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Mitigating Heat Buildup in Water Tanks During Summer

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Abstract
Effective thermal insulation of overhead water tanks is essential to maintaining water temperature and improving energy efficiency, particularly in regions with extreme weather conditions. This research presents a novel multi-layered insulation system utilizing **bamboo Fiber**, **polyurethane foam**, and **virgin plastic** as insulation materials. The aim is to reduce heat transfer, minimize water temperature fluctuations, and ensure water quality in domestic and industrial applications. Two tank models were fabricated: one without insulation and the other with the proposed multi-layer insulation. The tanks were tested under varying external temperatures, and comprehensive data collection was carried out using real-time monitoring systems. The insulated tank demonstrated significantly reduced heat absorption, keeping the water temperature close to the desired range of 24°C-27°C even in harsh environmental conditions.
The analysis revealed that the insulated tank maintained thermal stability up to 30% more effectively than the non-insulated tank. The insulation materials were chosen for their eco-friendly properties, durability, and low thermal conductivity, which contributed to enhanced thermal resistance. Additionally, the study explored the cost-effectiveness of the insulation setup, confirming that the multi-layered system offers long-term savings on energy and maintenance. This project highlights the importance of using sustainable and locally available materials like bamboo Fiber in improving water storage solutions. The findings also indicate a significant potential for reducing energy consumption in water heating systems, making this approach viable for widespread implementation in both residential and industrial contexts.

Keywords: Thermal insulation, overhead water tanks, bamboo fiber, polyurethane foam, heat transfer reduction, multi-layer insulation, thermal stability, energy efficiency, eco-friendly materials, water temperature control.

Introduction

Overhead water tanks are widely used in domestic and industrial applications, but maintaining stable water temperature remains a challenge in extreme climates. In hot regions, solar radiation raises water temperature, making it unsuitable for domestic use and increasing reliance on energy-intensive cooling systems. Conversely, in colder regions, low temperatures reduce usability and comfort 8.
To address this, researchers are exploring efficient and sustainable insulation materials. Conventional methods are often costly and environmentally unsustainable. Natural fibers such as bamboo and banana fibers have gained attention due to their low thermal conductivity and eco-friendly properties 24.
This study investigates a multi-layer insulation system using bamboo fiber, polyurethane foam, and virgin plastic to reduce heat transfer and stabilize water temperature in overhead tanks, offering an energy-effic-

ient and sustainable solution.

Water tank insulation is crucial for energy conservation and sustainable building practices. Proper insulation maintains water temperature within an optimal range, reducing dependence on mechanical heating and cooling systems, lowering energy consumption, and enhancing tank durability by minimizing thermal stress6.

Natural fibers like bamboo provide an eco-friendly alternative to synthetic insulations, effectively reducing heat transfer and improving temperature stability under varying environmental conditions 47.

Selecting insulation materials requires balancing thermal performance, durability, and cost. Conventional materials such as fiberglass and polyurethane foam are effective but expensive and less sustainable. Natural fibers offer eco-friendly benefits but slightly higher thermal conductivity. This study proposes a multi-layer insulation system combining bamboo fiber, polyurethane foam, and virgin plastic to enhance thermal resistance while keeping costs manageable3.

Objectives

The primary objective of this study is to design, fabricate, and evaluate a multi-layer insulation system for overhead water tanks using bamboo fiber, polyurethane foam, and virgin plastic. The specific objectives are:

- Develop a cost-effective and eco-friendly insulation system.
- Compare the thermal performance of insulated and non-insulated tanks under real-time weather conditions.
- Analyze the influence of insulation thickness and material combinations on temperature stabilization and energy efficiency.
- Evaluate the durability and sustainability of bamboo fiber as an insulation material.

LITERATURE REVIEW

Maintaining thermal stability in overhead water tanks has been widely investigated due to increasing energy demands and extreme climatic variations. Studies report that conventional plastic and metal tanks experience significant heat gain from solar radiation, leading to elevated water temperatures and increased dependence on mechanical cooling systems8. Effective insulation is therefore essential to minimize thermal fluctuations and improve energy efficiency.

Recent research emphasizes the use of sustainable and eco-friendly insulation materials. Natural fibers such as bamboo and banana fibers have gained attention due to their renewability, biodegradability, and relatively low thermal conductivity 24. Bamboo fiber, in particular, demonstrates favorable thermal resistance, lightweight characteristics, and structural durability. In contrast, polyurethane foam exhibits one of the lowest thermal conductivity values among commercial insulation materials, making it highly effective in reducing heat transfer 36.

Multi-layer insulation systems have shown superior performance compared to single-layer configurations. Combining materials with different thermal properties enhances overall thermal resistance and structural durability. Studies indicate that integrating natural fibers with synthetic insulating layers, along with protective outer materials such as virgin plastic or reflective barriers, significantly reduces solar heat gain and stabilizes internal water temperature 58.

Although previous research has examined individual insulation materials, limited studies have focused on optimizing a cost-effective multi-layer system specifically for overhead water tanks under real-time

environmental conditions. Furthermore, the combined thermal performance and sustainability assessment of bamboo fiber integrated with polyurethane foam remains insufficiently explored.

METHODOLOGY

Materials Used

Three main materials were used:

Material	Thermal Conductivity (W/m·K)	Specific Heat (J/kg·K)	Density (kg/m³)
Virgin Plastic	0.33	1900	950
Bamboo Fiber	0.048	1250	600
Polyurethane Foam	0.021	1500	30

Experimental Setup

Two identical 15-liter tanks were fabricated:

- Model 1: Non-insulated (Control)
- Model 2: Multi-layer insulated

Both tanks had identical dimensions (30.56 cm × 25 cm).

(Water Tank Before Insulation)

Insulation Layer Design

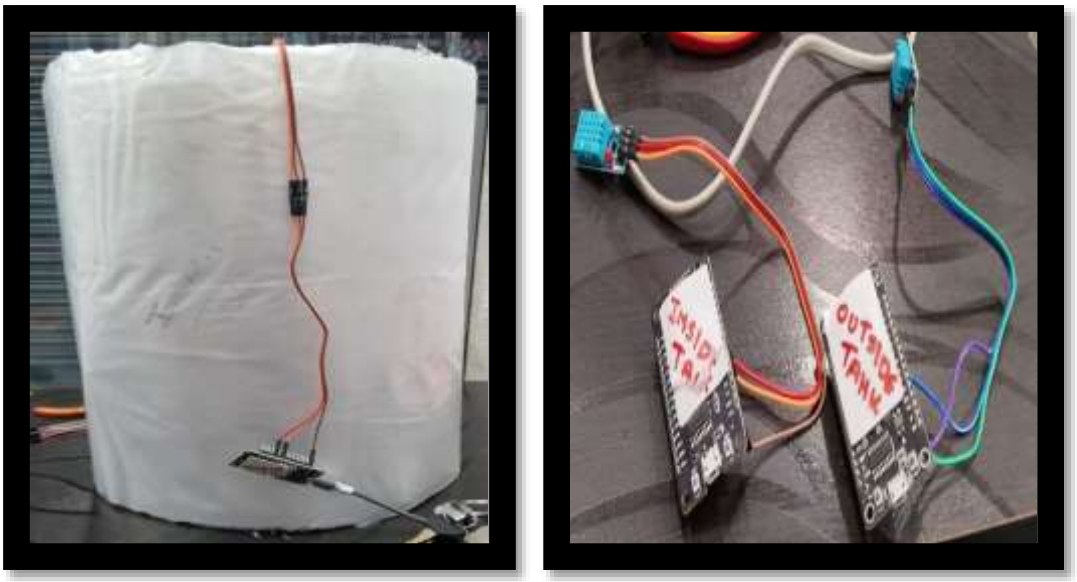
The insulated tank consisted of:

- Inner Virgin Plastic Layer – 3 mm
- Bamboo Fiber Layer – 12 mm
- Polyurethane Foam Layer – 25 mm
- Outer Virgin Plastic Layer – 7 mm

(Fully Assembled Insulated Water Tank)

IoT Monitoring System

Temperature sensors (DHT11) were installed inside and outside both tanks. Data was transmitted using ESP8266 Wi-Fi module to Adafruit IO cloud platform.



(Experimental Setup)

Data Collection

Temperature was recorded hourly over 24 hours under summer conditions.

Observations:

- Non-insulated tank peak: 42°C
- Insulated tank peak: 27.6°C
- Temperature difference: up to 14.4°C

Heat Transfer Analysis

Heat transfer rate was calculated using:

For single layer:

$$Q = \frac{kA\Delta T}{d}$$

For multilayer insulation:

$$Q = \frac{\Delta T}{\Sigma R_{th}}$$

Where:

- Q = Heat transfer rate (W)
- k = Thermal conductivity
- A = Surface area
- ΔT = Temperature difference
- d = Thickness
- Rth = Thermal resistance

Thermal Resistance

Material	Thermal Resistance (Rth, °C/W)
Virgin Plastic Tank (3mm)	0.044
Bamboo Fiber (12mm)	0.888
Polyurethane Foam (25mm)	2.475
Virgin Plastic (7mm)	0.104

Thermal Resistance of Materials

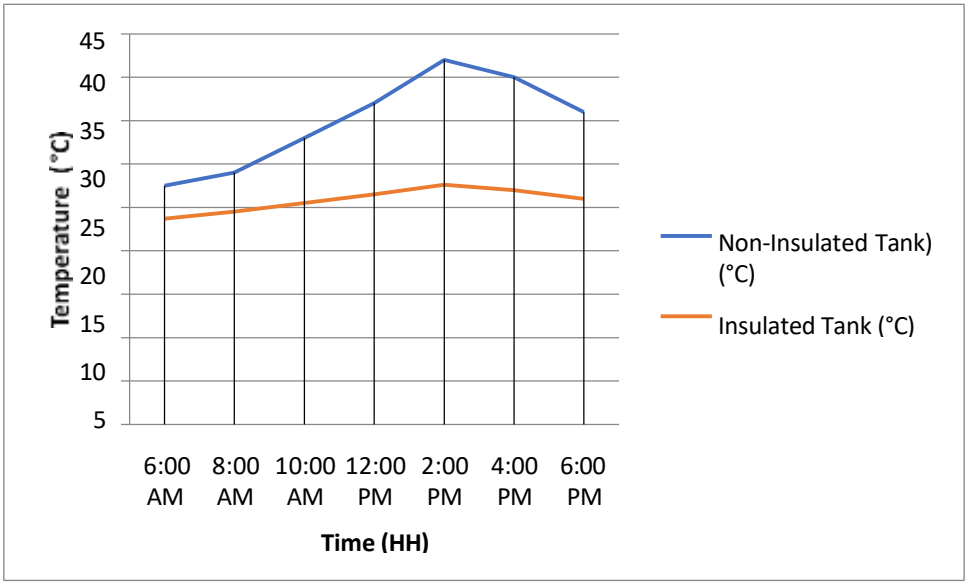
Heat Transfer Results

Model	Heat Transfer (W)	Thermal Resistance (°C/W)
Non-Insulated	16 W	0.044
Insulated	2.34 W	3.511

Temperature Comparison

Temperature Difference (Insulated vs. Non-Insulated Tank) Time (HH)	**Non-Insulated**	**Insulated**	**Temperature Difference**
06:00 AM	27.5	23.7	3.8
08:00 AM	29	24.5	4.5
10:00 AM	33	25.5	7.5
12:00 PM	37	26.5	10.5
02:00 PM	42	27.6	14.4
04:00 PM	40	27	13.0

06:00 PM	36	26	10.0



The insulated tank maintained 10–15°C lower temperature during peak hours.

RESULTS

The multi-layer insulation system significantly reduced heat transfer. Bamboo fiber provided natural insulation while polyurethane foam enhanced resistance due to low thermal conductivity.

The combined insulation improved thermal resistance from 0.044 °C/W to 3.511 °C/W, resulting in:

- 85% reduction in heat transfer
- Stable water temperature
- Improved thermal efficiency

CONCLUSION

The study confirms that a multi-layer insulation system using bamboo fiber and polyurethane foam effectively reduces heat absorption in overhead water tanks. The insulated model showed a maximum temperature reduction of 14.4°C during peak hours and reduced heat transfer rate by approximately 85%. This eco-friendly and cost-effective solution can be implemented in residential water storage systems in tropical regions.

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