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Research article

Experimental Performance of a Roof Solar Fiber-Cement Chimney and Thermoelectric Power Generation

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Abstract: Experimental performance of a roof solar fiber-cement chimney and thermoelectric power generation can enhance ventilation and mitigate heat gain in the attic. This paper presents initial experimental findings on the thermal performance of an advanced roof design using a recently introduced solar chimney configuration that incorporates ten thermoelectric modules. Specifically, one thermoelectric module (MT2-1, 6-127), measuring 40 x 40 mm, was placed in the roof solar fiber-cement chimney, which has a surface area of 0.24 m², and installed on the roof of a small south-facing room measuring 120 cm x 120 cm x 120 cm. Field test results demonstrated that this roof solar fiber-cement chimney, designed with thermoelectric modules, effectively fulfills its intended purposes of promoting ventilation and reducing heat gain through the roof envelope. Therefore, the proposed roof solar fiber-cement chimney with ten thermoelectric modules represents an innovative and viable alternative for various applications, including natural ventilation, indoor air circulation, and reduced roof heat gain. The roof solar fiber-cement chimney and thermoelectric power generation conserve energy and promote solar energy use.

Keywords: Roof solar fiber-cement chimney; heat gain reduction; thermoelectric power generation

1. Introduction

The roof is a vital component of a residential home, and heat beneath it can be used to generate electricity through thermoelectricity. This innovative approach not only harnesses renewable energy but also reduces dependency on fossil fuels. By optimizing design and materials, energy efficiency in buildings can be significantly enhanced (see Figure 1), providing protection against rain (moisture) and helping shield against sunlight, including intense solar radiation (shortwave radiation). During the day, when sunlight hits the roof surface, some rays are reflected while others are absorbed, transferring heat into the house. Consequently, the roof surface becomes hotter than both the outside air and the home's interior. This temperature difference causes heat to flow from the roof surface to the outside air. The accumulated heat in the roofing material conducts heat through the layers, moving from the exterior roof surface to the interior. This results in convection between the air beneath the roof and the interior roof surface, raising the temperature in that area. Following this, convection between the air under the roof and the ceiling leads to heat conduction through the ceiling material, transferring heat to the interior

ceiling. Lastly, convection between the indoor air and the ceiling further elevates the temperature inside the house. Because Thailand is in a hot, humid climate zone with hot, rainy weather year-round [1], temperatures range from 32 to 38°C, air humidity is 59-100%, and solar radiation intensity is approximately 17 MJ/m²/day. This radiation strikes the roof tiles, causing heat to accumulate and transfer through the roof structure into the building, resulting in heat and humidity buildup in the attic. This process raises indoor temperatures, leading to heat-accumulation problems in modern houses and buildings, which is a significant concern for residents' comfort. Therefore, the primary solution is to use mechanical air conditioners to reduce indoor temperatures and improve thermal comfort, which increases electricity consumption in residential houses or buildings. To combat this issue effectively, it is also crucial to consider energy-efficient alternatives, such as enhanced insulation and improved ventilation systems. By implementing these strategies alongside mechanical cooling, homeowners can maintain a comfortable indoor environment while minimizing energy consumption and associated costs.

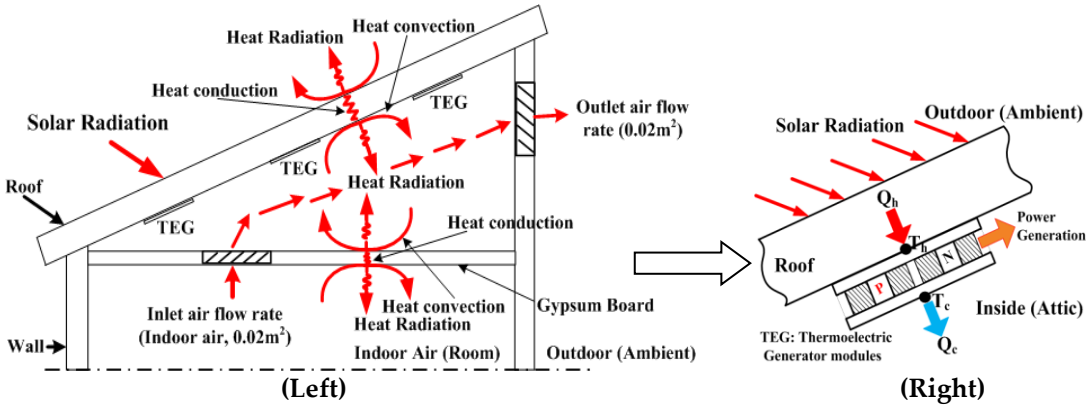


Figure 1. Schematic representation of heat transfer through roof solar fiber-cement chimney (left) and thermoelectric power generation (right).

In hot and humid climates, excessive solar heat gain and heat accumulation within building envelopes significantly affect indoor thermal comfort and increase cooling requirements [3]. In Thailand, as in many other tropical regions, residential buildings are increasingly featuring modern roof designs that are both visually appealing and cost-effective. Common roof types in housing estates include hip roofs, triangular gable roofs, and square or curved roofs. While these designs effectively protect against rain and shield against direct short-wave solar radiation during the day, they remain inadequate in mitigating long-wave radiation. Consequently, the roof surface absorbs solar heat and transfers it indoors through conduction, convection, and radiation. This process raises indoor temperatures above ambient levels, forcing air-conditioning systems to work harder and increasing electricity consumption and household energy costs [2–4].

Thailand's hot and humid climate, characterized by consistently high solar radiation and lengthy rainy seasons, worsens indoor heat buildup. [5]. To address these challenges, research efforts have focused on reducing heat gain through roofing materials and ventilation strategies. Levinson et al. [6] demonstrated that the color and reflectivity of roof tiles influence heat absorption, while Ogoli [7] investigated the benefits of attic insulation in minimizing heat transfer. Experimental studies have further confirmed that both cool roof designs and thermal insulation can lower indoor air temperatures. Building upon this, Chantawong, Khedari, Waewsak, and colleagues [8–12] explored naturally ventilated roofs and turbine-ventilated systems, showing that improved roof configurations significantly enhance airflow and reduce indoor thermal loads. Their findings highlight the critical role of roof design and orientation in improving ventilation efficiency and thermal regulation.

Against this backdrop, integrating passive cooling strategies with innovative energy-harvesting technologies offers a promising pathway toward sustainable building design. This study introduces and evaluates a roof solar fiber-cement chimney (RSFCT). This research employs carefully designed and controlled field tests to evaluate the effectiveness of hybrid passive–active roofing systems in reducing

household energy demand and improving thermal comfort. The study focuses on integrating a fiber-cement solar roof chimney with thermoelectric modules (RSFCT) and compares its performance against a conventional simple cement roof (SCR) under Thailand's hot and humid conditions. The originality of this work lies in developing and evaluating a dual-function roofing system that simultaneously enhances natural ventilation and harvests renewable energy. Unlike conventional roofing systems that focus solely on thermal regulation or ventilation improvement, the proposed Roof Solar Fibre-Cement Chimney integrated with thermoelectric modules (RSFCT) combines passive cooling and energy generation in a single system. This integrated approach improves indoor thermal comfort, reduces cooling energy demand, and provides supplementary electricity, supporting sustainable building design in tropical climates. The outcomes are expected to demonstrate how such systems can lower cooling requirements, enhance natural ventilation, and provide supplementary energy generation. Beyond Thailand, the findings have broader relevance for other tropical regions that face similar challenges in balancing indoor comfort with sustainable energy use.

2. Experimental Methodology

Building on the research framework outlined in the Introduction, the experiment compared two model houses: one equipped with a fiber-cement solar roof chimney with ten thermoelectric modules (RSFCT) and the other with a standard fiber-cement roof (SCR). Both houses were identical in size and materials, differing only in roofing design. Each had a volume of 2.016 m^3, a south-facing orientation to maximize solar exposure, plaster walls (8 mm, painted white), a 6 mm plasterboard ceiling, and pearl-blue fiber-cement roof tiles set at a 30° slope with a roof area of about 2.04 m^2, consistent with international and domestic testing practices[13,14].

Figure 1- 2 illustrates the overall layout and configuration of the model houses. The walls were constructed from plaster sheets approximately 8 mm thick and finished with white paint to enhance reflectivity. The ceiling consisted of 6 mm plasterboard, while the roofs were covered with pearl-blue fiber-cement tiles inclined at 30°. Each house had a roof surface area of about 2.04 m^2. Home 1 (SCR) used a conventional roof configuration. For Home 2 (RSFCT), the roof was modified to include a solar chimney with a two-layer structure. The upper layer consisted of blue pearl-colored double-corrugated fiber-cement tiles designed to enhance ventilation, while the inner layer consisted of flat fiber-cement tiles approximately 8 mm thick. A thermoelectric module (MT2-1, 6-127, 40 × 40 mm) and the thermoelectric specifications in Table 1 were used; ten TEG modules were installed in the RSFCT channel (Figure 2). The gap between the upper and lower roof layers was approximately 0.01 m, creating a ventilation pathway. The 10 mm gap was selected primarily as a practical design constraint to facilitate integration with the existing fiber-cement roofing structure while maintaining a compact, low-profile configuration suitable for residential roof applications. Such a narrow channel may increase viscous resistance and influence airflow development within the chimney. The larger channel gaps are generally associated with lower flow resistance and may enhance buoyancy-driven ventilation performance. However, channel geometry, chimney height, solar heat gain, and temperature difference also play important roles in determining the overall airflow characteristics.

Openings of about 0.02 m^2 were provided at both the lower (indoor side) and upper (outdoor side) ends of the channel to promote buoyancy-driven airflow. Additional construction features included a 0.6 m^2 plastic door (7.5 cm thick) installed on the north wall and a 0.4 m^2 louver to allow additional air exchange; the thermal performance of these two houses is shown in Table 2. The overall construction followed previous studies on roof ventilation and thermal performance carried out by Chantawong, Khedari, Waewsak, and colleagues, but was extended here to incorporate thermoelectric energy harvesting [15, 16].

Table 1. Specifications of Thermoelectric MT2-1, 6-127 [17]-[19]

Leg height (mm)	1.5
Area of the thermoelement (mm²)	1.96
Contact height (mm)	1.0
Insulator plate thickness (mm)	0.63
Module height (mm)	3.9
Area-to-length ratio	1.27
No. of couples (number)	127
Maximum operating hot side temperature (°C)	150
Thermal conductivity (W/m K)	1.647

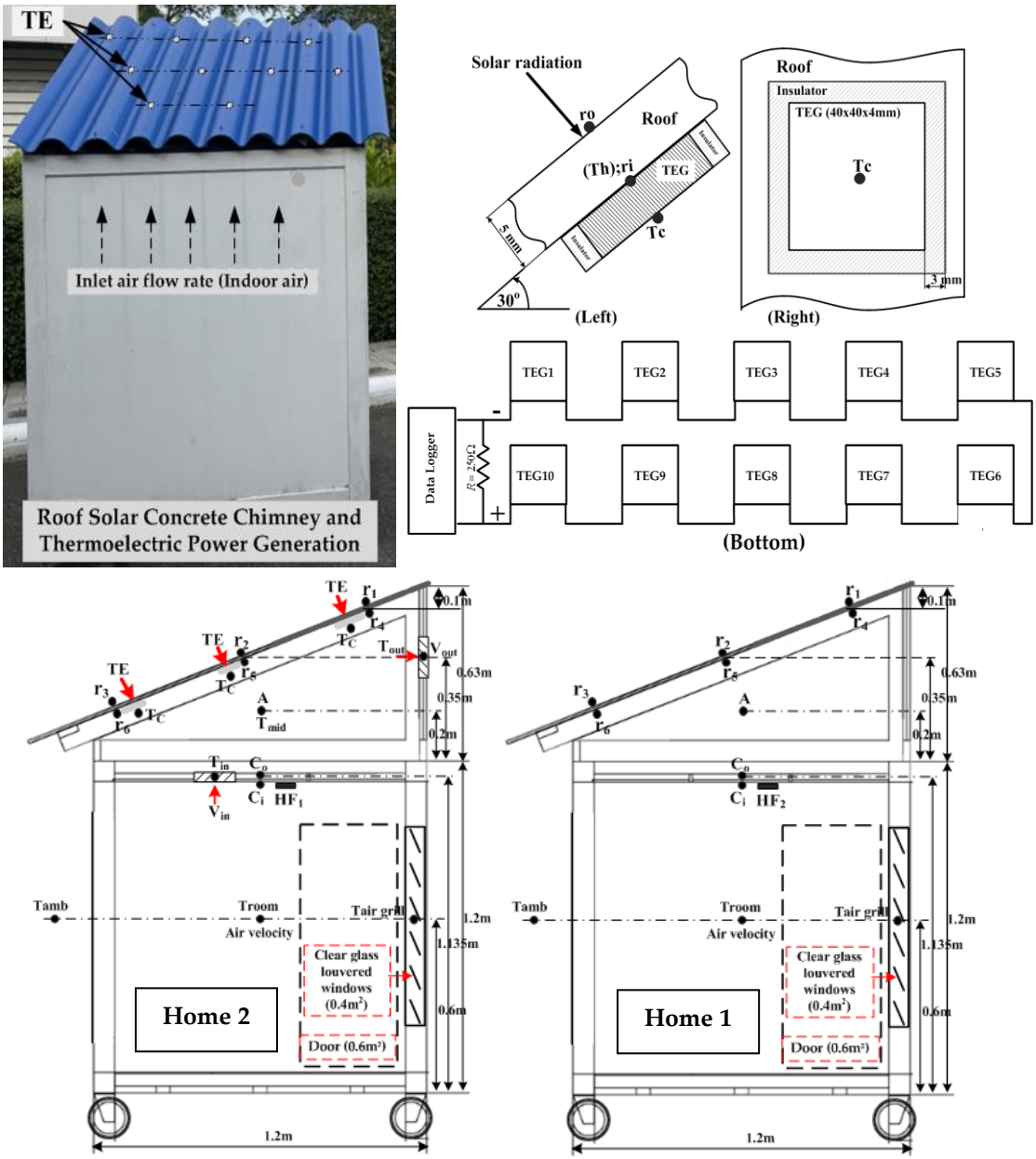


Figure **2.** South-facing through-roof solar fiber-cement chimney view of the experimental houses (left), TEG modules (right), house dimensions and positions of measurement (Bottom).

Table 2. Materials thermal properties [14].

Type of material	Fiber-cement board	Thermal insulation
Thermal conductivity (W/m.K)	0.297	0.029
Density (kg/m^3)	775	120
Specific heat capacity (kJ/kg.K)	1.09	840
Emissivity	0.95	0.9

The experiments were carried out on 2 November 2025, with the air-conditioning system switched off to isolate natural ventilation and heat-transfer effects. Measurements focused on ambient conditions, indoor air performance, and roof thermal behavior. Solar radiation was measured using an MS 402 EKO pyranometer with an accuracy range of 0–1000 W/m^2. Temperature variations were captured using Type-K thermocouples (range: 0–1250°C; accuracy: ±0.5°C), installed at multiple points, including indoor air, ceiling, roof surfaces, and the chimney interior. Wind speed was monitored using a TSI Model 8380 anemometer with a range of 0–50 m/s and an error margin of ±5%, both inside and outside the houses. Airflow velocity was measured at the inlet (Vin) and outlet (Vout).

Roof heat flux was recorded using an EKO Heat Flow Meter MF-140, operating from –20°C to 120°C with an error margin of ±5%. The thermoelectric module's voltage was monitored via 20 AWG UL1007 wiring (rated at 80°C and 300 V), connected to a 250 Ω matched load resistance, and power output was calculated using Ohm's law. Data from all instruments were logged at five-minute intervals between 8:00 AM and 6:00 PM using a Hioki 8422-52 data logger, which has a recording accuracy of ±0.8%. Figure 2 shows the placement of the measuring instruments within the test houses for the SCR model, and Figure 3 shows it for the RSFCT model. Through this methodology, the study evaluated a wide range of performance indicators, including changes in environmental temperature, solar radiation intensity, indoor and ceiling temperature variations, roof surface temperature, and temperature fluctuations inside the RSFCT chimney. The analysis also included wind speed profiles inside and outside the model houses, heat flux through the roof surfaces, and the thermoelectric module's electrical performance. The comprehensive dataset ensured that the RSFCT system could be rigorously assessed for its capacity to reduce heat gain, promote ventilation, and generate supplementary power, thereby advancing sustainable building design for tropical climates.

3. Results and Discussion

The experimental investigation generated a comprehensive dataset on environmental conditions, indoor thermal performance, ventilation behavior, and thermoelectric output for the two model houses. Figure 4 illustrates the variations in indoor temperature, ambient temperature (Tamb), and solar radiation intensity (It) during the test period. The ambient temperature ranged between 27.5°C and 36.5°C, while solar radiation intensity varied between 0.59 and 1,298 W/m^2, peaking around 1:50 PM. A comparison of heat flux (HF1 and HF2) showed that the model house with the RSFCT (Home 2) experienced significantly lower heat transfer through the roof than the SCR house (Home 1). Specifically, the RSFCT reduced roof heat conduction by approximately 78.8% over the course of the day, highlighting the system's capacity to mitigate heat accumulation, and daytime air circulation measurements further confirmed the system's effectiveness. Internal airflow in the RSFCT house ranged from 0.013 to 0.75 m/s, which was markedly higher than that in the SCR house (0.01–0.015 m/s). The observed maximum velocity of 0.75 m/s occurred during periods of maximum solar radiation and temperature difference across the solar chimney, which enhanced buoyancy-driven airflow through the chimney channel.

External wind speeds were measured between 1.1 and 2.2 m/s, while the RSFCT's outlet ventilation reached 0.82–1.12 m/s, demonstrating the chimney's role in expelling indoor air and improving ventilation efficiency.

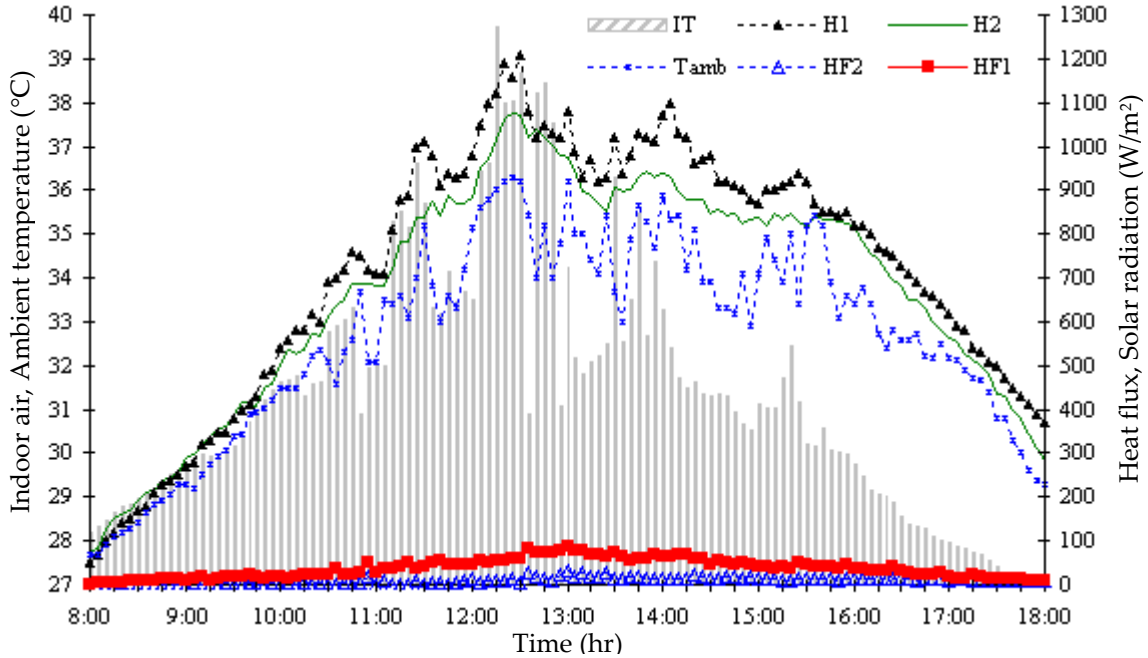


Figure 3. Changes in indoor temperature, ambient temperature, heat flux (HF1 and HF2), and solar radiation intensity.

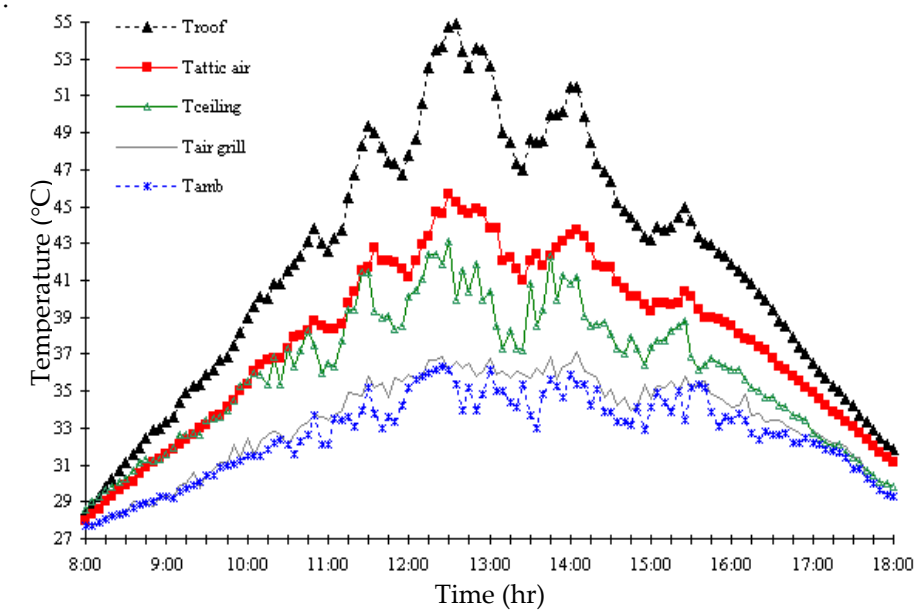


Figure 4. Results of temperature changes inside the installed test house with an SCR (Home 1).

Figures 4 to 6 show the temporal evolution of indoor temperatures in the two houses. Home 2, equipped with the RSFCT, maintained an indoor temperature approximately 0.2–2.8°C lower than Home 1 throughout the daytime. While the roof surface temperatures were similar for both houses—since they used identical materials and colors—the temperature inside the RSFCT chimney was consistently higher than both the indoor and ambient air. This thermal gradient generated buoyancy-driven airflow, enhancing natural ventilation. The 10 mm air gap used in the present RSFCT configuration is smaller than those commonly reported in solar chimney and ventilated roof studies, which typically range from 30 to 150 mm.

While a narrow channel may increase viscous resistance and potentially restrict airflow, it was selected in this study to enable practical integration with the fiber-cement roofing structure and to maintain a compact roof profile. The measured airflow enhancement suggests that buoyancy-driven ventilation was still successfully established under the tested conditions. Nevertheless, the influence of channel width on airflow resistance, thermal performance, and thermoelectric power generation warrants further investigation. Future studies should evaluate alternative gap dimensions to identify optimal design parameters for tropical building applications.

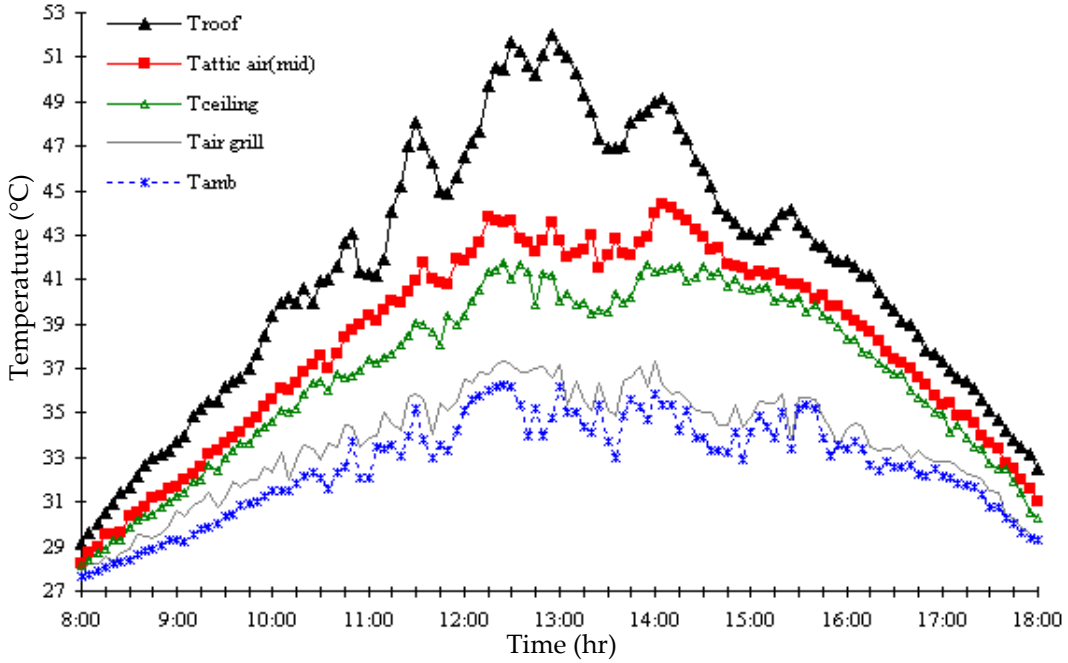


Figure 5. The results of temperature changes inside the installed test house with RSFCT (Home2).

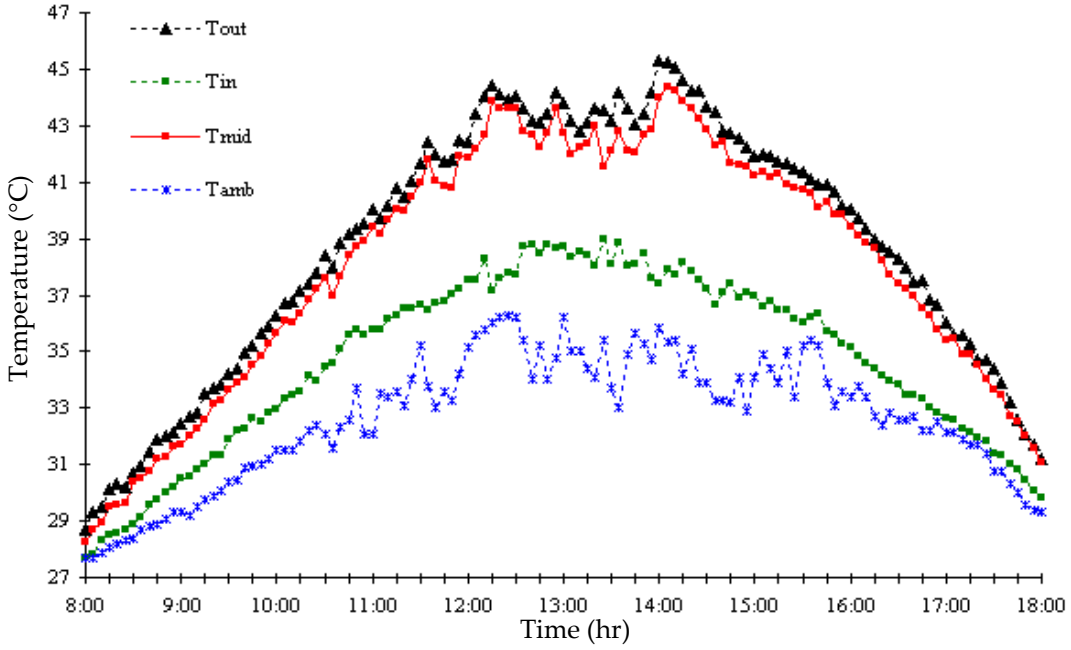


Figure 6. Results of temperature changes inside the RSFCT (Home 2).

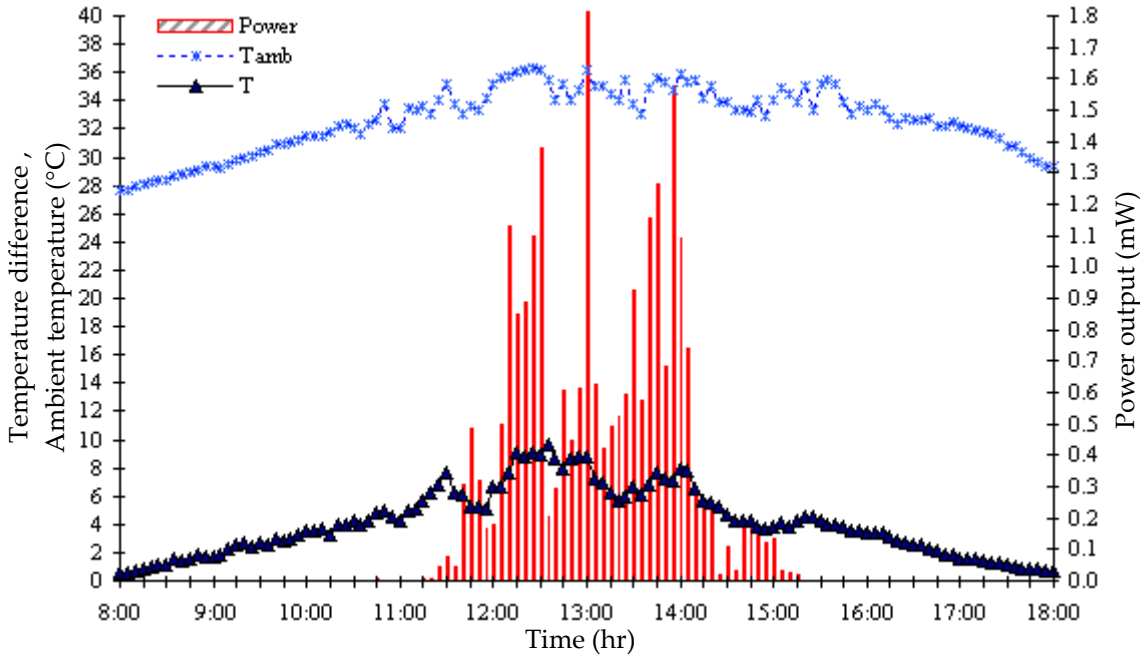


Figure 7. The results of the temperature change of the ambient, the temperature difference of the thermoelectric, and the power output (Home 2)

The electrical performance of the thermoelectric module is presented in Figure 7. Power generation ranged from 0.12 to 1.8 mW, depending on the temperature difference between the module's hot and cold sides. Although modest, this output demonstrates the potential of the RSFCT system to provide supplementary power alongside its primary function of improving indoor thermal comfort. Several limitations of this study should be acknowledged. First, the experimental evaluation was conducted over a single measurement day under specific climatic conditions. While the selected day was representative of typical hot and humid weather in Thailand, the results do not capture potential variations arising from seasonal changes, cloud cover fluctuations, rainfall events, or other meteorological factors. Consequently, the findings should be interpreted as an initial proof-of-concept assessment of the proposed Roof solar fiber-cement Chimney integrated with thermoelectric modules (RSFCT) rather than a comprehensive long-term performance evaluation. Second, the experiment was performed using a specific test-house configuration and roof geometry. The thermal and ventilation performance of the RSFCT system may vary depending on building characteristics, roof orientation, construction materials, occupancy patterns, and local climatic conditions. Therefore, exercise caution when generalizing the results to other building types or geographical regions. Third, the electrical power generation from the thermoelectric modules was evaluated under the temperature gradients achieved during the test period. Variations in solar radiation intensity and ambient conditions may influence the thermoelectric performance under different operating scenarios. Th and Tc will be observed for a more complete assessment of TEG operating conditions. The optimization of chimney gap width was beyond the scope of the present study. Future investigations will evaluate a wider range of channel dimensions to determine the optimal balance between thermal performance, airflow enhancement, structural practicality, and thermoelectric energy generation. Moreover, future work will include detailed electrical characterization of the TEG array, including load-matching analysis and maximum-power-point determination, to optimize energy-harvesting performance. Future work will involve numerical modeling and full-scale experimental validation to investigate the scalability of the proposed system and quantify its performance under realistic residential operating conditions. Because the present study was based on a single experimental campaign, statistical uncertainty bands derived from repeated measurements were not available. Future studies involving repeated experimental trials will enable a more comprehensive

uncertainty analysis and statistical assessment of system performance. Finally, future studies should extend the monitoring period to encompass multiple days, seasons, and weather conditions to evaluate long-term performance, repeatability, and reliability. In addition, numerical simulations and economic assessments could be incorporated to investigate further the scalability and practical implementation potential of the proposed RSFCT system in tropical buildings.

4. Conclusion

This study presented a comparative evaluation of the thermal insulation performance between a fiber-cement solar roof chimney integrated with thermoelectric modules (RSFCT) and a conventional fiber-cement roof (SCR). The findings indicate that heat flow through the roof of the house with SFR was higher than that of the RSFCT-equipped house. Integrating RSFCT improved interior air circulation, reducing heat accumulation and enhancing natural ventilation. Such performance demonstrates the potential of FSRC as an energy-saving approach for building applications. Unlike solar cell roof ventilation systems, which typically rely on forced ventilation through DC fans [8]-[9], the RSFCT system is a simple modification of conventional roofs and operates as an open, naturally ventilated design. In addition, the thermoelectric modules incorporated into the RSFCT enabled small-scale electricity generation in the range of approximately 0.12–3.8 mW, adding further value through energy co-benefits. Specifically, the observed results demonstrate the potential of the proposed system under the specific environmental conditions tested. We emphasize that additional experiments over multiple days, seasons, and weather conditions are needed to validate the long-term performance, reliability, and generalizability of the findings. Overall, the development and application of RSFCT technology highlights a promising pathway for utilizing solar energy as a free, sustainable source to improve building thermal comfort, reduce energy consumption, and generate supplementary electricity. Future advancements in such roof ventilation systems could play a significant role in promoting renewable energy utilization and sustainable housing practices.

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