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A COMPREHENSIVE REVIEW ON SOLAR-ASSISTED EARTH-AIR HEAT EXCHANGER (EAHE) SYSTEMS FOR RESIDENTIAL COOLING APPLICATIONS

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ABSTRACT

With increasing concerns over global energy consumption and climate change, there is a growing need for passive and sustainable cooling technologies in residential buildings. Earth-Air Heat Exchanger (EAHE) systems, when integrated with solar-assisted components like solar chimneys, offer an effective means of reducing indoor temperatures and minimizing reliance on conventional HVAC systems. This review presents a comprehensive analysis of solar-assisted EAHE systems, covering their working principles, design configurations, performance evaluations, and integration strategies. A detailed literature review is included to highlight past and recent developments, simulation tools, and field studies. The paper concludes by discussing current challenges and future research directions.

Key Words: *Earth-Air Heat Exchanger (EAHE), Solar Chimney, CFD Simulation, Thermal Comfort, Energy Conservation, Passive Cooling, Residential HVAC.*

I. INTRODUCTION

India's rising energy demand, especially in residential sectors, demands sustainable alternatives to conventional HVAC systems. Buildings alone consume 32% of global power, with air conditioning accounting for 15–20% of residential energy usage. Earth-Air Heat Exchangers (EAHEs) offer an effective passive cooling strategy by utilizing the thermal inertia of underground soil to pre-cool incoming air. When integrated with solar chimneys (SC), their performance is further enhanced via natural ventilation. This study investigates the experimental and simulated performance of solar-coupled EAHE systems and explores design modifications for optimal thermal performance.

The building sector contributes significantly to global energy consumption, especially in regions with extreme climates where heating or cooling is essential. Traditional HVAC systems are often energy-intensive and environmentally detrimental. Earth-Air Heat Exchanger (EAHE) systems present a viable alternative by using the relatively constant underground temperature for air pre-conditioning. The performance of these systems can be further enhanced when coupled with solar-assisted systems like solar chimneys. This hybrid approach combines the advantages of geothermal and solar technologies, promoting sustainability and energy efficiency in residential applications.

The rapid pace of industrialization and urbanization has drastically increased energy consumption worldwide, with a significant share attributed to the building sector. In India, residential buildings alone account for a substantial portion of electricity use, particularly for space cooling through air conditioning systems. Conventional HVAC systems, while effective in controlling indoor climates, rely heavily on fossil fuels, contributing to environmental degradation, greenhouse gas emissions, and rising operational costs. This has intensified the need for alternative energy-efficient cooling systems that are both environmentally friendly and economically viable.

One such promising solution is the Earth-Air Heat Exchanger (EAHE), a passive system that utilizes the relatively

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stable underground temperature for heating or cooling incoming air. The EAHE consists of pipes buried beneath the surface through which ambient air is passed. Due to the thermal inertia of the soil, the air gets cooled in summer and heated in winter before being supplied indoors, reducing the reliance on active air conditioning systems.

Recent studies have explored the integration of EAHE with renewable energy systems, particularly solar chimneys (SC), to further enhance natural ventilation and indoor air quality. The solar chimney, a vertical shaft with an absorber surface, uses solar radiation to create a thermal draft, which drives warm air out of the building, drawing in cooler air through the EAHE system. This hybrid configuration not only reduces energy consumption but also ensures occupant comfort without mechanical support.

II. Principle of Solar-Assisted EAHE Systems

An EAHE system involves burying a network of pipes underground through which air is passed. Due to the stable sub-surface temperature, the air is cooled in summer and warmed in winter before being supplied to indoor spaces. When integrated with a solar chimney, the system utilizes solar energy to create a buoyant flow, drawing cool air through the EAHE and improving airflow and ventilation without mechanical assistance.

III. Literature Review

Several studies have investigated the design, simulation, and performance of EAHE systems across various climatic conditions.

Ghaith et al. (2023) validated a full-scale EAHE system in Dubai using TRNSYS and highlighted the practical benefits of hybrid systems in arid climates. Zhai and Wang (2021) demonstrated through simulations that integrating solar chimneys improves airflow and overall cooling effectiveness. Nayak and Tiwari (2018) applied EAHEs in Indian greenhouses and emphasized system adaptability. Schlaich et al. (2018) explored solar chimney designs and their synergy with EAHE systems. Rawat and Sharma (2018) compared different pipe materials, concluding that aluminum pipes offer better thermal performance due to high conductivity.

Bisoniya et al. (2014) analyzed the thermal performance of EAHEs in India, showing significant potential for cooling in hot and dry climates. Zhang and Haghighat (2009) used CFD tools like ANSYS Fluent to examine airflow and temperature distribution in EAHE systems. Chel and Tiwari (2009) evaluated passive cooling using EAHE in greenhouses, concluding that pipe material and soil properties are crucial for system efficiency. Shukla et al. (2006) investigated the influence of soil moisture and air velocity on the performance of EAHEs and found that increased moisture significantly enhanced cooling potential.

Kumar et al. (2003) explored energy saving potentials in composite climates and emphasized the need for region-specific EAHE designs. Hollmuller and Lachal (2001) analyzed long-term dynamic behavior of buried pipe systems and validated thermal models using experimental data from Switzerland.

These studies provide a foundational understanding of system parameters, regional feasibility, and optimization strategies. Despite promising results, gaps remain in long-term performance studies, cost-benefit analyses, and integration with smart building technologies.

IV. System Design and Simulation Approaches

EAHE systems can be designed in open-loop or closed-loop configurations. Key design parameters include pipe diameter, length, material, depth of burial, and soil type. CFD simulations and software like TRNSYS are extensively used to model heat transfer, airflow, and thermal comfort indices. Mesh quality, boundary conditions, and solver settings significantly influence simulation accuracy.

V. Integration with Solar Chimneys

Solar chimneys function by heating air through a solar absorber plate, creating a vertical air draft. When connected to an EAHE system, they enhance the natural airflow, reducing the need for mechanical ventilation. This integration is especially useful in off-grid or low-energy buildings. Studies have shown that combining EAHE and SC systems can lead to a temperature reduction of 6–10°C indoors.

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VI. Advantages and Challenges

Solar-assisted EAHE systems are environmentally friendly, reduce grid dependency, and operate with minimal maintenance. However, challenges such as high initial costs, land requirement for pipe installation, and performance variability across seasons need to be addressed. Standardization of design methods and government incentives can help in promoting adoption.

VII. Conclusion

Solar-assisted EAHE systems represent a promising solution for sustainable residential cooling, particularly in hot and arid regions. The synergy between geothermal and solar principles allows for efficient air temperature regulation with reduced energy input. As building codes increasingly emphasize sustainability, the adoption of hybrid EAHE systems is expected to grow, provided ongoing research continues to address existing limitations.

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