NUMERICAL SIMULATION OF TEMPERATURE DISTRIBUTION IN A SCALED-DOWN TEST HUT WITH COIR FIBER REINFORCED NATURAL RUBBER COMPOSITE INSULATING MATERIALS USING COMPUTATIONAL FLUID DYNAMICS

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ABSTRACT: Numerical simulation studies were carried out to improve energy efficiency in a scaled-down test hut with coir fiber reinforced natural rubber composite roofing insulation material. This research paper investigates the temperature distribution of materials which are used for roofing insulation, such as expanded polystyrene (EPS), fiber glass (FG), polyurethane foam (PUF) and coir-fiber reinforced natural rubber composites. A pitch type scaled-down test hut measuring 1 m × 1 m × 1 m was created to analyze the performance of these insulation materials using Computational Fluid Dynamics (CFD) simulations. Insulation thicknesses of 0.05, 0.1, 0.15, and 0.2 m were applied to the roof of the test hut. The analysis was conducted by varying mesh sensitivities to coarse, medium, and fine meshes to improve the accuracy of the results. This fine mesh analysis was chosen for further studies to compare the thermal behavior inside the scaled-down test hut under insulated and non-insulated conditions. The results demonstrate that considering the thermal conductivity of the insulated roof is critical for a detailed thermal analysis of the scaled-down test hut. The studies utilized the commercial CFD tool, Flow Simulation, available in SolidWorks software. A comparison of results suggests that the necessary thermal comfort requirements can be maintained in the scaled-down test hut while simultaneously reducing total energy consumption by correctly using roofing insulation materials.

Keywords: roofing materials, solar radiation, solid works flow simulation, coir fiber, natural rubber

1 INTRODUCTION

Presently, energy efficiency and indoor thermal comfort are two primary goals in building design due to rising energy demand, climate change, and growing sustainability agenda. Buildings consume approximately one-third of the total energy worldwide, with nearly 40% of this energy used in commercial buildings for HVAC (Heating Ventilation and Air Conditioning) systems (González-Torres et al., 2022). Roof structures, especially in single-story buildings or those with roof floors, are one of the primary avenues for solar heat gain, accounting for approximately 35% of thermal transmittance into interior spaces (Sudarshana et al., 2024). This problem can be prevented by using thermal insulation systems beneath roofing layers (Chamath et al., 2020). Several insulation options are available; however, this chapter focuses on natural fiber composites as a viable choice due to their low cost, biodegradability, and reduced environmental impact (Sudarshana et al., 2024). Coconut coir fiber is abundant in Sri Lanka, possessing suitable thermal insulating properties, such as low thermal conductivity and acceptable moisture resistance (Chamath et al., 2022). Investigations into reinforcing natural rubber matrices with coir have demonstrated that coir-based composites offer improved mechanical stability and are ideal for construction applications, such as roof insulation (Chamath et al., 2023). This research examines the scope of thermal performance through numerical simulation of heat transfer processes in roof assemblies. Natural rubber (NR) is regarded as a sustainable polymer matrix in green composites. Recent studies have explored the interactivity of natural fibers and biopolymers to create composite systems with acceptable thermal insulating performance (Udayakumara et al., 2022); likewise, advanced manufacturing, such as Vacuum-Assisted Resin Transfer Molding (VARTM), has been applied to existing composites to create composite systems with higher strength and thermos-mechanical performance (Sudarshana et al., 2025). The importance of material selection and processing techniques is highlighted by a study on alkaline treatment and durability of coir fibers in composite systems (Chamath et al., 2025). This research paper indicates that numerical simulation studies have been carried out to improve energy efficiency in a scaled-down test hut using coir fiber reinforced natural rubber composite. Traditional insulating materials including mineral wool, expanded polystyrene (EPS), and polyurethane foams are frequently utilized, because of their excellent thermal properties. These materials, however, are costly to make and dispose of, petroleum based, and non-biodegradable. They are less appropriate for use in green building applications due to their lifetime emissions, which also cause environmental problems. As a result, engineers and researchers are increasingly focusing on coir fiber reinforced natural rubber composite mats as a substitute for synthetic insulating materials.

1.1 Problem Statement

The advantages of coir fiber composites are widely established; however, limited information is available on their thermal properties when used in conjunction with natural rubber latex, particularly with advanced fabrication methods like VARTM. Although natural fiber composites are becoming increasingly popular, most available information focuses on mechanical strength or thermal behavior in isolation, rather than in a comprehensive thermal-mechanical-simulation relationship.

1.2 Significance of the Study

By blending coir fiber and latex into a novel roof insulation material, this research makes a significant contribution to the development of sustainable building materials. In line with this, the project contributes to ongoing efforts to improve fiber treatments and manufacturing processes, such as VARTM (Sudarshana et al., 2025), and aims to prolong the lifespan and improve the reliability of natural fiber composites (Chamath et al., 2025). Ultimately, this research will serve as a stepping stone for eco-friendly construction materials and contribute to the global sustainability agenda.

2 METHODOLOGY

A scaled-down test hut measuring 1 m × 1 m × 1 m was designed to analyze the temperature distribution of traditional insulating materials and newly introduced coir-fiber reinforced natural rubber composite mats, using SolidWorks flow simulations. The wall thickness of each side of the test hut was assumed to be 0.05 m. This scaled-down test hut was isolated (assuming doors and windows assumed to be closed) to ensure that no mass transfer between the atmospheric air and the air volume inside the test hut. SolidWorks software was utilized to create a three dimensional model of test hut as displayed in Figure 1(a). Coarse, medium, and fine meshes were prepared as shown in Figure 1(b, c, d), using the global mesh tool available in SolidWorks flow simulation package, to identify any improvements in the accuracy of the temperature distribution results .

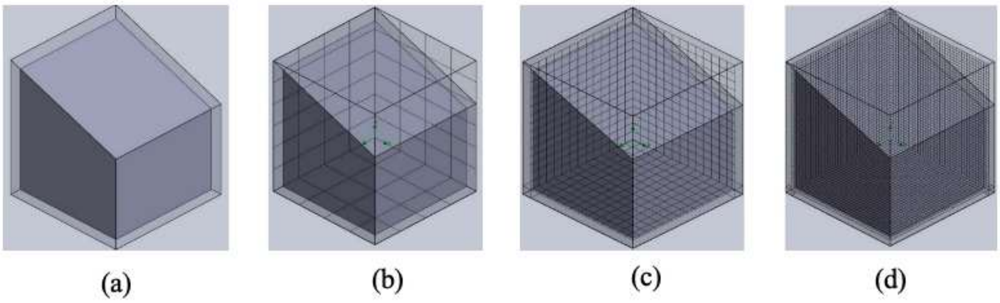

Figure 1. Isometric views: (a) three dimensional model of the test hut, (b) Coarse, (c) Medium, and (d) Fine meshes

Temperature distributions primarily depend on the mesh when the mesh size is fairly coarse, but this dependency diminishes as the mesh size becomes finer. A mesh comparison must be conducted to optimize computation time while improving the validity of the temperature distribution values. A numerical analysis was performed under solar radiation conditions in the Homagama area (6.84° N 80.00° E) located in Colombo, Sri Lanka. Table 1 provides details of the characteristics of the materials used in the numerical analysis.

Table 1. Characteristics of materials applied for SolidWorks simulation

Material	**Density (kg/m^3)**	**Specific heat capacity J/(kg·K)**	**Thermal conductivity (W/(m·K))**
Wood	500	1700	0.15
Expanded Polystyrene (EPS)	24	1340	0.04
Fiber Glass	16	1000	0.04
Polyurethane Foam (PUF)	32	820	0.03
Coir Fiber Reinforced Natural Rubber Composite Mats	1150	2290	0.07
Air	1.185	1004.4	0.03

The present study considered insulating materials of varying thicknesses: 0.05, 0.1, 0.15, and 0.2 m. A boundary was established between the asbestos roof and the inside air of the test hut with each material, expanded polystyrene (EPS), fiber glass (FG), polyurethane foam (PUF), and coir fiber reinforced natural rubber composite mats used as the insulation (Aravind et al., 2015).

3 RESULTS AND DISCUSSION

This research conducted a numerical analysis to examine the internal temperature distribution of a test hut when different insulation materials are used. The results in Figure 2 clearly show a considerable reduction in temperature inside the room when thermal insulation materials are used. A comparison of the outcomes indicates that the required thermal comfort in the scaled-down test hut, can be maintained while reducing total energy consumption simultaneously by using roofing insulation materials correctly. As shown in Table 2, it is evident that approximately 16K temperature reduction can be achieved using these insulation materials.

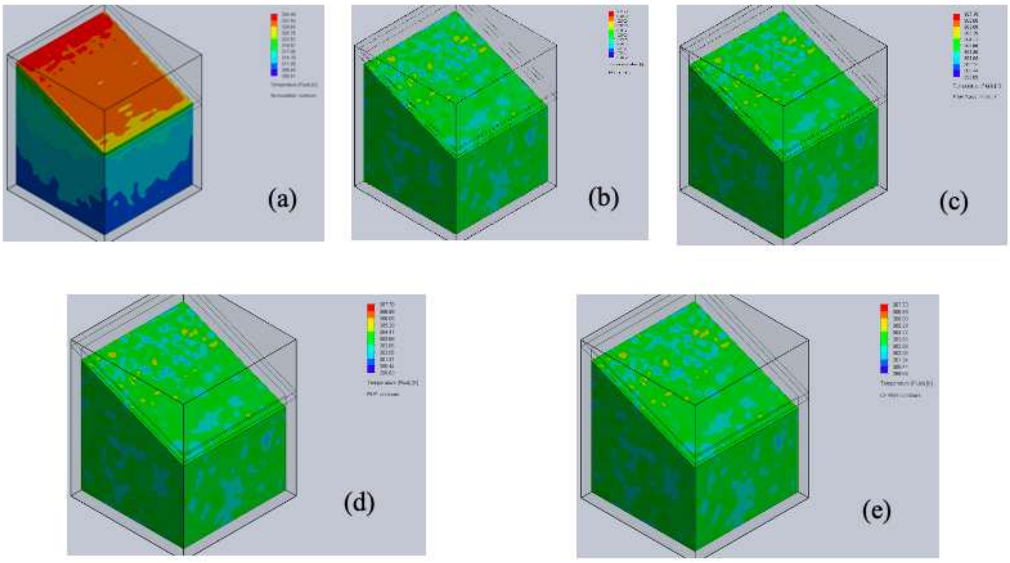

Figure 2. Distribution of temperature inside the scaled-down test hut with (a) No insulation, (b) EPS insulation, (c) FG insulation (d) PUF insulation (e) Coir fiber reinforced natural rubber composite mats insulation

Table 2. Results obtained from SolidWorks flow simulation

Method of Insulation	Minimum and Maximum Temperatures (K)	Average Temperature (K)
No insulation	305-334	320
EPS insulation	300-308	304
FG insulation	300-308	304
PUF insulation	300-308	304
Coir fiber reinforced natural rubber composite mats insulation	300-308	304

4 CONCLUSION

The study demonstrated that the SolidWorks flow simulation CFD tool can reasonably predict temperature distribution in an insulated, scaled-down test hut under isolated conditions. Traditional insulating materials including mineral wool, expanded polystyrene (EPS), and polyurethane foams are commonly utilized due to their excellent thermal properties. These materials, however, are costly to produce and dispose of, petroleum based, and non-biodegradable. They are less appropriate for use in green building applications due to their lifetime emissions, which also contribute to environmental problems. As a result, engineers and researchers are increasingly focusing on coir fiber reinforced natural rubber composites as a substitute for synthetic insulating materials. In order to improve building designs with more accurate validation of experimental data, further studies are necessary to investigate factors such as ventilated air charge per hour (ACPH), leakages through vents, heating ventilations and air conditioners, as well as the availability of ceilings.

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