A comparative study of direct current electricity generation using thermoelectric modules at different installation positions on the clear glass surface single-pane windows of a model house

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Abstract

This research article presents an experimental study comparing direct current electricity generation using thermoelectric modules installed at different positions on the surface of a single-pane transparent glass window of a small-scale house model with a volume of approximately 4.05 m³. The electrical energy was generated by utilizing the temperature difference between the outdoor and indoor environments throughout the day via the glass window of the small test house located in Bangkok, Thailand. The transparent glass window used in the experiment had dimensions of 72 × 42 cm² and a thickness of approximately 0.5 cm. It was installed on the south-facing wall of the test house. Six thermoelectric (TE) modules, model MT2-1, 6-127, each with dimensions of 40 × 40 mm, were installed and tested under normal weather conditions.The thermoelectric modules were arranged in two rows at three different positions on the inner side of the glass window: top, middle, and bottom. The experiment was conducted for all three positions. The measured data indicate that the proposed concept is feasible, as the temperature difference between the outside and inside of the house over the daily cycle could successfully generate electric current. Owing to the simplicity of the proposed concept, further studies are recommended to explore potential applications and improve system performance.

Keywords: Solar radiation, thermoelectric modules, electricity generation, clear glass surface

Introduction

Nowadays, the design of residential buildings in Thailand has increasingly been influenced by modern architectural concepts adopted from international practices. Glass windows have become a key architectural component of the building envelope, playing a crucial role in determining the energy and environmental performance of buildings. In addition to their aesthetic value and ability to provide natural daylight, glass windows significantly affect indoor thermal conditions through heat transfer, solar radiation gain, and the movement of air and moisture. A well-integrated building envelope system can effectively regulate energy flows—such as heat transfer and solar radiation—as well as mass transfer, including air and moisture. Moreover, such systems can incorporate technologies that convert renewable energy sources, including solar radiation, wind, and thermal mechanisms, into usable forms of energy such as heat and electricity, thereby meeting diverse building energy demands. However, in hot and humid climates like Thailand, solar radiation transmitted through walls and windows is a major contributor to the building cooling load, accounting for approximately 40% to 70% of the total cooling demand. Therefore, reducing solar heat gain through the building envelope, particularly through glass windows, is a critical strategy for minimizing energy consumption in air-conditioning systems. Consequently, numerous studies have focused on improving the thermal and optical properties of glazing materials and developing techniques to reduce heat transfer through windows and walls [1–3]. At the same time, transparent glass windows offer significant advantages, including enhanced natural daylighting, improved visual comfort, and the ability to maintain visual connection with the outdoor environment. These benefits can reduce the need for artificial lighting during daytime. Therefore, optimal design strategies should aim to balance the reduction of heat gain with the effective utilization of natural daylight, while also exploring innovative approaches to harness and utilize the energy transmitted through building windows more efficiently.

Thailand is located in the equatorial region, resulting in a hot and humid climate [4]. The average daily solar radiation is approximately 17.5 MJ/(m^2·day), with ambient temperatures ranging between 30–35°C and relative humidity levels of 50%–80% [5]. Under such conditions, solar radiation incident on and transmitted through glass windows and walls leads to significant heat accumulation within buildings. This increases indoor temperatures and consequently raises energy consumption for air-conditioning systems.

Previous studies have explored passive cooling strategies, such as solar chimney ventilation integrated with double-glazed façades, which can enhance natural ventilation and reduce energy consumption [6]. However, global energy instability—particularly geopolitical tensions in major oil-producing regions such as the Middle East—has contributed to fluctuations in fuel prices. In Thailand, where retail fuel prices are largely influenced by market mechanisms, this has resulted in increased energy costs and associated environmental impacts, including air pollution.

Therefore, alternative approaches for energy utilization and efficiency improvement are essential. This research aims to investigate the feasibility of utilizing accumulated heat on transparent glass windows—caused by solar radiation during daytime—for electricity generation using thermoelectric generator (TEG) technology. The system operates based on the natural temperature difference between the indoor and outdoor environments across the glass window of a small-scale house model with a volume of approximately 4.05 m^3 (as shown in Fig. 1).

The transparent glass window used in this study has an area of 72 × 42 cm^2 and a thickness of approximately 0.5 cm. It is installed on the south-facing wall of the test house. Six thermoelectric (TE) modules (model MT2-1, 6-127) [10], each with dimensions of 40 × 40 mm, are installed in two vertical rows at three positions: top, middle, and bottom, as illustrated in Fig. 2.

This research builds upon previous work by Pasinpong Souppornsingh et al. [6]–[11]. The experimental study was conducted on March 23, 2026, under typical Thai climatic conditions, with the air-conditioning system turned off. Key parameters investigated include ambient temperature, solar radiation intensity, outer and inner glass surface temperatures, indoor temperature variation, temperature difference across the hot and cold sides of the thermoelectric modules, wind velocity both inside and outside the house (with the glass façade facing south), and heat transfer through the glass.

Research Methodology

Two identical small-scale house models were constructed and tested in Bangkok, Thailand (as shown in Fig. 1–Fig. 2). The study aimed to evaluate and compare the performance of transparent glass windows under real climatic conditions.

Each test house was equipped with a single-pane transparent glass window with dimensions of 72 × 42 cm² and a thickness of approximately 0.5 cm. The window was installed on the south-facing wall of the test house to maximize solar exposure. Thermoelectric (TE) modules (model MT2-1, 6-127) [10], each with dimensions of 40 × 40 mm, were mounted on the inner surface of the glass window.

A total of six TE modules were installed and arranged in two vertical rows. The experiments were conducted under normal ambient weather conditions to assess the system's performance in realistic environmental settings.

Thermoelectric sizing

The selection and sizing of thermoelectric (TE) modules were determined based on the available glass surface area, module dimensions, installation feasibility, and expected temperature difference across the window under real climatic conditions. The chosen TE module (MT2-1, 6-127) with dimensions of 40 × 40 mm was selected due to its suitability for low-temperature difference applications. A total of six modules were installed on the inner surface of the glass window, arranged in two vertical rows, ensuring effective surface coverage while maintaining proper spacing for heat transfer and airflow.

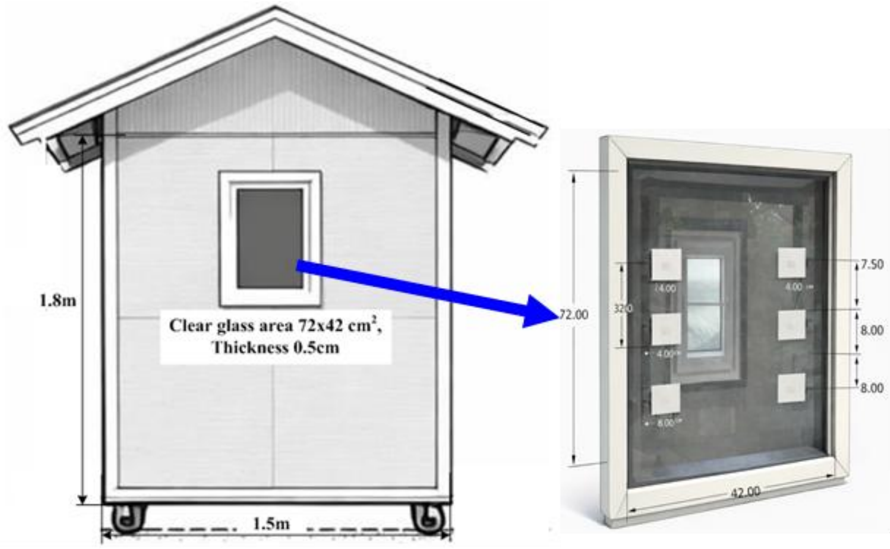

Figure 1 Small-scale house models used in the experiment.

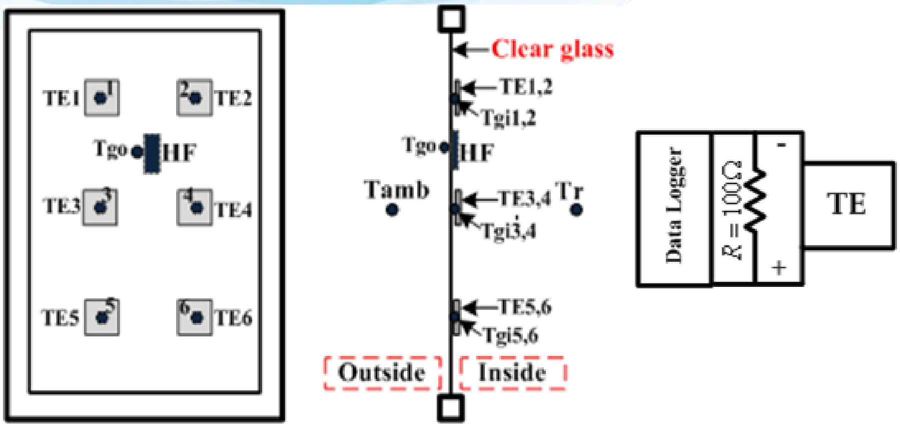

Figure 2 Measurement setup and electrical circuit of thermoelectric modules.

The small-scale house model, with an internal volume of approximately 4.05 m³ (as shown in Fig. 1), was constructed using gypsum board walls with smooth surfaces, painted white on both sides. The wall thickness was approximately 0.008 m. The roof was designed as a gable type with a total area of approximately 5.29 m². The roof structure consisted of an outer transparent poly sheet with a thickness of 0.004 m, and an inner gypsum ceiling panel with a thickness of approximately 0.006 m. A door with dimensions of 0.45 m × 1.45 m and a thickness of 0.075 m, made of rigid plastic material, was also installed.

This study was developed based on previous work by Pasinpong Souppornsingh et al. [6]–[11]. The experimental investigation was conducted on March 23, 2026, under typical climatic conditions in Thailand, with the air-conditioning system turned off.

The parameters investigated included ambient temperature, solar radiation intensity, glass surface temperatures (both outer and inner sides), indoor air temperature variation, temperature difference between the hot and cold sides of the thermoelectric modules, and wind velocity inside and outside the test house. The glass façade of the model house was oriented toward the south.

Solar radiation was measured using an MS-402 EKO pyranometer (range: 0–1000 W/m²). Wind velocity was measured using a TSI Model 8380 anemometer (range: 0–50 m/s, error ±5%). Temperature measurements at various locations were obtained using Type K thermocouples (range: 0–1250°C, accuracy ±0.5°C). Natural light intensity (illuminance) was measured using a UNI-T UT383 lux meter (range: 0–9999 lux, accuracy ±4%).

Heat flux through the glass window was measured using an EKO heat flow meter (Model MF-140, temperature range: -20°C to 120°C, error ±5%). All data were recorded using a data logger (Hioki Model 8422-52, accuracy ±0.8%), with measurements taken at 5-minute intervals from 08:00 to 18:00.

The direct current (DC) electrical power output from the thermoelectric modules was calculated based on electrical measurements obtained through a dedicated measurement circuit, as illustrated in Fig. 2 (right)

Equations

The following equations are relevant to this study:

(1) Electrical power (DC):

$$P=VI$$

where
P = electrical power (W),
V = voltage (V),
I = current (A)

(2) Electrical power with load resistance:

$$P=V^2/R$$

where
R = load resistance (Ω)
3) Temperature difference across the thermoelectric module:

$$\Delta T=Th-Tc$$

where
Th = hot-side temperature,
Tc = cold-side temperature

(4) Heat transfer:

$$Q=q''A$$

or in terms of heat flux:

$$q''= Q/A$$

where
Q = heat transfer rate (W),
q″ = heat flux (W/m^2),
A = area (m^2)

(5) Seebeck effect relationship:

$$V=\alpha\Delta T$$

where
α = Seebeck coefficient (V/K)

Result

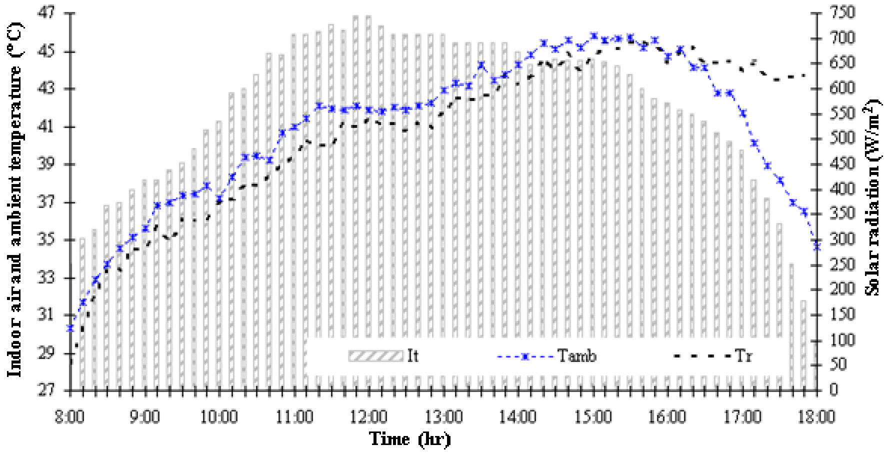

Figure 3 Variation of ambient temperature, indoor temperature, and solar radiation.

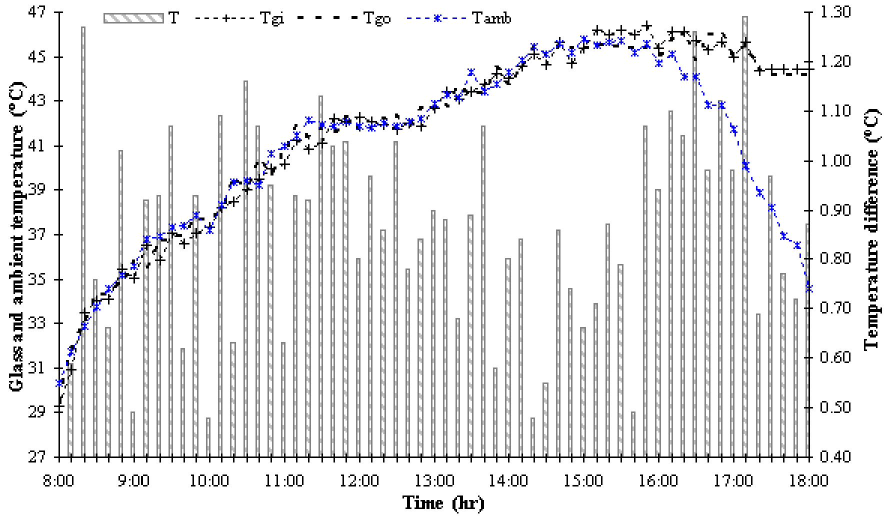

Figure 4 Temperature variation and temperature difference across thermoelectric modules.

Figure 3 illustrates the variations in ambient temperature (Tamb), indoor temperature of the test house, and solar radiation intensity (It) at the experimental site. The results indicate that the ambient temperature ranged from approximately 29 to 45.5°C, while the solar radiation intensity varied between 0.2 and 745 W/m². The solar radiation increased continuously throughout the morning and reached its peak at approximately 11:55.

The indoor temperature of the test house ranged from 28.9 to 44.3°C, which was slightly higher than the ambient temperature by approximately 0.12–0.45°C. Air circulation within the test house during the experiment showed an indoor air velocity of approximately 0.011–0.22 m/s, while the outdoor wind speed ranged between 1.41 and 2.4 m/s.

The natural light intensity (illuminance) varied from approximately 200 to 3000 lux. The results also revealed that the temperature variation on the glass surface was relatively similar to the ambient temperature, indicating a limited thermal gradient across the glass.

Furthermore, the temperature difference between the hot and cold sides of the thermoelectric modules was found to be relatively small, ranging from approximately 0.42 to 1.28°C, as shown in Fig. 4. This limited temperature difference directly affects the electrical output performance of the thermoelectric system.

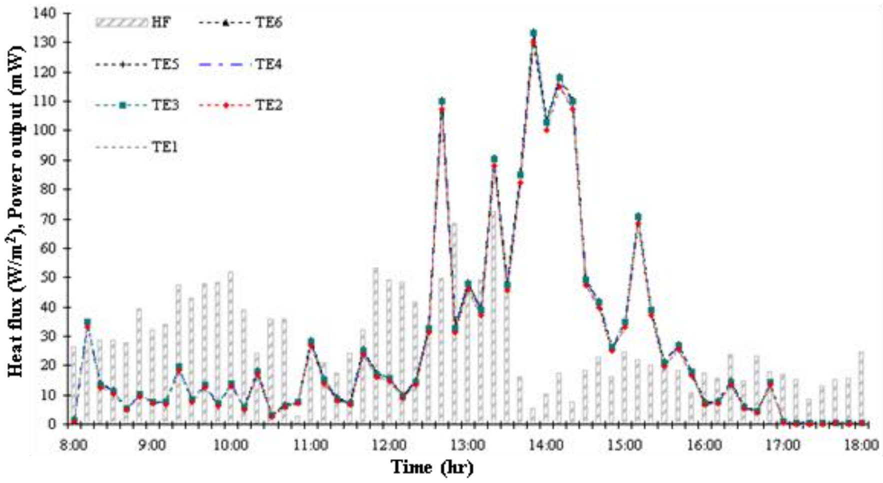

Figure 5 Heat flux through the glass and comparison with electrical output.

Electrical Output and Heat Flux Analysis

The variation of heat flux through the transparent glass window and the comparison of direct current (DC) electrical power generation from thermoelectric modules at different positions on the glass are presented in Fig. 4–5.

The results indicate that the electrical output generated by the thermoelectric modules installed at different locations on the glass window exhibited very similar values throughout the daytime. The generated voltage ranged from approximately 0.028 to 139 mV, with the maximum value observed at around 13:55. During this period, the heat flux through the glass showed a decreasing trend.

The heat flux through the transparent glass window ranged from approximately 0.2 to 78 W over the entire testing period. In addition, previous research by Pasinpong Soupparnsingh [11] reported that the heat flux (thermal transmittance) of transparent glass is approximately 33.33% lower than that of other types of glazing materials.

Furthermore, the temperature difference across the hot and cold sides of the thermoelectric modules remained relatively low, ranging from approximately 0.45 to 1.28°C. This limited temperature gradient is a key factor affecting the relatively low electrical output of the thermoelectric system.

Table 1 Summary of Comparative Experimental Results

Parameter	Range / Value	Observation
Ambient Temperature (Tamb)	29 – 45.5 °C	Increased continuously and peaked in the afternoon
Indoor Temperature	28.9 – 44.3 °C	Slightly higher than ambient (≈0.12–0.45 °C)
Solar Radiation (It)	0.2 – 745 W/m²	Maximum around midday (~11:55–13:00)
Heat Flux (HF)	0.2 – 78 W	Increased with solar radiation, then decreased after peak
TE Voltage Output	0.028 – 139 mV	Peak around ~13:55, similar across all positions
Temperature Difference (ΔT, TE)	0.45 – 1.28 °C	Relatively low, limiting power generation
Indoor Air Velocity	0.011 – 0.22 m/s	Low air circulation inside the model
Outdoor Wind Speed	1.41 – 2.4 m/s	Moderate external airflow
Illuminance	200 – 3000 lux	Increased with solar radiation intensity

Discussion and conclusions

This study presents an experimental investigation of electricity generation using thermoelectric (TE) modules based on the temperature difference between indoor and outdoor environments over a daily cycle. The experiment was conducted using a small-scale house model with a volume of approximately 4.05 m^3, located in Bangkok, Thailand.

A transparent glass window with dimensions of 72 × 42 cm^2 and a thickness of approximately 0.5 cm was installed on the south-facing wall of the test house. Six thermoelectric modules (model MT2-1, 6-127), each measuring 40 × 40 mm, were mounted on the inner surface of the glass and tested under normal ambient conditions.

The results demonstrate that heat accumulated on the inner surface of the glass can be utilized to generate direct current (DC) electricity using thermoelectric technology. Although the temperature difference across the thermoelectric modules was relatively small, the system was able to produce measurable electrical output, confirming the feasibility of the proposed concept.

The performance of the thermoelectric modules was strongly influenced by the temperature difference across the glass surface. Although solar radiation and heat flux increased significantly during midday, the temperature difference (ΔT) across the thermoelectric modules remained relatively low (0.45–1.28°C), which limited the electrical output.

The results also indicate that the electrical output from different module positions was similar, suggesting that heat distribution across the glass surface was relatively uniform. This confirms that the primary limitation of the system is the insufficient thermal gradient rather than module placement.

Suggestion

Based on the findings of this study, future research should focus on the integration of thermoelectric systems with hybrid energy systems. In particular, combining thermoelectric modules with other renewable energy technologies, such as photovoltaic (PV) systems, has the potential to enhance overall energy efficiency and maximize energy harvesting from solar radiation.

Acknowledgements

The authors would like to express their sincere gratitude to Global Seal Co., Ltd. for their support in this research. The authors also appreciate the valuable technical assistance, resources, and facilities provided, which contributed significantly to the successful completion of this study.

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