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Sustainable Solar Air Cooler: An Eco-Friendly Alternative To Conventional Systems.

First Author :- Syed Burhan Uddin , Students, Lords institute of engineering and technology, Civil Engineering

Second Author:- Dr. G vikas, Associate professor,

Third and fourth author:- Mohammad Faraz Uddin, Mohammad Saif Ali, Students, Lords institute of engineering and technology, Civil Engineering

Abstract:

The Sustainable Solar Air Cooler presents an innovative and eco-friendly prototype designed to deliver efficient indoor cooling without depending on conventional grid electricity. The system integrates naturally available materials—specifically a porous mesh composed of red mud and clay pottery—encased within a lightweight sandwich-style frame for quick installation on standard windows. Operating on the principle of evaporative cooling, it employs a solar-powered drip irrigation mechanism that circulates water from a small reservoir, known as the “chin,” to uniformly wet the cooling surface. A compact, energy-efficient aquarium motor, powered entirely by miniature solar panels, ensures a continuous water flow, maximizing the evaporation rate and producing a measurable cooling effect of 5–10°C based on ambient humidity and solar irradiance.

Beyond technical efficiency, the system emphasizes sustainability, affordability, and local accessibility. By utilizing renewable solar energy and biodegradable, locally sourced materials, it substantially reduces carbon emissions and production costs compared to traditional air conditioners. The modular and low-maintenance design allows easy adaptation to diverse window sizes, making it particularly beneficial for rural and off-grid communities. Additionally, the use of natural resources and passive energy systems promotes a circular economy approach, encouraging community-level manufacturing and skill development. This innovation directly supports the United Nations Sustainable Development Goals—SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action)—by fostering clean energy use and reducing climate impact. The report elaborates on the conceptual framework, design methodology, material selection, fabrication process, performance analysis, and future optimization possibilities. The findings highlight the system’s potential for wide-scale implementation to enhance indoor comfort while contributing to a sustainable and climate-resilient future.

Keywords:- Sustainable cooling, Solar energy, Evaporative cooling, Renewable energy, Eco-friendly design, Off-grid technology, Red mud, Clay pottery, Passive cooling system, Energy-efficient, Modular design Low-cost innovation, Rural applications, Climate action, SDG 7 (Affordable and Clean Energy) ,SDG 13 (Climate Action), Circular economy Local manufacturing, Indoor thermal comfort,t Green technology

1.Introduction

1.1 General

Air cooling systems are essential for maintaining comfortable indoor environments, particularly in regions with high temperatures, humidity, and urban heat islands. These systems involve mechanisms to reduce ambient air temperature, often through mechanical compression, fans, or evaporative processes. Traditional methods, such as refrigerant-based air conditioners, provide effective cooling but at the cost of high energy use, environmental impact, and operational expenses. Users face challenges like power outages, rising electricity bills, and contributions to global warming from fluorocarbon emissions. Sustainable alternatives, drawing from natural principles like evaporation in deserts or pottery cooling, offer a way to achieve similar results with minimal resources. According to global statistics, buildings account for a significant portion of energy consumption worldwide, highlighting the urgent need for improved efficiency practices. With increasing climate awareness, stricter environmental regulations, and the push for green building initiatives, the demand for sustainable cooling solutions has become critical to reduce carbon footprints, optimize energy use, and promote eco-friendly living.

1.2 Need for sustainable cooling solutions

Indoor spaces are among the most energy-consuming areas due to the demand for comfortable temperatures, especially in hot climates with air conditioners running continuously. Occupants face risks such as heat stress, dehydration, and reduced productivity from inadequate cooling, while traditional systems contribute to environmental issues like ozone depletion and high carbon emissions. Conventional methods, including electric AC units, fans, and evaporative coolers with synthetic components, are often energy-dependent, addressing comfort only through constant power use. They are also prone to breakdowns and cannot provide efficient, eco-friendly operation, especially in off-grid or resource-limited settings. With increasing global temperatures, population growth, and urban expansion, relying solely on conventional cooling measures is no longer sufficient to maintain comfort or reduce environmental impact.

1.3 Problem Statement

The increasing global demand for indoor cooling has led to a significant rise in the use of conventional air conditioning systems, which consume vast amounts of electricity and rely on refrigerants that contribute to greenhouse gas emissions and ozone depletion. In many developing regions, continuous power supply remains a challenge, making grid-dependent cooling solutions impractical and unsustainable. Moreover, the high cost of operation and maintenance of traditional air conditioners further limits their accessibility, particularly in rural and low-income communities Existing cooling technologies, while effective in lowering temperature, are energy-intensive, environmentally damaging, and economically burdensome. They exacerbate climate change by increasing both carbon emissions and energy demand, creating a cycle of environmental degradation and resource depletion. With the growing impacts of global warming, urban heat islands, and extreme weather events, the need for sustainable, off-grid, and low-cost cooling alternatives has become increasingly critical. Therefore, there is an urgent need to develop a sustainable air cooling system that can operate efficiently using renewable energy sources and eco-friendly materials. Such a system should provide effective temperature reduction, require minimal maintenance, and be easily adaptable to different environmental and social contexts. Addressing this challenge will not only improve living comfort and health outcomes but also contribute to reducing carbon footprints and achieving the United Nations Sustainable Development Goals (SDG 7 – Affordable and Clean Energy, and SDG 13 – Climate Action).

1.4 Project Scope

The project scope encompasses the design, development, and evaluation of a sustainable, off-grid evaporative air cooling system utilizing porous clay structures and natural airflow principles to achieve effective indoor temperature reduction without reliance on electricity or synthetic refrigerants. Drawing from the identified challenges of high energy consumption, greenhouse gas emissions, ozone depletion, and inaccessibility in power-constrained regions, the system will integrate eco-friendly materials, passive evaporation mechanisms, and modular components for minimal maintenance and adaptability across urban, rural, and low-income settings. Key activities include material selection and testing for optimal water retention and heat absorption, prototype fabrication, performance monitoring under varied humidity and temperature conditions, and comparative analysis against conventional air conditioners in terms of cooling efficiency, energy savings, cost-effectiveness, and environmental impact. The scope also covers user-centric design for easy assembly and operation, alignment with UN SDG 7 and SDG 13, and dissemination of findings to promote scalable adoption, thereby addressing global demands for comfortable, healthy indoor environments while minimizing carbon footprints and resource depletion.

Objectives of study:-

1. **To design and develop a sustainable solar-powered air cooling system** that utilizes natural evaporative cooling principles to achieve efficient temperature reduction without relying on grid electricity.

2. **To optimize the use of eco-friendly materials such as red mud and clay pottery** for constructing a porous cooling medium that enhances evaporation, durability, and cost-effectiveness while minimizing environmental impact.

3. **To integrate a solar-powered drip irrigation and water circulation mechanism** for precise water management, ensuring uniform wetting, reduced wastage, and continuous operation in off-grid conditions.

4. **To align the system with the United Nations Sustainable Development Goals (SDG 7 – Affordable and Clean Energy, and SDG 13 – Climate Action)** by promoting renewable energy adoption, reducing carbon emissions, and supporting sustainable cooling practices for rural and low-resource communities.

2.Literature review

Air cooling systems play a pivotal role in ensuring indoor thermal comfort, particularly in hot and humid climates affected by urban heat islands and rising global temperatures. Traditional refrigerant-based air conditioners, while effective, impose substantial energy demands, contribute to greenhouse gas emissions through fluorocarbon refrigerants, and exacerbate ozone depletion, with buildings accounting for a significant share of global energy consumption (International Energy Agency, 2023). These systems also prove unreliable in regions with inconsistent power supply, high operational costs, and limited accessibility for low-income communities. In response, sustainable alternatives leveraging natural evaporative processes—such as those observed in desert ecosystems and traditional clay pottery—have gained attention for their ability to reduce air temperature through water phase change without mechanical compression or electricity.

Studies such as Patil and Kulkarni (2019) and Rathore and Panwar (2020) have explored solar-assisted evaporative coolers, yet these often rely on grid-dependent pumps, fans, or expensive photovoltaic systems, limiting applicability in off-grid and rur. Similarly, while Singh et al. (2018) and Kumar and Sharma (2020) demonstrated the thermal potential of natural materials like clay, terracotta, and red mud, most investigations remain confined to laboratory conditions, lacking real-world assessments of material durability, porosity optimization, or performance across diverse climatic zones. Moreover, existing prototypes tend to be bulky, stationary, and mechanically complex, neglecting modularity, ease of installation (e.g., window-mounted units), and affordability for domestic use. Long-term performance under fluctuating humidity, solar irradiance, and wind remains underexplored, as does material degradation over extended periods. Critically, few studies explicitly link technical outcomes to the United Nations Sustainable Development Goals, particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), missing opportunities to integrate cooling innovations within broader frameworks of climate resilience, resource conservation, and social equity.

2.1 Research Gaps

While numerous studies have explored evaporative cooling systems, sustainable materials, and solar-assisted mechanisms individually, a review of existing literature reveals several **critical research gaps** that highlight the need for an integrated and context-specific approach to sustainable air cooling technologies. Existing literature on evaporative cooling systems reveals significant gaps in achieving complete grid independence, with many studies, such as Patil and Kulkarni (2019) and Rathore and Panwar (2020), relying on complex or costly solar setups that remain impractical for low-income and rural users. Moreover, while materials like clay and red mud have shown cooling potential in works by Singh et al. (2018) and Kumar and Sharma (2020), research lacks comprehensive evaluation of composite natural materials under real-world conditions, including durability, porosity optimization, and regional adaptability. Water management remains inefficient in most designs, with studies like Ali et al. (2021) and Gupta et al. (2020) depending on mechanical or manual systems, neglecting low-cost drip irrigation or capillary mechanisms that could ensure uniform wetting and minimize wastage, particularly in water-scarce regions.

Additionally, current prototypes are often large, stationary, and complex, with little emphasis on modularity, user accessibility, or domestic scalability, limiting adoption in underserved communities. Long-term performance under variable environmental conditions—such as fluctuating humidity, solar irradiance, and wind—is rarely assessed, leaving uncertainties about material degradation and system reliability over time. Finally, despite growing focus on energy efficiency, few studies explicitly align innovations with UN Sustainable Development Goals, particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), missing opportunities to frame cooling solutions within broader metrics of climate resilience, carbon reduction, and social equity.

3: Materials and Properties

The performance, sustainability, and efficiency of the *Sustainable Solar Air Cooler* depend greatly on the selection and integration of materials used in its construction. The design philosophy emphasizes eco-friendliness, local availability, cost-effectiveness, and durability, ensuring that the final product remains accessible and replicable in both rural and urban contexts.

3.1 Core Materials of the Cooling System

The core cooling system is built around four key material categories: a porous cooling medium made from a red mud–clay composite that facilitates efficient evaporative heat absorption; a lightweight structural frame constructed as a wooden or aluminum sandwich for durability and portability; water circulation components including a plastic reservoir, tubing, and drip emitters to ensure controlled and uniform water distribution; and solar and electrical components comprising photovoltaic panels, a low-power pump, and wiring to enable off-grid operation and automated water flow.

3.2 Additional Supporting Materials

To enhance durability, hygiene, and environmental compatibility, the cooling system incorporates supplementary materials, including eco-safe silicone sealants applied at joints and connections to prevent water leakage while ensuring non-toxic performance; an optional filter mesh made from fine jute or cotton fabric positioned at the air inlet to trap dust, pollen, and airborne particles, thereby improving indoor air quality and reducing maintenance; and protective coatings of natural varnish or linseed oil brushed onto wooden or composite surfaces to provide water resistance, inhibit mold growth, and extend material lifespan under humid conditions without introducing synthetic chemicals.

3.3 Sustainability Justification

The sustainability of the proposed evaporative cooling system is firmly grounded in its low environmental impact and resource-efficient design. By utilizing natural clay, industrial byproduct red mud, and sustainably sourced wood or aluminum, the system significantly reduces embodied energy compared to conventional refrigerant-based units. Components are either biodegradable—such as the red mud–clay composite and jute filter mesh—or fully recyclable, including the aluminum frame and plastic reservoir, thereby minimizing waste generation and supporting circular economy principles. The design promotes local craftsmanship and small-scale manufacturing, enabling communities to produce, repair, and maintain units using readily available materials and traditional skills, which fosters economic resilience and reduces transportation emissions. Furthermore, seamless integration with compact solar photovoltaic panels and a low-power DC pump ensures complete off-grid functionality, eliminating reliance on fossil fuel-derived electricity and enhancing energy access in remote or underserved regions, while aligning directly with renewable energy adoption and long-term ecological balance.

4: Methodology

The methodology adopted for the *Sustainable Solar Air Cooler* focuses on a systematic approach to designing, fabricating, and testing an eco-friendly air cooling system that operates using renewable energy and locally available materials.

This chapter elaborates on the overall design concept, material integration, fabrication process, operational mechanism, and testing procedure, providing a complete framework from conceptualization to performance evaluation.

4.1 Conceptual Design

The conceptual design was developed with the objective of creating a low-cost, modular, and self-sustained air cooling system that can be easily installed on a standard window frame. The design employs evaporative cooling, which relies on the natural process of water evaporation to absorb heat and reduce air temperature.

4.2 Design objectives

The primary design objective of the Sustainable Solar Air Cooler methodology is to create an affordable, modular evaporative cooling system capable of reducing indoor air temperature by 5–10°C in hot, arid climates (ambient conditions of 35–42°C and 30–60% relative humidity) while operating entirely on renewable solar energy. This requires integrating compact 5–10W photovoltaic panels to power a low-energy pump and fan, ensuring complete off-grid functionality without reliance on electricity grids. The system must utilize locally available, environmentally friendly materials—such as a porous cooling mesh composed of 30% red mud and 70% natural clay, combined with lightweight aluminum or treated wood for the structural frame—to keep production costs low and support local economies.

Furthermore, the methodology targets long-term sustainability by minimizing environmental impact compared to conventional air conditioning systems, reducing both energy demand and water waste while avoiding synthetic refrigerants. The system should require minimal upkeep—such as periodic cleaning of the mesh and solar panels, and seasonal inspection of tubing and electrical connections—to ensure reliable performance over multiple cooling seasons. Ultimately, the design seeks to deliver a socially equitable, scalable cooling solution that enhances thermal comfort in underserved regions, supports energy independence, and contributes positively to ecological conservation.

4.3 Working Principle

The Sustainable Solar Air Cooler operates on the principle of evaporative cooling within a closed-loop, self-sustaining system powered by solar energy. The process begins with air intake, where ambient hot and dry outdoor air is drawn into the unit through a porous cooling mesh (typically made of natural fibers or cellulose pads) mounted on the exterior side of a window frame. This mesh serves as the primary medium for heat and mass transfer.

4.4 System components

The Sustainable Solar Air Cooler prototype was built using eco-friendly, locally sourced materials. The porous cooling mesh was made by mixing 30% red mud with 70% natural clay, molding it into panels, air-drying for 48 hours, and firing at 400–500°C for durability. The frame used lightweight aluminum or treated wood with insulation and adjustable slots for window compatibility.A closed-loop water system included a base reservoir, a low-power pump, drip tubes for even distribution, and a return channel to minimize waste. Solar power was provided by 5–10W panels connected directly to the pump, with optional battery storage for off-grid operation.

Testing occurred on a south-facing window under 35–42°C ambient temperature, 30–60% humidity, and 800–1000 W/m² solar irradiance. Parameters like temperature, humidity, airflow, and water use were measured hourly. Performance was analyzed for temperature drop, cooling efficiency, and resource use.

The system achieved 5–10°C cooling, full solar operation, low water consumption (<3 L/hr), and cost-effectiveness. Safety and maintenance involved insulated wiring, sealed joints, regular cleaning, and seasonal checks.

5: Results and Discussion

5.1 Result

The Sustainable Solar Air Cooler prototype was tested under natural conditions from April to June, with ambient temperatures of 35–42°C and peak sunlight hours (11:00 AM–4:00 PM). Experiments compared baseline air temperature without water circulation to full operation with solar-powered water flow. Key results showed an average temperature drop of 7.17°C (maximum 8.1°C at 2:00 PM), cooling efficiency averaging 17.8% (peaking near 20%), and consistent performance even as relative humidity rose from 38% to 48%. Water consumption was highly efficient at 2.6 L/hr (total 10.4 L over 4 hours), enabled by a closed-loop system and drip irrigation, while a 10W solar panel reliably delivered 7–9W to power a 5W DC pump across irradiance levels of 870–960 W/m².

Performance analysis confirmed the system's effectiveness through evaporative cooling using a red mud–clay porous mesh, with optimal results at air velocities of ports 2.5–3 m/s and peak solar intensity. Compared to conventional air coolers, it used 80% less water (2–3 L/hr vs. 15–20 L/hr) and negligible energy (0.01–0.02 kWh/hr vs. 0.8–1.5 kWh/hr), though with a slightly lower temperature drop (5–10°C vs. 8–12°C). The design offers easy installation, minimal maintenance, zero grid dependency, and no environmental footprint, with a prototype cost under ₹2,000.

The study validates a feasible, low-cost, off-grid cooling solution ideal for resource-limited areas, supporting SDG 7, 12, and 13 through renewable energy, waste material use, and reduced emissions. Limitations include reliance on sunlight, reduced efficiency above 60% humidity, suitability for small–medium rooms, and manual water refilling, indicating opportunities for future automation and performance enhancement under variable conditions.

Recorded Temperature Readings

Time (Hours)	Ambient Temperature (°C)	Outlet Temperature (°C)	Temperature Drop (°C)	Relative Humidity (%)	Solar Irradiance (W/m²)
	11:00 AM	36.5	31.2	5.3	38
870		12:00 PM	38.0	31.5	6.5
40	920		1:00 PM	39.4	31.8
7.6	43	940		2:00 PM	40.6
32.5	8.1	46	960		3:00 PM
41.2	33.5	7.7	48	910	
4:00 PM	39.8	32.0	7.8	45	880

Average Temperature Drop: 7.17°C Maximum Cooling Efficiency: ~20%

5.2 Discussion of Findings

The experimental findings underscore the viability of the Sustainable Solar Air Cooler as a low-cost, off-grid solution for resource-limited communities. The system achieved substantial temperature reduction of up to 8.1°C under ideal conditions, operated entirely on solar energy with zero grid dependency, and utilized nearly 80% less water than conventional evaporative systems. The red mud–clay mesh demonstrated excellent durability and thermal efficiency using locally sourced materials, while the prototype's total cost remained under ₹2,000, with no greenhouse gas emissions or noise pollution. These outcomes highlight the potential for sustainable, economical cooling in rural and semi-urban areas.Additionally, the system directly contributes to: SDG7,SDG12 and SDG13

Chapter 6: Conclusions

The research and development of the Sustainable Solar Air Cooling System have successfully demonstrated that it is possible to achieve effective indoor cooling through an eco-friendly, low-cost, and energy-independent approach. The project was conceived as a response to the growing environmental challenges posed by conventional air conditioning systems, which consume high amounts of electricity and contribute significantly to greenhouse gas emissions.The experimental evaluation of the prototype revealed a consistent temperature reduction ranging between 5°C and 10°C, depending on ambient humidity, solar irradiance, and airflow conditions. This range of cooling performance is particularly effective in hot, dry regions where conventional systems are either unaffordable or inaccessible due to unreliable power supply. The average cooling efficiency of 17–20% recorded during testing validates the technical viability of the concept and confirms that significant temperature moderation can be achieved without grid electricity.

A key aspect of this research is its use of locally available, biodegradable materials, which not only reduce manufacturing costs but also minimize ecological impact. The red mud–clay composite mesh provided excellent water absorption, high porosity, and thermal durability, ensuring effective evaporation and uniform air cooling. Moreover, the lightweight, modular window-mounted frame simplified installation, making the system adaptable to a variety of building types and locations.From a sustainability perspective, the project aligns strongly with the United Nations Sustainable Development Goals (SDGs)—particularly:

SDG 7: Affordable and Clean Energy, by enabling renewable energy utilization for cooling applications;
SDG 12: Responsible Consumption and Production, by employing waste-derived and natural materials; and
SDG 13: Climate Action, by reducing greenhouse gas emissions and promoting environmentally responsible technology.
In conclusion, the Sustainable Solar Air Cooler exemplifies how green engineering and indigenous material innovation can be integrated to address real-world challenges such as rising temperatures, energy scarcity, and climate change. The results of this study confirm that sustainable cooling is not only achievable but also practical, scalable, and essential for creating a climate-resilient and energy-secure future.

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