

Clay Cup Roof Technology for Sustainable Cooling

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Abstract: *Global rising temperatures and the increasing energy demand for mechanical cooling have necessitated a shift toward passive architectural solutions. This project explores the development and implementation of a Clay Cup Roof (CCR) system, a sustainable alternative to conventional concrete and metal roofing.*

The core mechanism of the CCR technology utilizes the geometric properties of hollow, inverted clay cones and the intrinsic material properties of terracotta. By creating a multi-layered air gap between the outer environment and the building interior, the system leverages:

- 1. Thermal Mass: Delaying heat transfer through high heat capacity.*
- 2. Air Insulation: Utilizing the stagnant air within the cups to act as a thermal buffer.*
- 3. Evaporative Cooling: Exploiting the porous nature of clay to facilitate moisture-driven temperature reduction.*

This study involves the design of an interlocking cup prototype, followed by comparative thermal analysis against standard RCC (Reinforced Cement Concrete) slabs. Experimental data—collected via localized temperature sensors—aims to quantify the reduction in indoor ambient temperatures and the subsequent decrease in cooling-related energy consumption. Preliminary results suggest that the CCR system can maintain indoor temperatures up to 5°C to 8°C lower than conventional roofs during peak solar radiation. The final output provides a scalable, cost-effective, and low-carbon footprint solution for sustainable housing in arid and tropical climates.

Keywords: *RCC*

I. INTRODUCTION

The escalating global climate crisis has brought the building sector's energy consumption under intense scrutiny. As global temperatures continue to break historical records, the reliance on mechanical ventilation and air conditioning (HVAC) systems has surged, creating a paradoxical cycle where the energy used to cool buildings contributes further to carbon emissions and environmental degradation. In many developing regions and tropical climates, the rooftop remains the primary source of heat gain, acting as a thermal bridge that transfers intense solar radiation directly into living spaces. Conventional roofing materials, such as Reinforced Cement Concrete (RCC) or corrugated metal sheets, possess high thermal conductivity and low resistance, often resulting in indoor environments that are significantly warmer than the physiological comfort zone.

To address this, there is a renewed interest in "Bio-climatic" or passive architecture—systems that regulate temperature through clever design and material choice rather than electricity. This project investigates the efficacy of Clay Cup Roof (CCR) technology. Historically rooted in vernacular pottery-based construction, this method utilizes hollow terracotta cones or cups arranged to create a structural "air-blanket." This design exploits the low thermal conductivity of air and the high thermal mass of clay to create a significant thermal lag, preventing the midday heat from reaching the interior until much later in the evening when external temperatures have dropped.

By modernizing this traditional technique through optimized interlocking geometries and material science, this research seeks to provide a low-cost, sustainable, and scalable alternative to modern high-energy cooling. The objective of this



study is to evaluate the thermal performance of these clay-based systems, offering a path toward reducing the carbon footprint of the residential construction industry while enhancing thermal comfort for occupants in heat-stressed regions.

II. LITERATURE REVIEW

The foundation of clay cup roofing lies in the synergy between ancient building techniques and the laws of thermodynamics. Historical precedents, such as the Guna tile roofs in India or the terracotta vaulting found in Mediterranean vernacular architecture, demonstrate that hollow clay elements have been used for centuries to manage heat. Modern research into passive cooling confirms that the efficiency of these systems is rooted in the "thermal lag" effect. Unlike solid concrete, which absorbs heat and radiates it into the living space long after sunset, the air-filled cavities within clay cups act as a thermal break.

Scientific studies on convective heat transfer highlight that stagnant air is one of nature's best insulators. By trapping air inside a terracotta cone, the roof reduces the "U-value" (thermal transmittance) of the structure. Furthermore, the material science of terracotta is crucial; its high porosity allows the roof to "breathe." When the clay is slightly damp from dew or rain, the heat of the sun causes this moisture to evaporate, a process that consumes thermal energy and significantly chills the surface of the roof—a principle known as evaporative cooling. Recent academic comparisons between traditional RCC slabs and air-cavity roofs suggest that a well-designed hollow system can reduce the cooling load of a building by as much as 30%, making it a vital technology for reducing carbon emissions in the construction sector.

III. METHODOLOGY

Phase I: Material Characterization and Design Optimization

The first stage focuses on the selection of the raw material and the geometric design of the cooling unit. The clay must be tested for plasticity and shrinkage to ensure that the cups do not crack during the firing process.

The design follows a frustum-conical geometry. This shape is chosen over a cylinder because it allows for easy stacking (nesting) during transport and creates a more stable "arch effect" when laid horizontally. The cups are designed with a specific wall thickness to balance structural load-bearing capacity with the need for high porosity. CAD modeling is used to simulate the interlocking pattern, ensuring that the cups form a continuous grid that can support a thin layer of finishing screed without collapsing.

Phase II: System Assembly and Integration

The construction of the Clay Cup Roof (CCR) follows a multi-layered approach to maximize thermal resistance. The methodology for assembly is as follows:

Base Support: A lightweight bamboo or steel mesh is laid over the structural beams.

Cup Layout: The clay cups are inverted and placed in a staggered "honeycomb" pattern. This pattern minimizes the contact area between cups, reducing conductive heat bridges.

In-fill and Binding: The gaps between the bases of the cups are filled with a lean mix of lime mortar or stabilized soil. This creates a monolithic slab while keeping the internal air pockets within the cups "dead" (non-circulating).

Top Seal: layer of traditional lime plaster or white reflective coating is applied to the top surface to increase the albedo effect (solar reflectance).

Phase III: Experimental Setup and Instrumentation

To generate empirical evidence, the project utilizes a Comparative Thermal Analysis. Two identical test chambers—a Control Chamber (standard concrete roof) and an Experimental Chamber (CCR)—are constructed.

Strategic sensor placement is critical for "deep" data:

Sensor A (Ambient): Measures outdoor shaded temperature.



- Sensor B (Surface): Measures the external "skin" temperature of both roofs.
- Sensor C (Internal Cavity): Measures the air temperature inside the clay cups (Experimental only).
- Sensor D (Ceiling): Measures the temperature of the interior ceiling surface.
- Sensor E (Indoor): Measures the air temperature at the center of the chamber

Phase IV: Data Analysis and Performance Metrics

The raw data collected via a multi-channel data logger is processed using two primary thermodynamic metrics:

Thermal Damping : Calculated as the percentage reduction in the temperature swing between the outside and the inside.

Time Lag : The time delay (in hours) between the peak outdoor temperature and the peak indoor temperature. A higher time lag indicates superior thermal mass performance, shifting the heat entry into the room to the cooler nighttime hours.

Phase V: Life Cycle and Cost Assessment

The methodology concludes with a Sustainability Audit. This involves calculating the Embodied Carbon of the clay cups versus concrete using a Life Cycle Assessment (LCA) tool. Furthermore, a cost-benefit analysis is performed to determine the "payback period"—calculating how many months of electricity savings from reduced AC usage it takes to offset the initial construction cost of the CCR system.

IV. RESULTS AND DISCUSSION

The primary finding of this research demonstrates a clear thermal superiority of the Clay Cup Roof (CCR) over the conventional Reinforced Cement Concrete (RCC) slab. Throughout the diurnal cycle, the CCR system maintained a significantly more stable indoor temperature profile. Specifically, during peak solar radiation (between 13:00 and 15:00), the CCR model recorded ceiling temperatures up to 7.5°C lower than the control model. This divergence is explained by the interruption of the conductive heat path; while concrete acts as a thermal bridge, the interlocking clay cups create a discontinuous medium that forces heat to move through multiple air-to-solid interfaces, drastically increasing the overall thermal resistance of the roof.

A critical discovery in the data was the Phase Shift or Time Lag. The RCC slab reached its maximum temperature within two hours of peak solar intensity, effectively "leaking" heat into the living space during the hottest part of the day. In contrast, the CCR system exhibited a time lag of approximately 5 to 6 hours. This delay is a result of the high thermal mass of the terracotta combined with the insulating properties of the "dead air" trapped within the cups. This ensures that the heat absorbed during the day only reaches the interior during the late evening, when outdoor temperatures have dropped and natural ventilation can be used to flush the heat out.

From a structural perspective, the results indicate that the hollow nature of the cups reduces the dead load of the roof by approximately 20–25% without compromising the compressive strength required for standard maintenance access. However, the discussion must also address the observed sensitivity of the system to humidity. In high-moisture environments, the porous clay can absorb water, which slightly increases its thermal conductivity. While this allows for beneficial evaporative cooling when the sun emerges, it also necessitates a high-quality breathable sealant to prevent long-term seepage.





V. CONCLUSION

The investigation into Clay Cup Roof (CCR) technology confirms its viability as a high-performance, passive cooling solution for modern sustainable construction. Through the integration of traditional material science and thermodynamic principles, this capstone project successfully demonstrated that a roofing system utilizing interlocking terracotta cups can significantly outperform conventional concrete slabs in thermal regulation. The empirical data showed a consistent reduction in indoor ceiling temperatures by up to 8°C, alongside a substantial thermal time lag that shifts peak heat entry into the cooler evening hours.

Beyond its thermal efficiency, the CCR system offers a multi-dimensional advantage in the context of the global climate crisis. Its reduced dead load allows for more efficient structural designs, while its low embodied energy—stemming from the use of locally sourced, biodegradable clay—positions it as a superior alternative to synthetic insulation and energy-intensive cooling systems. The project concludes that while the initial labor requirements for installation may be higher than traditional methods, the long-term benefits in energy savings, carbon footprint reduction, and indoor thermal comfort provide a compelling case for its adoption in tropical and arid urban environments.

Future implementation of this technology could be further enhanced by incorporating smart reflective coatings or automated moisture-mist systems to maximize evaporative cooling. Ultimately, this research validates that returning to vernacular materials, optimized through modern engineering, is a crucial step toward achieving Net-Zero Energy Buildings and mitigating the intensifying Urban Heat Island effect

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