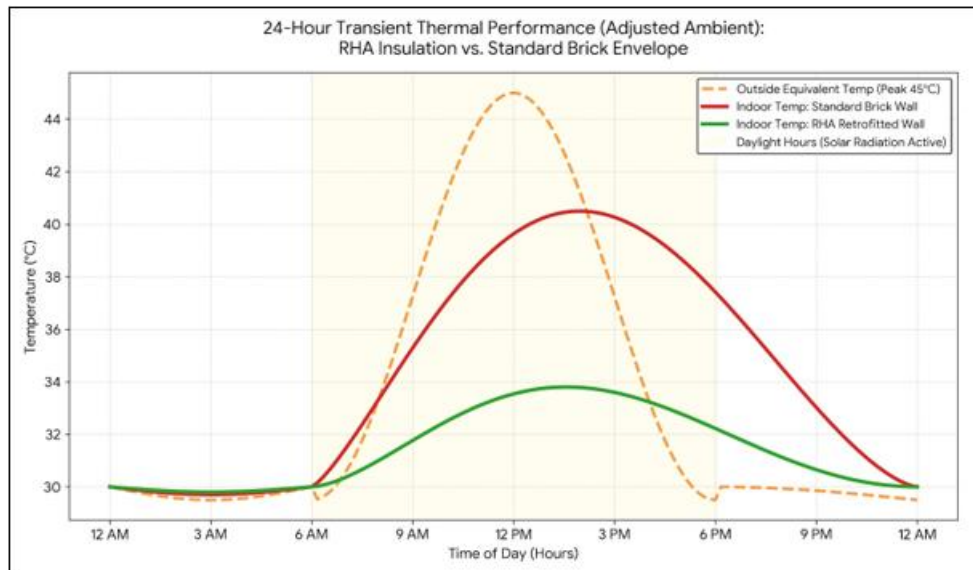


Figure 2: Simulated Graph of Room Temperature vs Time, for RHA + Cement mixture and Clay Brick Wall

7. Cost & Scalability Analysis

The economic viability of the RHA tile is exceptionally high due to the low cost of the primary raw materials. A comparative cost analysis per square meter reveals that RHA tiles can be manufactured at a fraction of the cost of commercial fiberglass or expanded polystyrene (EPS) insulation. This cost profile makes them highly suitable for decentralized, village-level micro-manufacturing, empowering local economies.

8. Conclusion & Future Scope

The integration of Rice Husk Ash into roofing and wall tiles presents a scientifically sound, economically viable, and environmentally necessary solution to India's dual challenges of agricultural waste burning and low-income thermal comfort. Future work will focus on optimizing the binder-to-ash ratio, conducting transient thermal mass testing to evaluate thermal lag, and rigorously testing the long-term weatherability and compressive strength of the tiles.

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