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Thermal Performance Optimization of Cement–Sand Roofing Panels Using Natural By-Product Insulation

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Abstract— *Roofs are a major pathway for heat gain in buildings located in tropical regions, often leading to high indoor temperatures and increased cooling demand. In this work, cement–sand roofing panels were modified by introducing several locally available natural by-products, namely sawdust, brick powder, coconut coir, haystack, and rice husk, and their influence on heat transfer behavior was experimentally examined. Panels were fabricated using four cements: sand: insulation ratios (2:3:0.25 to 2:3:1.00) and two thicknesses (8 mm and 16 mm). Thermal response was evaluated using a steady-state hot-plate method by monitoring temperature evolution on the cold surface of each panel. The results show that higher insulation content consistently delays temperature rise, while increased thickness further suppresses heat transfer. Among the materials investigated, rice husk and coconut coir exhibited the most pronounced insulation effect. These findings demonstrate that agro-based by-products can be effectively used to enhance the thermal performance of roofing panels, offering a practical and low-cost approach for improving indoor comfort in hot climates.*

I. Introduction

Roofs are a major pathway for heat gain in buildings located in tropical regions, often leading to elevated indoor temperatures and increased energy demand for mechanical cooling. Improving the thermal performance of roofing materials is therefore essential for enhancing indoor comfort and reducing energy consumption in hot climates [1].

In recent years, increasing attention has been directed toward the use of natural and agro-industrial by-products as thermal insulation materials in construction. Agricultural residues such as rice husk, sawdust, and coconut coir are produced in large quantities and are often treated as waste, despite possessing favorable insulation characteristics due to their low density and porous structure [2]. Several studies have demonstrated that incorporating such materials into cement-based composites can significantly reduce thermal conductivity compared to conventional cement–sand systems [3].

Rice husk–based materials, in particular, have shown strong insulation potential, with reported thermal conductivity values comparable to commercial insulation products when properly processed [4]. Similarly, coconut coir fibres have been reported to improve thermal performance while contributing to enhanced toughness in cementitious composites, although durability considerations remain important [5]. Sawdust and wood-based fillers have also been widely studied and shown to reduce heat transfer in mortar and concrete composites, especially at higher replacement levels [6].

Brick powder has been investigated mainly as a partial replacement for cement or sand, with studies indicating moderate reductions in thermal conductivity depending on particle size and replacement ratio [7]. However, direct comparative studies evaluating multiple natural by-products under identical experimental conditions, particularly for roofing panel applications, remain limited.

The present study addresses this gap by experimentally evaluating the thermal performance of cement–sand roofing panels incorporating different natural by-products. The effects of insulation type, mix ratio, and panel thickness are systematically investigated to identify optimized configurations suitable for low-cost and sustainable roofing in tropical environments.

II. Materials and Experimental Methods

Materials

Ordinary Portland cement and natural river sand were used as the base materials. Five natural by-products—sawdust, brick powder, coconut coir, haystack, and rice husk—were selected based on local availability and reported insulation potential. Prior to use, all insulation materials were air-dried to minimize moisture effects and prepared to achieve reasonably uniform particle sizes.

Panel Preparation

Roofing panels were cast using cement: sand: insulation ratios of 2:3:0.25, 2:3:0.50, 2:3:0.75, and 2:3:1.00. For each composition, panels with thicknesses of 8 mm and 16 mm were produced. After casting, the samples were allowed to cure under ambient conditions until sufficient rigidity was obtained for handling and testing.

Thermal Testing Procedure

Thermal performance was assessed using a hot-plate arrangement designed to simulate heat flow through a roof element. Each panel was placed on the heating surface, and temperatures on both the exposed (hot) side and the opposite (cold) side were recorded at fixed time intervals. Measurements were continued until the temperature rise on the cold side approached a steady trend, indicating near steady-state heat transfer.

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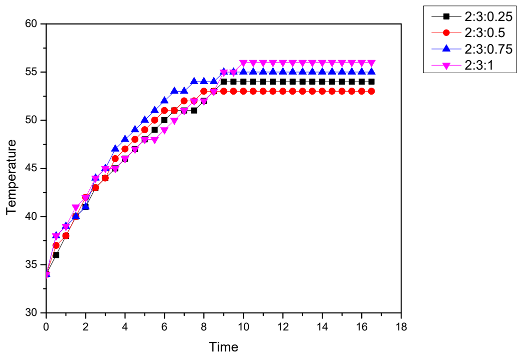
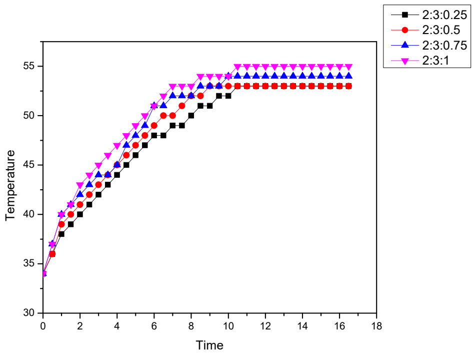
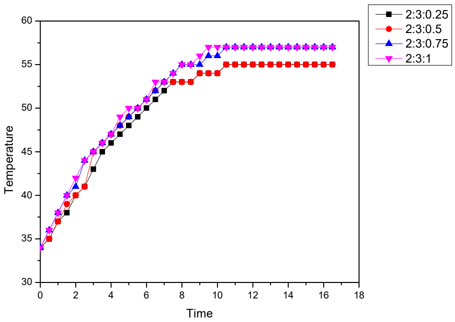
III. Results and Discussion



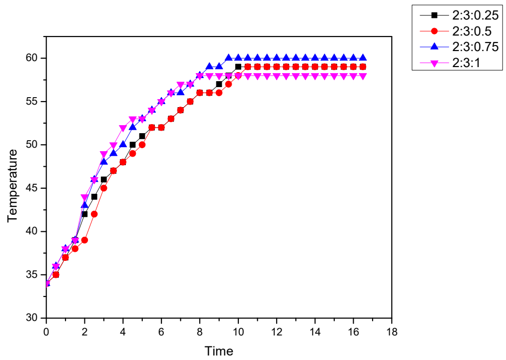
Graph 1: Material (Saw Dust); Temperature vs Time (8mm)



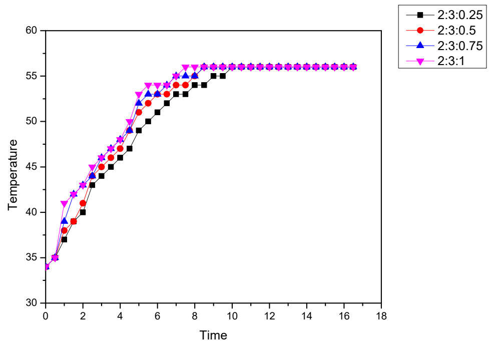
Graph 2: Material (Brick Powder); Temperature vs Time (8mm)



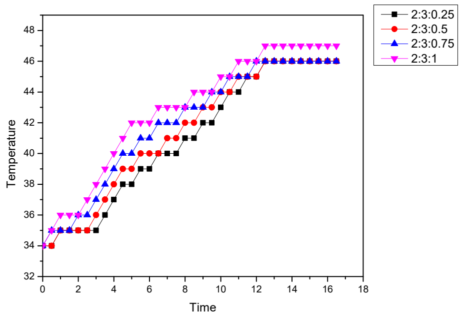
Graph 3: Material (Coconut Coir); Temperature vs Time (8mm)



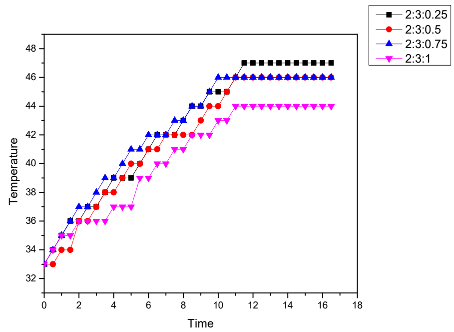
Graph 4: Material (Haystack); Temperature vs Time (8mm)



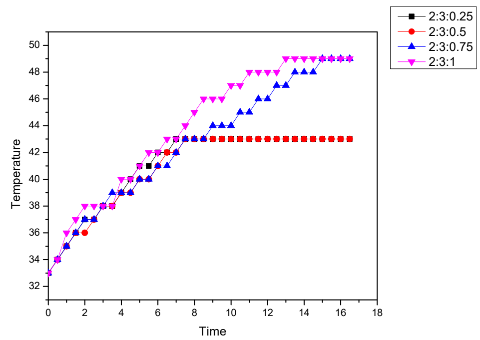
Graph 5: Material (Rice husk); Temperature vs Time (8mm)



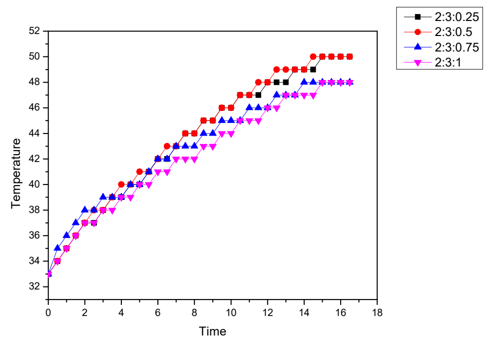
Graph 6: Material (Saw Dust); Temperature vs Time (16mm)



Graph 7: Material (Brick Powder); Temperature vs Time (16mm)



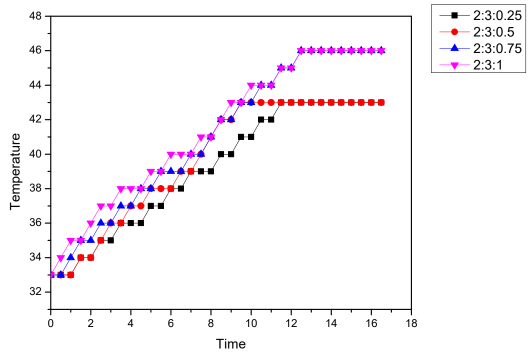
Graph 8: Material (Coconut Coir); Temperature vs Time (16mm)



Graph 9: Material (Haystack); Temperature vs Time (16mm)

For all insulation materials, the cold-side temperature increased gradually with time before reaching a quasi-steady state. Panels containing higher proportions of natural insulation exhibited noticeably slower temperature rise, confirming the role of the added materials in restricting heat flow. This trend was observed consistently for both panel thicknesses.

Panel thickness had a clear influence on thermal behavior. Compared with 8 mm samples, 16 mm panels showed significantly lower cold-side temperatures under the same heating conditions. The increased thickness effectively extended the heat transfer path, leading to improved thermal resistance regardless of insulation type.



Graph 10: Material (Rice husk); Temperature vs Time (16mm)

Among the materials tested, rice husk and coconut coir produced the lowest cold-side temperature rise across most mix ratios. Their superior performance can be attributed to their highly porous and fibrous structures, which trap air and hinder thermal conduction. Sawdust and haystack provided moderate insulation benefits, while brick powder, being denser, exhibited comparatively higher heat transfer.

Overall, the results highlight the combined importance of material selection, insulation content, and thickness in controlling heat transfer through cement–sand roofing panels.

IV. Conclusions

The experimental investigation demonstrates that natural by-products can be effectively integrated into cement–sand roofing panels to improve thermal insulation performance. Increasing the proportion of insulation material and using thicker panels both contribute to reduced heat transfer. Rice husk and coconut coir were identified as the most effective insulation materials among those studied. The findings support the use of agro-waste-based roofing panels as an affordable and environmentally friendly solution for improving thermal comfort in buildings located in tropical climates.

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