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Experimental Investigation on Thermoelectric Power Generation Using Diurnal Temperature Difference Through Glazed Windows

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ABSTRACT

Harvesting ambient temperature is attractive for different purposes. In this paper, a pioneer study on thermoelectric power generation using natural diurnal temperature difference between ambient and indoor space through glazed windows (TEGW) is investigated experimentally. To this end, a small south facing window with 5 mm green tinted glass, 0.45 m wide and 1.05 m high located in a room of 25.74 m³ volume located at the first floor of a residential house in Nonthaburi province (Thailand) was used. Three thermoelectric (TE) modules (MT2-1, 6-127) 40×40 mm were installed at the inner side of the glass window at three positions near the top, middle and bottom. Tests were conducted with close and open curtain and air and non-air-conditioned spaces. Measured data demonstrated that the proposed concept is feasible as an electrical current could be generated: The hotter the day, the higher is the temperature difference between the hot and cold sides of TE modules and the higher the amount of current generated. When air conditioning is used, the temperature difference between the sides of TE modules increased and higher electrical voltage is generated varying between 0.5-1.9 mV compared to 0.1-0.6 mV without air conditioning. Closing curtain did affect the generated electrical voltage significantly as it reduced the cooling of the inner side of TE modules due to reduced air circulation especially at the middle and top of window. Due to its simplicity, the proposed concept offers new perspectives for thermoelectric power generation development and its application in residences and buildings.

1. INTRODUCTION

In the old times, people used to spend a significant part of their time outdoors for various activities. Today, this trend has been drastically changing worldwide due to social, technological, and cultural developments. For instance, Americans and Europeans spend about 90% of their time indoors and almost an additional 5% inside vehicles [1]. In Thailand houses and residences are now built using the concept of modernity which is influenced by foreign cultures. Glazed windows and walls are widely used, as they look nice, offer beautiful views and are modern. Due to its location within the equatorial belt, Thailand weather is classified as hot and humid [2]. The average daily intensity of solar radiation is 17.5 MJ/(m² day) and the averages daily temperature and relative humidity vary between 30-35℃ and 50%-80% respectively [3]. Consequently, a significant amount of heat from incident solar radiation is transmitted through glazed windows and walls leading to heat accumulation and discomfort. To improve indoor conditions, mechanical ventilation systems and air conditioning are widely used resulting in a high amount of electric energy consumption. The use of the heat transmitted through glazing and construction materials received considerable attention by researchers, professionals, architects, and engineers. A huge amount of published works is available in different journals conferences proceedings. Let just cite the study reported in the study of Chantawong et al. [4] where an attempt to harvest the heat transmitted through glazed windows to induce ventilation using the solar chimney concept was reported.

On the other hand, increasing demand on energy worldwide reveals a need to find new energy resources and different ways and alternatives for power generation. The recent decades see extensive development of thermoelectric devices to recover waste [5, 6]. Niu et al. [7] tested a TE device for low temperature waste heat power recovery. Ismail and Ahmed [8] patented TE power generation using waste heat energy. Sateikis et al. [9] carried out an energy evaluation of the thermoelectric generator (TEG) operating at a low temperature difference.

In the recent years, harvesting ambient energy gained interest worldwide. Recent research's focused on the development of advanced and sophisticated materials such as micro-thermoelectric generator through glass pillars developed by Liu et al. [10], transparent power-generating windows based on solar-thermal-electric conversion by combining solar-thermal-electric conversion with a material's wavelength-selective absorption reported by Zhang et al. [11]. Enhancement of solar thermoelectric power generation by optical and thermal management with highly transparent aerogel window was proposed by Kim et al. [12].

The objective of this paper is to conduct a pioneer experimental study to investigate a simple concept to harvest natural diurnal temperature difference between ambient and indoor space to generate electricity using commercial TE modules through glazed windows of residences located in hot countries.

2. EXPERIMENTAL METHODOLOGY

Figure 1 shows a schematic of the experimental house (top), a south facing glazed window with three thermoelectric (TE) modules (MT2-1, 6-127) 40×40 mm installed at the inner side of the glass window near the top, middle and bottom using thermal grease for improved contact between the TE modules and glass and adhesive tape. This concept is referred to as (TEGW) and shown in the Figure 1, middle.

A 0.7×1.60 m commercial synthetic cream-yellow coloured curtain (Figure 1, bottom) was installed in front of the window.

Table 1. Thermal and physical properties of glazing [13]

Thickness (mm)	5
Solar Energy Reflectance (out)	0.06
Solar Energy Transmittance	0.48
Solar Energy Absorptance	0.47
U Value (W/m².K)	5.8
K Value (W/m.K)	0.029

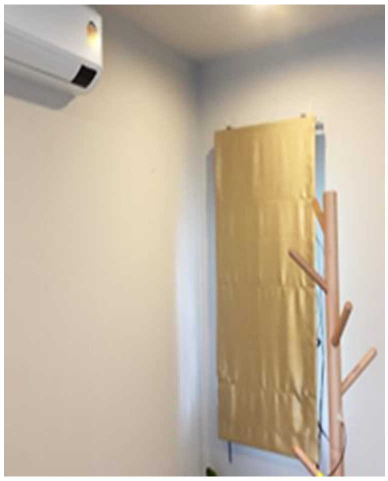
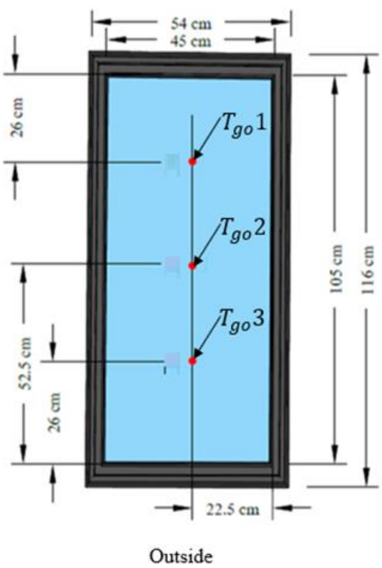


Figure 1. Schematic of the experimental house (top), TEGW (middle) and curtain (bottom)

The TEGW 0.45m wide and 1.05m high with 5mm green tinted glass assembled in a black aluminium frame is situated in a room of 25.74 m³ volume (3 m×3.3 m×2.6 m) at the first floor of a residential house in Nonthaburi province (Thailand). In the daytime and since the sunrise, ambient temperature will increase gradually. Consequently, the exterior surface of glass gets heated. This heat accumulated on the outer surface gradually transfer inward to the inner surface through the glass thickness. This causes heat convection and radiation between the inner surface, air and walls and floor inside the room. Also, as temperature difference exists between the TE hot side (in contact with glass) and cold side (room air), TE modules will generate electrical current.

The room was equipped with a split-type air conditioning 12,000 BTU/h. The fan coil was installed at the centre of eastern wall at 2.2 m elevation near the window (Figure 1 top). The temperature of the air-conditioning was setup at 25°C with automatic mode. Table 1 give the specifications of glass of the window. For the thermoelectric modules specification, refer to data published in the study of Thanthong et al. [14].

To assess the performance of TEGW, several parameters were measured including temperature, air velocity, heat flux transmitted, indoor illuminance as schematically shown in Figure 2.



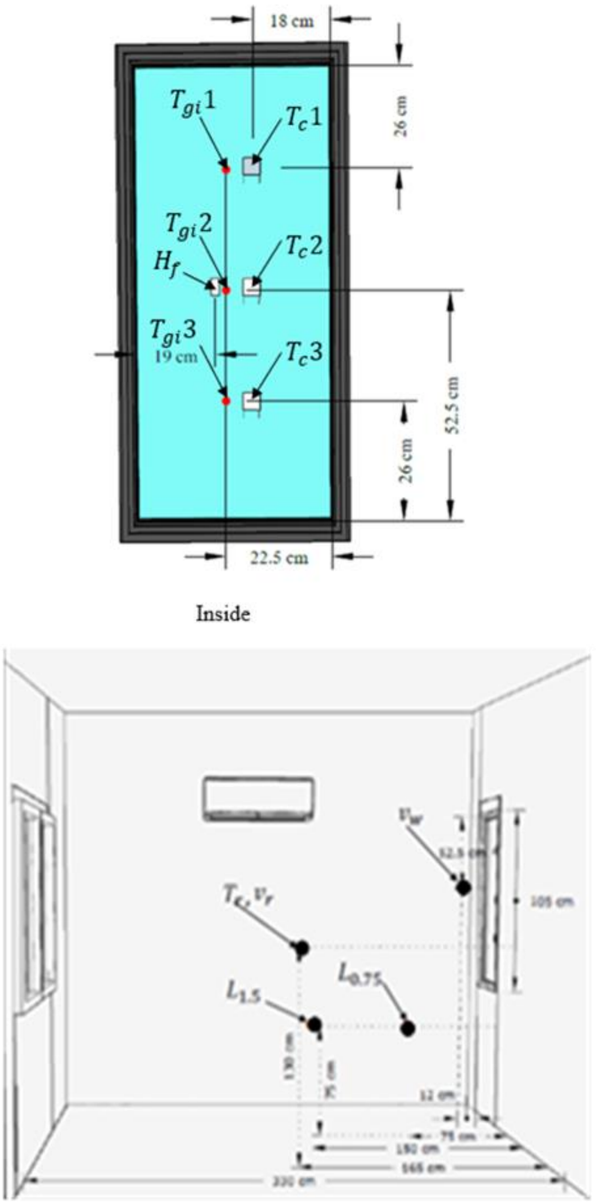


Figure 2. Positions of measurement at the TEGW outside (top), inside (middle) and room (bottom)

Temperatures were measured using type T thermocouples (range: -200°C to +350°C, accuracy ± 0.5°C). Voltage of current generated was measured using electric wire type 20AWG UL1007 (80°C, 300V). The thermocouples and electric wire were connected to a datalogger "HIOKI" model LR8400-20 (±0.2s/day @23°C). Ambient and room air velocity are measured using "TESTO" model 452 [range 0 to 20m/s ± (0.03m/s + 5% of mV.)]. Lux meter was measured UNI-T model UT383 (range 0 to 9999 Lux ± 4%) and heat flux through glass pane was measured using "EKO" Heat Flow Meter model MF-180 (range -30 to 120°C). Incident solar radiation was measured using "EKO" Pyranometer ML-020VM. Tests were conducted on several days with open and close curtain. Data were recorded continuously from 8.00 a.m. to 5 p.m. and averaged every 10 minutes.

3. RESULTS AND DISCUSSION

Even though tests were conducted during various days with different ambient conditions, subjective analysis can be made with respect to our objective.

3.1 Temperatures

Figure 3 shows the hourly variations of the solar radiation (**I$_t$**), ambient temperature (**T$_a$**), and outdoor glass surface temperature (**T$_{go}$**) at the top (**T$_{go}$1**), middle (**T$_{go}$2**) and bottom (**T$_{go}$3**) whereas Figure 4 shows those of the heat flux (**H$_f$**), indoor glass surface temperature (**T$_{gi}$**), at the top (**T$_{gi}$1**), middle (**T$_{gi}$2**) and bottom (**T$_{gi}$3**) and indoor temperature (**T$_r$**) with close and open curtain for non-conditioned room.

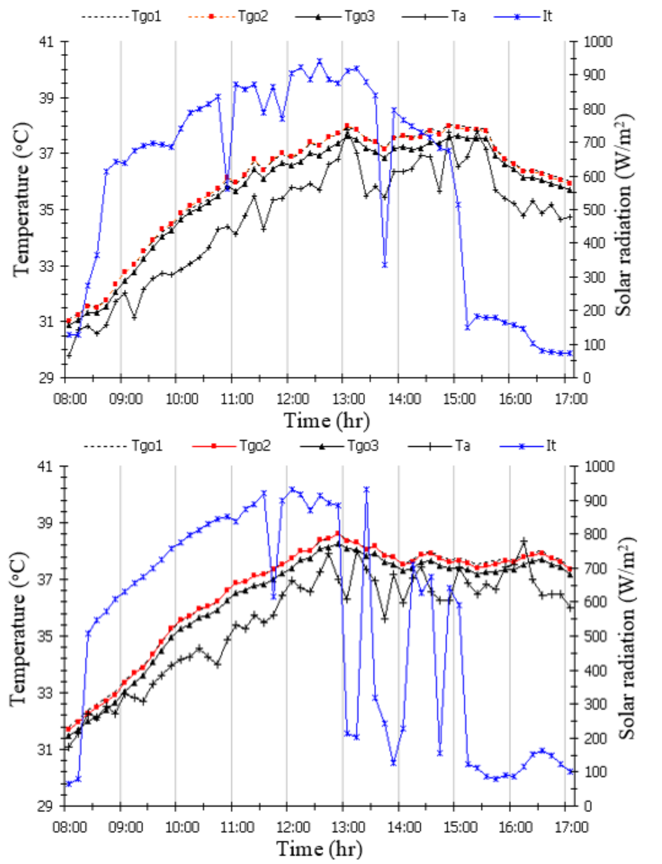


Figure 3. Hourly variation of outdoor glass surface temperatures (**T$_{go}$**), ambient temperature (**T$_a$**) and solar radiation (**I$_t$**), (top: close curtain: 21/05/2021, bottom: open curtain: 03/06/2021)

The different parameters measured followed well the variations of ambient conditions. The higher the intensity of incident radiation, the hotter is the day and the higher are the measured temperatures and heat fluxes. Under test conditions, the maximum ambient temperature and room temperature were about 37-38°C (Figure 3) and 34-35°C (Figure 4) respectively. The glass temperatures at the top and middle psoitions were close and lowest temperature is observed near the bottom. The calcuated duirnal temperature difference through glazing varied between 0.1°C to 0.7°C. Closing or opening curtain did not affect outdoor and indoor glass surface temperatures significantly as no noticeable difference between the plotted profiles at the measured positions is observed.

3.2 Electrical current

Figure 5 shows the hourly variations of the electrical voltage generated by the three TE modules at the top (**Ete1**), middle (**Ete2**), and bottom (**Ete3**) with close and open curtain for non-air-conditioned space.

As expected, the generated voltage varied following the fluctuations of the ambient conditions: The hotter the day, the higher the ambient temperature and the higher is the temperature difference between the hot and cold sides of TE modules leading to higher amount of electrical voltage generated.

Under the test conditions, with open curtain (Figure 5, top), the top TE module generates a maximum voltage of about 0.6 mV whereas with close curtain (Figure 5, bottom), it generates the lowest. This is obviously due to the reduced temperature difference between the two sides of TE modules caused by the curtain that limited ventilation between the inner side of TE modules especially at the top. The lowest TE module generates similar amount of that located at the middle with open curtain but higher than that at the top due to reasons explained above.

Figure 6 shows the hourly variations of the electrical voltage generated by the three TE modules at the top (**Ete1**), middle (**Ete2**), and bottom (**Ete3**) with close and open curtain with air-conditioned space.

When air conditioning is used, the duirnal temperature difference through glazing increased significantly and varied between 1 to 4°C. This leads to create higher temperature difference between the hot and cold sides of TE modules.

Consequently, the TEGW generates a higher electrical voltage varying between 0.5-1.9 mV compared to 0.1-0.6 mV without air conditioning. With open curtain (Figure 6, top), the top TE module generates the highest voltage due to the well-established temperature stratification and its position close to the air conditioning whereas that at the bottom generates less. Closing curtain did affect the generated electrical voltage noticeably as it reduced the cooling of the inner side of TE modules due to reduced air circulation especially at the middle and top of window as discussed earlier in the case without air-conditioning.

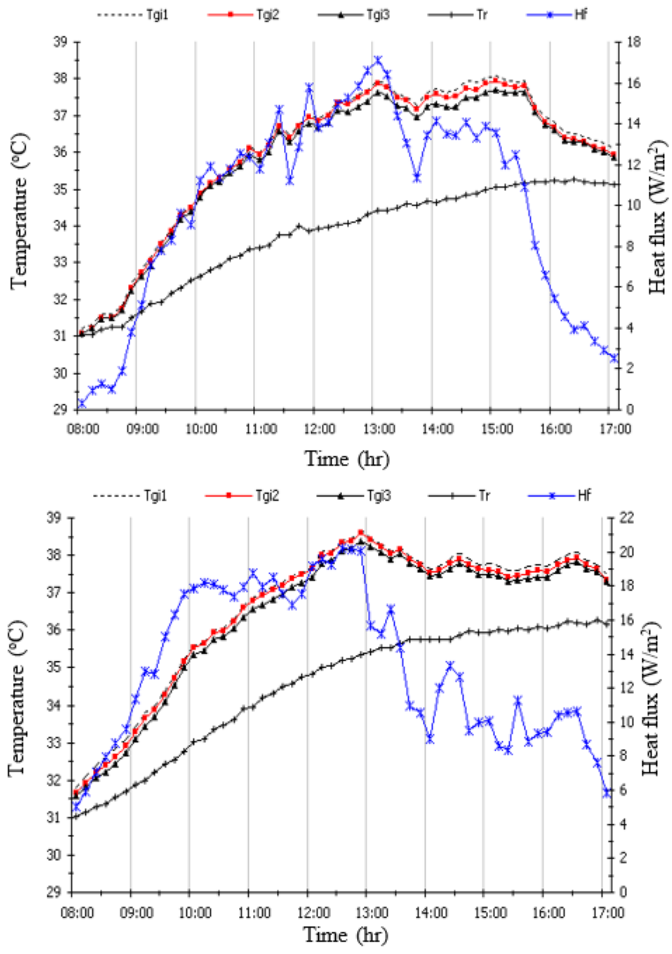


Figure 4. Hourly variation of indoor glass surfaces (**T_{gi}**), heat flux (**H_f**) and indoor temperature (**T_r**) (top: close curtain: 21/05/2021, bottom: open curtain: 03/06/2021)

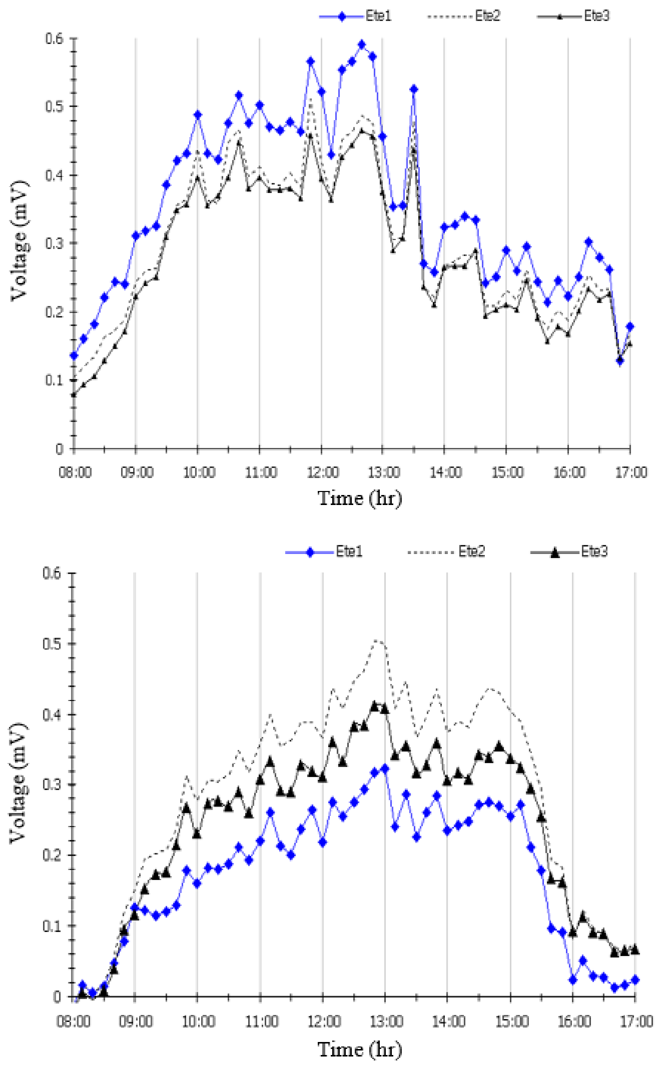


Figure 5. Hourly variations of electrical voltage of current generated (**Ete**) by the three TE modules (top: open curtain: 03/06/2021, bottom: close curtain: 21/05/2021)

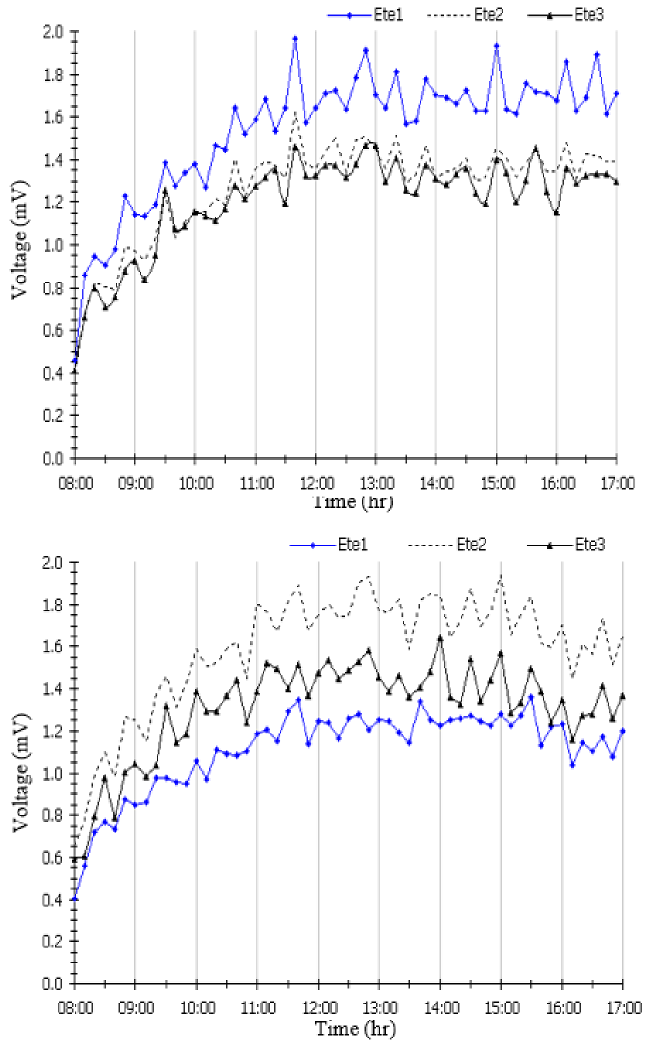


Figure 6. Hourly variations of voltage generated (**Ete**) by the three TE modules for air-conditioned room (top: open, the TEGW curtain:19/05/2021, bottom: close curtain close curtain: 02/06/2021)

4. CONCLUSION

Experimental investigation conducted using a small window located in a residential house in Thailand demonstrated that the proposed simple concept of thermoelectric power generation using diurnal temperature difference between ambient and indoor through glazed windows (TEGW) is feasible as an electrical current could be generated.

Three thermoelectric (TE) modules (MT2-1, 6-127) 40×40 mm were installed at three positions near the top, middle and bottom at the inner side of the glass window. The generated current followed well the ambient conditions: The higher the incident solar radiation, the higher is the temperature difference between the hot and cold sides of TE modules and the higher the amount of voltage generated. The use of air conditioning increased the TEGW performance considerably and higher electrical voltage is generated varying between 0.5-1.9 mV compared to 0.1-0.6 mV without air conditioning. With open curtain, the top TE module generates the highest voltage whereas that at the bottom generates less. Closing curtain did affect the generated electrical voltage noticeably as it reduced the cooling of the inner side of TE modules due to reduced air circulation especially at the middle and top of window.

Due to its simplicity, the proposed concept deserves further investigations such increasing the number of modules connected in series and parallel prior application in residences and buildings. Finally, this concept can be applied for cold countries to harvest warm indoor temperature and cold ambient temperature.

REFERENCES

[1] Eicker, U. (2009). Low Energy Cooling for Sustainable Buildings, John Wiley & Sons, NY, 276.

[2] Khedari, J., Sangprajak, A., Hirunlabh, J. (2001). Thailand climatic zones. Journal of Renewable Energy, 25(2): 267-280. https://doi.org/10.1016/S0960-1481(01)00005-2

[3] Namprakai, P., Thepa. S., Hirunlabh, J. (1989). Statistical estimation of solar for Bangkok Thailand. King Mongkut's University of Technology Thonburi Magazine, 12(2): 42-61.

[4] Chantawong, P., Hirunlabh, J., Zeghmati, B., Khedari, J., Teekasap, S., Win, M.M. (2006). Investigation on thermal performance of glazed solar chimney walls. Solar Energy, 80(3): 288-297. https://doi.org/10.1016/j.solener.2005.02.015

[5] Ong, K.S., Jiang, L., Lai, K.C. (2018). 4.20 thermoelectric energy conversion. Comprehensive Energy Systems, 4: 794-815. https://doi.org/10.1016/B978-0-12-809597-3.00433-8

[6] Rowe, D.M. (2006). Review, Thermoelectric waste heat recovery as a renewable energy source. International. International Journal of Electrical Power & Energy Systems, 1: 13-23.

[7] Niu, Z., Yu, J., Wang, S. (2009). Experimental study on low temperature waste heat thermoelectric generator. Journal of Power Sources, 188(2): 621-626. https://doi.org/10.1016/j.jpowsour.2008.12.067

[8] Ismail, B.I., Ahmed, W.H. (2009). Thermoelectric power generation using waste heat energy as an alternative green technology. Recent Patents on Electrical Engineering, 2(1): 27-39. https://doi.org/10.2174/1874476110902010027

[9] Sateikis, I., Ambrulevicius, R., Lynikiene, S. (2010). Investigation of a micro power thermoelectric generator operating at a low temperature difference. Elektronika ir Elektrotechnika, 10: 11-16. https://eejournal.ktu.lt/index.php/elt/article/view/9137.

[10] Liu, S., Hu, B., Liu, D., Li, F., Li, J.F., Li, B., Li, L., Lin, Y.H., Nan, C.W. (2018). Micro-thermoelectric generators based on through glass pillars with high output voltage enabled by large temperature difference. Applied Energy, 225(1): 600-610. https://doi.org/10.1016/j.apenergy.2018.05.056

[11] Zhang, Q., Huang, A., Ai, X., Liao, J., Song, Q., Reith, H., Cao, X., Fan, Y. (2021). Transparent power-generating windows based on solar-thermal-electric conversion. Advanced Energy Materials, 11(30): 2101213(1-9). https://doi.org/10.1002/aenm.202101213

[12] Kim, C., Kim, K. (2021). Enhancement of solar thermoelectric power generation by optical and thermal management with highly transparent aerogel window. Solar Energy Materials and Solar Cells, 230(15): 111224.

https://doi.org/10.1016/j.solmat.2021.111224
[13] Rezaei, D.S., Shannigrahi, S., Ramakrishna. S. (2017). A review of conventional, advanced, and smart glazing technologies and materials for improving indoor environment. Solar Energy Materials & Solar Cells, 159: 26-51. https://doi.org/10.1016/j.solmat.2016.08.026
[14] Thanthong, P., Chantawong, P., Khedari, J. (2022). Radiation-based thermoelectric power generation with finned heat absorber. International Journal of Renewable Energy Research, 12(1): 231-238. https://doi.org/10.20508/ijrer.v12i1.12409.g8441