Sustainable Cooling with Clay Tubes in Honeycomb Structures

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Abstract: - This study explores the effectiveness of dimpled and protruding clay tubes within a honeycomb structure as a sustainable cooling solution, validated through experimental data. By continuously dripping water over clay tubes and passing ambient air through the structure at varying velocities (1 m/s to 3.5 m/s), a significant temperature drop of 9-11°C was achieved. The results provide detailed insights into airflow and heat transfer mechanisms. This sustainable cooling method shows promise for applications in large spaces like malls and auditoriums, offering an eco-friendly alternative to traditional systems. Future research will focus on optimizing design for enhanced efficiency.

Keywords*: Sustainable cooling, clay tubes, Honeycomb Structure.*

1. Introduction

In the pursuit of sustainable building practices, the demand for energy-efficient cooling solutions is increasingly critical, especially in regions with high ambient temperatures. Traditional mechanical cooling systems, while effective, often consume significant amounts of electricity, leading to environmental degradation and escalating energy costs. This has driven researchers and engineers to explore passive cooling technologies as viable alternatives that can reduce energy consumption while maintaining indoor thermal comfort. Among these technologies, earthen tubes, also known as earth tube systems, have gained attention for their ability to harness geothermal energy for efficient cooling and heating [1][2].

Earthen tubes function as passive cooling systems by exploiting the stable underground temperatures to condition incoming air within buildings. The system facilitates heat exchange between the ambient air and the earth, thereby providing cooling during hot seasons and heating in colder months [1][2]. The performance of earth tube heat exchangers (ETHE) is influenced by factors such as installation depth, pipe diameter, and material thermal conductivity, all of which are crucial in enhancing heat transfer efficiency [3]. Numerous studies have demonstrated the effectiveness of ETHE systems in reducing energy consumption in buildings, particularly in hot climates, where they can be complemented with green walls to further enhance cooling performance [4]

A related variation, the earth air pipe heat exchanger, expands the application of passive cooling by utilizing geothermal energy for indoor climate control. These systems offer environmentally friendly and cost-effective alternatives to conventional mechanical cooling [6][7]. Optimizing the shape and pattern of the inlet, including features like aerofoil-shaped tabulators, can significantly enhance system efficiency by improving air circulation within the cooling space [9]. Additionally, earth air tunnel heat exchangers have demonstrated dual functionality, using the ground as a heat sink in summer and a heat source in winter, ensuring year-round indoor thermal comfort [10].

Despite the advancements in passive cooling technologies using earthen tubes, there are still gaps in the literature, particularly concerning the integration of innovative materials and structures to further enhance cooling efficiency. This research aims to address these gaps by investigating the effectiveness of dimpled and protruding clay tubes installed within a honeycomb structure as a sustainable cooling solution.

The proposed system operates by continuously dripping water onto the clay tubes within the honeycomb structure while ambient air passes through. By varying air velocities and Reynolds numbers, the cooling effects were analyzed, showing significant temperature drops at the tube inlets and exteriors. This cooling method, particularly effective during summer, offers substantial temperature reductions without the excessive electricity consumption typical of conventional systems. The success of this system suggests its potential applications in various settings, such as malls, community halls, and auditoriums.

In conclusion, this study underscores the promising role of dimpled and protruding clay tubes within honeycomb structures as a sustainable cooling solution in diverse environments. Future research could focus on optimizing the design for enhanced efficiency and exploring broader implementation scalability, further advancing the field of passive cooling technologies.

2. Literature Review

The growing demand for sustainable and energy-efficient cooling solutions is particularly pressing in regions with high temperatures. In India, the building sector's electricity consumption is projected to rise significantly, driven by the increasing use of air conditioning systems that rely on energy-intensive and greenhouse gas-emitting technologies (Bhamare, 2019). This has prompted the exploration of passive cooling techniques as viable alternatives.

Passive cooling methods, such as evaporative cooling using local materials like terracotta, have shown promise in maintaining indoor comfort while reducing energy consumption. Monish Siripurapu’s beehive-inspired design with terracotta cones exemplifies this approach, combining traditional materials with modern computational analysis for optimized cooling (Ant Studio, 2019).

Surface modifications, including dimples and protrusions, have been demonstrated to enhance heat transfer in heat exchangers. Research shows that these modifications, which increase turbulence and reduce flow resistance, can significantly improve cooling efficiency (Rao, Li, and Weingand, 2021). Computational Fluid Dynamics (CFD) analysis has been instrumental in validating these enhancements, showing that features like teardrop dimples yield higher heat transfer rates than smooth surfaces (Ye Min Oo, 2021).

The Indian Government’s Cooling Action Plan further underscores the importance of developing non-vapor compression HVAC technologies to meet cooling demands while reducing energy use and environmental impact (Indian Cooling Action Plan, 2019). This literature review highlights the potential of passive cooling techniques, supported by advanced surface modifications, to provide sustainable alternatives to traditional air conditioning systems.

3. Experimental work

A. Objective

Objective of this experiment is to investigate how patterned irregularities, such as dimples or protrusions, on the inner surface of terracotta tubes affect the heat transfer rate. These tubes are intended for use in an evaporative cooler.

B. Materials

To achieve the objective, experimental testing was conducted on two types of terracotta tubes at five different velocities:

1. Dimpled Tube: A conical clay tube that has been baked and is open at both ends. The inner surface features dimples, while the outer surface remains smooth.
2. Protrusion Tube: A baked conical clay tube, also open at both ends, with uniform clay protrusions on the inner surface and a smooth outer surface.

Fig. 1. Test Tubes (a) Protrusion Tube, (b) Dimpled Tube

All tubes are identical in shape, size, and dimensions, except for the structure of their inner walls.

Tube Specifications:

The inner diameter at the larger end of the tube (D1) is 100 mm,

while at the smaller end (D2), it is 50 mm.

The tube length (L) measures 400 mm.

The diameter of the dimples (d) is 10 mm.

The spacing between successive dimples (l) is 8 mm.

The tube material is Potter’s Clay.

Figure 1 illustrates the cross-sectional views of the various tube types employed in the experiment. A specialized test rig has been developed to facilitate the experimentation under carefully controlled conditions. Figure 2 provides a schematic representation of the experimental test rig, with all its components listed sequentially.

C. Experimentation

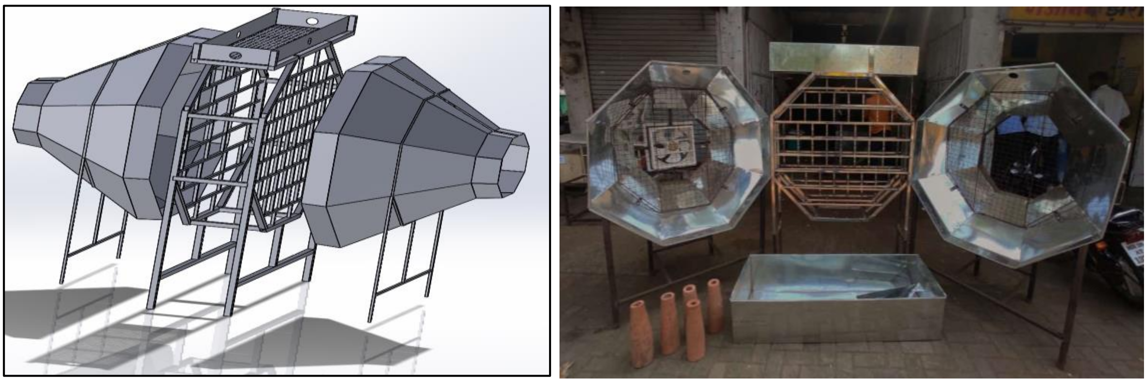

Fig. 2. Experimental model

In this study, two different types of tubes were evaluated for their heat transfer rates at six distinct airflow velocities. Each tube was individually placed in a test section within a honeycomb structure. The airflow was initiated by turning on the suction fan, which directed air through the tube from the larger end to the smaller end. The velocity of the airflow was precisely controlled using a speed regulator.

Fig. 3. Experimental set-up

Once the airflow was stabilized at a set velocity, water pumps were activated to draw water from a reservoir and deliver it to the top tray. Water was then sprayed onto the clay test tube through perforations in the tray, ensuring the tube's surface remained consistently wetted at a temperature of 25°C. Excess water was collected back into the reservoir through openings in the base tray.

In this experiment, a total of 16 thermocouples were used: 8 placed at the air inlet and 8 at the outlet where cooling effects were observed. Temperature sensors and data loggers recorded air temperatures at these points at regular intervals. Each tube was tested at three different velocities by adjusting the airspeed with the regulator. An anemometer was used to measure the air velocity at both the inlet and outlet. This procedure was consistently applied across all the test specimens.

4. Results

A. Results from Experimental work

1)Temperature Drop Analysis:

From the experimental data, the temperature drop in both protrusion and dimple tubes was measured across various air velocities. The dimple tube showed a slightly higher temperature drop compared to the protrusion tube at most velocities. The temperature drops for the dimple tube ranged from 7.68°C to 11.1°C, while for the protrusion tube, it ranged from 7.73°C to 10.7°C. This indicates that the dimple tube is marginally more efficient in cooling the air.

TABLE I. PROTRUSION TUBE WITH EACH VELOCITY'S AND THEIR TEMPERATURE DIFFERENCE

S.N.	*Velocity (m/s)*	*Inlet Temp.(^0C)*	*Outlet Temp. (^0C)*	*Temp. difference*
1	1.5	39.83	32.07	7.73
2	2.0	38.11	29.7	8.42
3	2.5	38.61	30.66	7.9
4	3.0	39.06	29.63	9.4
5	3.5	39.6	29	10.7

TABLE II. DIMPLE TUBE WITH EACH VELOCITY'S AND THEIR TEMPERATURE DIFFERENCE

S.N.	***Velocity (m/s)***	***Inlet Temp.(^0C)***	***Outlet Temp. (^0C)***	***Temp. difference***
1	1.5	39.91	30.65	09.26
2	2.0	39.15	28.08	11.10
3	2.5	39.72	29.87	09.86
4	3.0	34.37	29.06	05.31
5	3.5	36.28	28.60	07.68

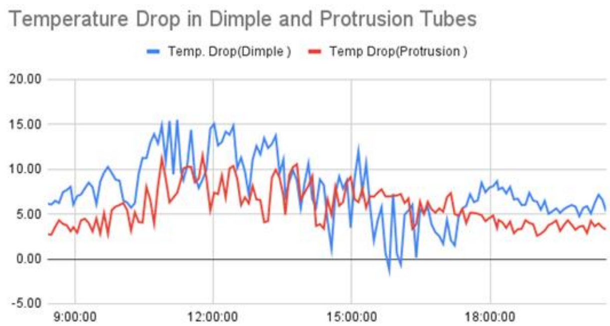

Fig. 4. Temperature Drop in Dimple and Protrusion tubes

2) Heat Transfer Coefficient:

The heat transfer coefficient was calculated using the Dittus-Boelter equation for both tubes. The dimple tubes generally exhibited higher heat transfer coefficients than the protrusion tubes, enhancing their cooling capability. For instance, at a velocity of 3 m/s, the heat transfer coefficient for the dimple tube was 8.52 W/m²K, while for the protrusion tube, it was 14.83 W/m²K.

TABLE III. HEAT TRANSFER COEFFICIENT AND REYNOLDS NUMBER

Ambient Temp ºC	***Velocity***	***Reynolds Number***	***Heat Transfer Coefficient***	***ΔT***	***Q (W)***
39.83	1.5 m/s	6293.10	08.52	07.76	05.09
38.11	2.0 m/s	8390.80	10.72	08.42	06.95
38.61	2.5 m/s	10488.50	12.82	07.90	07.80
39.06	3.0 m/s	12580.20	14.83	09.40	10.74
39.60	3.5 m/s	14683.90	16.78	10.70	13.84

3) Reynolds and Nusselt Numbers:

The calculations showed that as the Reynolds number increased, both the Nusselt number and the heat transfer coefficient increased. This indicates that higher velocities improve the cooling efficiency of both tube types. The dimple tubes demonstrated better performance at lower Reynolds numbers, making them suitable for applications with lower airflow rates.

5. Discussion

The dimple and protrusion earthen tube coolers demonstrated significant potential in enhancing heat transfer efficiency. The dimple tubes outperformed the protrusion tubes slightly in terms of temperature drop and heat transfer coefficient, primarily due to the increased turbulence and surface area provided by the dimples. However, the protrusion tubes also showed robust performance and could be preferable in scenarios where pressure drop needs to be minimized.

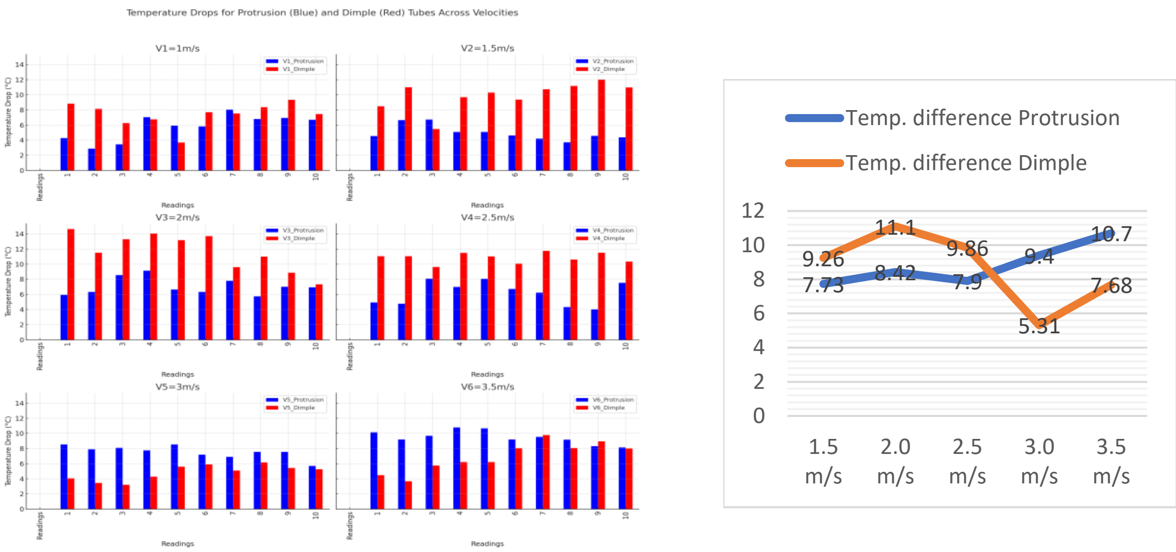

Fig. 5. Temperature Drop in Dimple and Protrusion tubes with different velocities

6. Conclusion

The study finds that protrusion tubes work better than dimpled tubes in evaporative coolers. Protrusion tubes improve heat transfer by about 37.78% and reduce temperature by about 18.3% more than dimpled tubes. Both types of tubes enhance flow characteristics, like Reynolds number and Nusselt number, without causing significant pressure drops. The increase in Reynolds number is due to the irregular inner surfaces and conical shape of the tubes.

Although higher air speeds improve heat transfer, they also cause more friction among air molecules and reduce contact with the tube's wet surface, leading to a smaller temperature drop. So, to achieve the best temperature drop, it's better to use lower air speeds. For the best cooling in systems like Deki evaporative coolers, protrusion tubes are recommended over dimpled tubes at lower air speeds. The simulation results align with the experimental data, confirming the findings.

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