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Experimental Study of the Effect of Window Glazing on Thermoelectric Power Generation

Saranya Sripisuttitham[1], Preeda Chantawong[1*], Tika Bunnag[2]

[1] Energy Engineering Technology Program, Department of Power Engineering Technology, College of Industrial Technology, King Mongkut's University of Technology North Bangkok, Bangkok 10800, Thailand
[2] Research and Innovation Development, Nine Infinite Group 1998 Co., LTD, Bangkok 10210, Thailand

Corresponding Author Email: cpreeda@yahoo.com

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ABSTRACT

The last decades saw extensive development of thermoelectric power generation (TEG) using building envelopes. A new concept of using natural diurnal temperature difference between ambient and indoor space through glazed windows (TEGW) was recently proposed. This paper reports an experimental study of the effect of type of glazing on TEGW performance. At the end, two small houses 120 cm × 120 cm × 135 cm were built using commercial materials. A 50 cm × 100 cm glass pane 0.06 cm thick was installed on each of the south facing walls. Two series of tests were conducted using different kinds of glazing. In the first, clear glass and clear low-emissivity glass "low-e glass" were tested and compared whereas in the second, clear dark and dark laminated glasses were used. In each test series, one Thermoelectric (TE) module (MT2-1, 6-127) 40 × 40 mm was installed at the middle inner side of the glass pane. Results showed that the generated power varied according to the ambient conditions and was dependent closely on the type of glass used: In the clear series tests, low-e clear glass leads to higher temperature difference between the hot and cold sides observed compared to the clear glass and higher amount of power is generated. The TE module on the low-e clear glass generates a maximum power of about 46 mW around 15:00 whereas that installed on the clear glass is about 29 mW. Whereas in the dark series, the TE module installed on the laminated dark glass pane performed better than that on the clear dark glass as less incident heat from the solar radiation was transmitted; a maximum of 19 mW was obtained compared to 9 mW, respectively. Therefore, for the practical application of TEGW, low-e clear glass gives the highest performance. The laminated dark glass gives good reasonable performance at relatively lower cost. The selection can be made upon designers' objectives and owners' expectation.

1. INTRODUCTION

When solar radiation strikes window glass panes, various types of energy interactions take place across the window. Figure 1 shows a schematic representation of heat transfer through the glazing (left) and thermoelectric power generator (right). Incident solar radiation over the external surface, are partially reflected, transmitted, and absorbed by the glass sheet. The portion absorbed increases the internal energy of the glass, and hence, its temperature also increases. Additionally, the glass window loses or gains heat from the internal and external ambient by conduction, convection, and longwave radiation. The heat accumulated on the outer surface gradually moves inward to the inner surface by heat transfer through the glass thickness (left). This causes heat convection and radiation from the inner wall into air and materials inside the room. These heat transfer mechanisms depend highly on the type of glazing used.

Today, new residences and buildings are often designed with extensive use of glazing as they look modern, offer visual comfort, panoramic views and are relatively easy to install and replace using new techniques. Industries offer a variety of types, colors, and forms. Innovative and advanced architecture glazing technologies can optimize natural daylight admission, decrease artificial lighting and energy usage [1, 2]. A review of conventional, advanced, and smart glazing technologies and materials for improving indoor environment was reported by Rezaei et al. [3]. Obviously, depending on prevailing ambient conditions, a wide range of glazing is available. For instance, electrically heated windows were investigated for Korean climate [4]. Heat insulation solar glass was studied by Young et al. [5] with application to energy efficiency buildings. Improving building efficiency using low-e coating based retrofit double glazing with solar films was reported by Somasundaram et al. [6]. A review on glazing systems integrating inter-pane shading devices was published [7]. A configuration of glazed solar chimney window configuration for heat gain reduction was investigated by Chantawong et al. [8].

In recent decades and due to industrial advances in manufacturing thermoelectric modules, which can convert heat into electricity, thermoelectric power generation (TEG) has received consideration worldwide [9]. TEG working using a low-temperature difference between the hot and cold sides is attractive for plenty of applications. Today, large amounts of TE commercial modules are available in the market. TE applications were developed rapidly because they can use different kinds of heat, waste heat, are easy to install and require less maintenance. Today, there are many TEG applications integrated into building envelope. A short review on thermoelectric glazing for sustainable built environment was published [10]. Enhancement of solar thermoelectric power generation by optical and thermal management with highly transparent aerogel window was investigated [11]. Semi-transparent solar thermoelectric nanogenerator for energy efficient glazing was developed [12]. Cogeneration solar system using thermoelectric module and Fresnel lens was considered by Hasan et al. [13] and an experimental study and modelling on solar system using linear Fresnel lens and thermoelectric module was conducted [14]. An interesting concept on the design, fabrication, and testing of thermoelectric generators integrated on a residential window frame was reported by Indab et al. [15]. Thanthong et al. [16, 17] introduced a new concept for TEG by harvesting energy using radiative heat exchange. Developments in flexible thermoelectric devices have been accelerated and summarized by Yang et al. [18]. Sateikis et al. [19] investigated micro power thermoelectric generator operating at a low temperature difference.

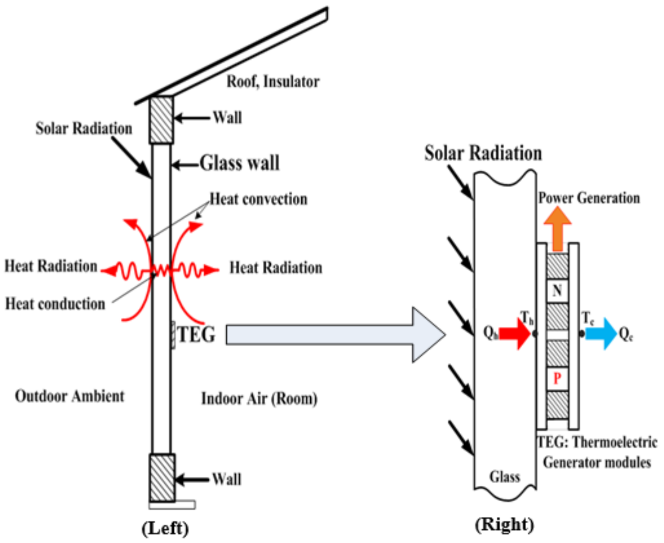


Figure 1. Schematic representation of heat transfer through glass window (left) and thermoelectric power generation (right)

Under Thailand hot and humid climate with an average daily intensity of solar radiation of 17.5 MJ/m^2 per day, and average temperature varying between 30-35°C [20], a significant temperature difference between window glazing and ambient is observed. Soupporsingh et al. [21] proposed a new concept of thermoelectric power generation using this natural diurnal temperature difference between ambient and indoor space through glazed windows (TEGW). The advantages of this concept are its simplicity as TE modules are fixed to the glazing directly to harvest heat from incident solar radiation instead of using window frame [15]. The objective of this paper is to conduct an experimental investigation to study the effect of type of window glazing on TEGW performance and power generation to give guidelines for applications in residences and buildings.

2. METHODOLOGY

Two small houses 120 cm × 120 cm × 135 cm were built using commercial materials available in the local market (Figure 2). The walls and ceiling are built with a 12 mm fiber-cement board. The roof is made from a corrugated metal sheet with 10 mm polyurethane insulation. A 50 cm × 100 cm glass pane 0.06 cm thick was installed on each of the south facing walls. Based on popular, available and affordable glass available on the market, four types of glazing were selected. For simplicity, we conducted two series of tests. In the first, clear transparent glass that allows clear visibility and clear low-emissivity material known as low-e (clear) or low-emissivity glass were tested and compared whereas in the second, a non-opaque material known as dark glass that allows light to pass through while retaining heat within it and laminated dark glass, which absorbs heat in the coated film and slow heat transfer into the room were used. In each window, one Thermoelectric (TE) module (MT2-1, 6-127) 40 × 40 mm (for TE module specification refer to data reported [16]) was installed at the middle inner side of the glass pane and well insulated on the four sides using commercial insulation material (Figure 2). The experimental houses were located at Krabang District, Bangkok 10520, Thailand.

Table 1 gives the thermal properties of materials used for constructing the experimental houses whereas Table 2 gives those of the different types of glazing selected in this study.

Table 1. Materials thermal properties [22-24]

Type of Material	Fiber-Cement Board	Metal Sheet	Thermal Insulation
Thermal conductivity (W/m.K)	0.297	43	0.029
Density (kg/m^3)	775	7800	120
Specific heat capacity (J/kg.K)	1.09	460	840
Emissivity	0.95	0.54	0.9

Table 2. Thermophysical properties of glazing [8, 25-27]

Property	Clear Glass	Low-e (Clear)	Clear Glass (Dark)	Laminated (Dark)
Thickness (mm)	6.0	6.0	6.0	6.38
Solar Energy Reflectance (out)	0.07	0.195	0.06	0.0968
Solar Energy Transmittance	0.80	0.705	0.41	0.3385
Solar Energy Absorptance	0.13	0.10	0.53	0.5647
Solar Energy Emissivity	0.89	0.20	0.86	0.87
U Value (W/m².K)	5.8	4.0	5.8	5.7
K Value (W/m.K)	0.0344	0.0342	0.815	0.0492

To assess the effect of window glazing, several parameters were measured including ambient conditions, heat flux transmitted through glazing, temperatures at different positions as schematically shown in Figure 2 (bottom), indoor illumination and TE power generated. Incident solar radiation was measured using “EKO” Pyranometer ML-020VM. Ambient, room, external, and internal glass temperatures, room and air grill were measured using type K (range: -200°C to +350°C, accuracy±0.5°C). Heat flux through glass pane was measured using “EKO”, heat flow meter model MF-180 (range -30–120°C). Lux meter was measured using UNI-T model UT383 (range 0-9999 Lux±4%). Voltage of current generated was measured using electric wire type 20 AWG UL1007 (80°C, 300 V) with a 1Ω matched load resistance and generated power was calculated using Ohm’s law. The thermocouples and electric wires were connected to a datalogger “HIOKI” model LR8400-20 (±0.2 s/day @23°C). Tests were conducted on several days. Data was recorded continuously from 7.00 a.m. to 7 p.m. and averaged every 10 minutes.

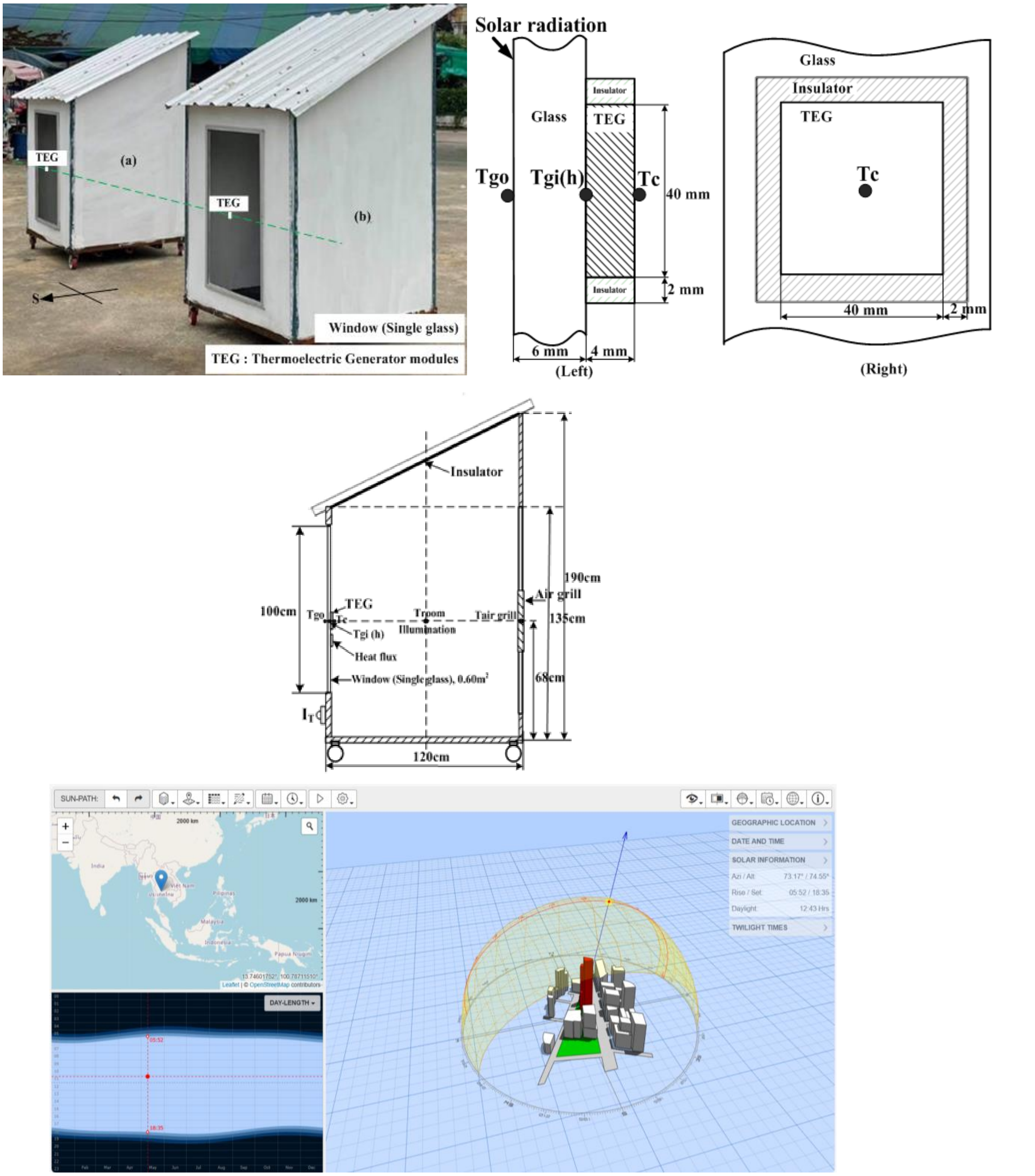


Figure 2. South-facing wall view of the experimental houses, TE module (top), houses dimensions and positions of measurement (middle) and geographical location and sun position at 10 a.m., July 1, 2023. (https://drajmarsh.bitbucket.io/PD: 3D Sun-Path (bottom)

3. RESULTS AND DISCUSSION

As mentioned above, tests were conducted using two small house models on different days with different ambient conditions. Subjective and comparative analysis are made by focusing analysis of various measured parameters for each series of tests. In this paper, results are reported for days with relatively high incident solar radiation.

3.1 Solar radiation, ambient temperature, heat flux

Figure 3 shows the hourly variations of measured heat flux through the different glazing of the two series of measurements compared to incident solar radiation and ambient temperature. Data indicated that solar radiation was relatively high and a maximum of 1150 W/m^2 and 980 W/m^2 were recorded for the clear and dark series, respectively. The corresponding maximum ambient temperatures were 38 and 34°C. In the afternoon, the ambient temperature decreased and increased due to clouds passage. The measured heat fluxes transmitted through glazing followed the incident solar radiation. The higher the intensity of incident radiation, the higher, the higher is the measured heat flux. In both series, the measured heat fluxes of each type of glazing varied similarly. Due to their thermophysical properties, low-e glass reflects a portion of infrared and ultraviolet radiation, whereas tinted dark glass reduces both light and heat. That's explains why clear glass and clear dark transmitted higher amount compared to the other types and noticeable differences are observed mainly in the afternoon.

3.2 Indoor illumination

Figure 4 shows the hourly variations of indoor illumination of the two houses for the two-test series. It could be observed that the indoor illumination inside the two houses is quite high and practically similar in each test series. Obviously, higher values are obtained when clear glass is used. Also, this clearly confirms that installing few thermoelectric modules on the glazing to generate electrical current as proposed by Souppornsingh et al. [21] would not impact the indoor illumination as high values are still obtained.

3.3 Temperatures

Figure 5 shows the hourly variations of temperature of the external glass (Tgo), internal glass (Tgi) considered equal to that of the hot-side temperature of the TE module (Tgi2=Th), ambient temperature (Tamb), cold-side temperature of the TE module (Tc), air grill temperature (Tair grill) and indoor temperature (Troom). The different measured temperatures varied following the ambient conditions and incident solar radiation. Due to the properties of low-e clear glass, higher external glass temperatures and lower room temperature are observed whereas the opposite is noted for the clear glass. Similarly, the same findings are observed with the laminated glass compared to the clear dark one (Figure 6). The heat flux transmitted through each type of glass used and the resulting temperature difference between the hot and cold sides of TE impact current generated by the TE module (to be discussed in the next section).

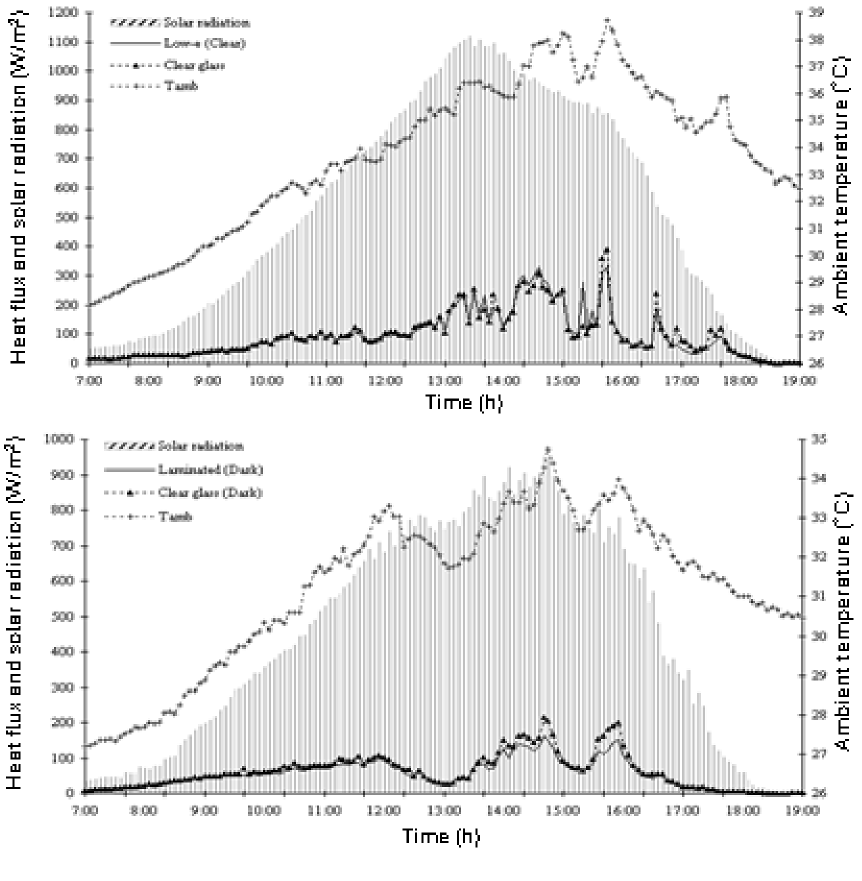
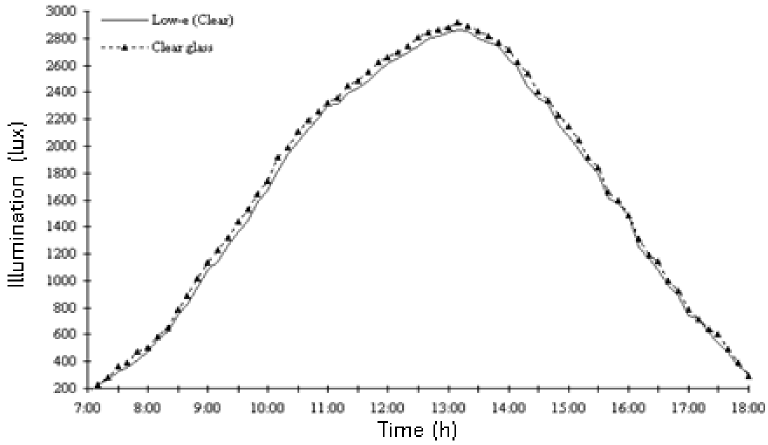


Figure 3. Hourly variations of measured heat flux through the different glazing compared to incident solar radiation and ambient temperature: (top) clear series, 1/07/2023, (bottom) dark series, 9/06/2023



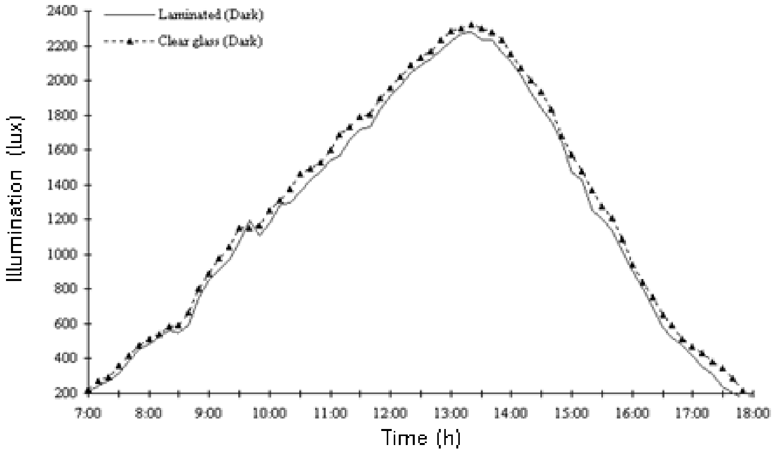
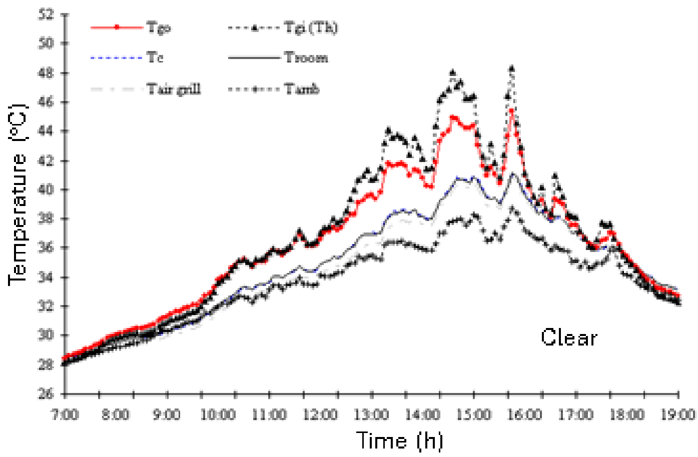


Figure 4. Hourly variations of indoor illumination of the two houses: (top) clear series, 1/07/2023, (bottom) dark series, 9/06/2023



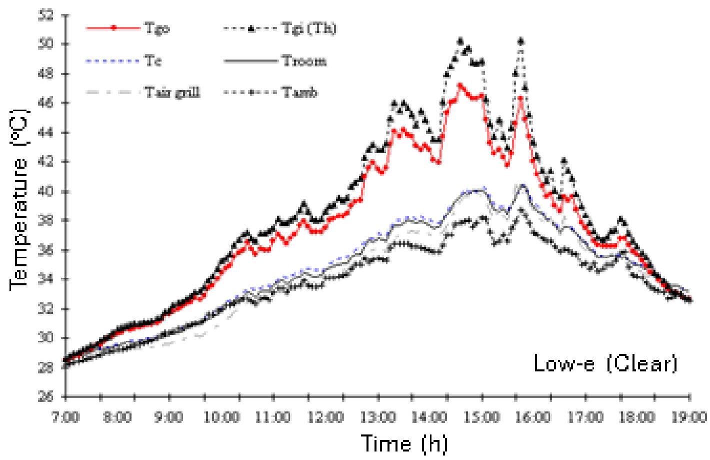


Figure 5. Hourly variation of different measured temperatures for the clear glass series: (1/07/2023): upper: Clear glass, lower: Low-e (Clear)

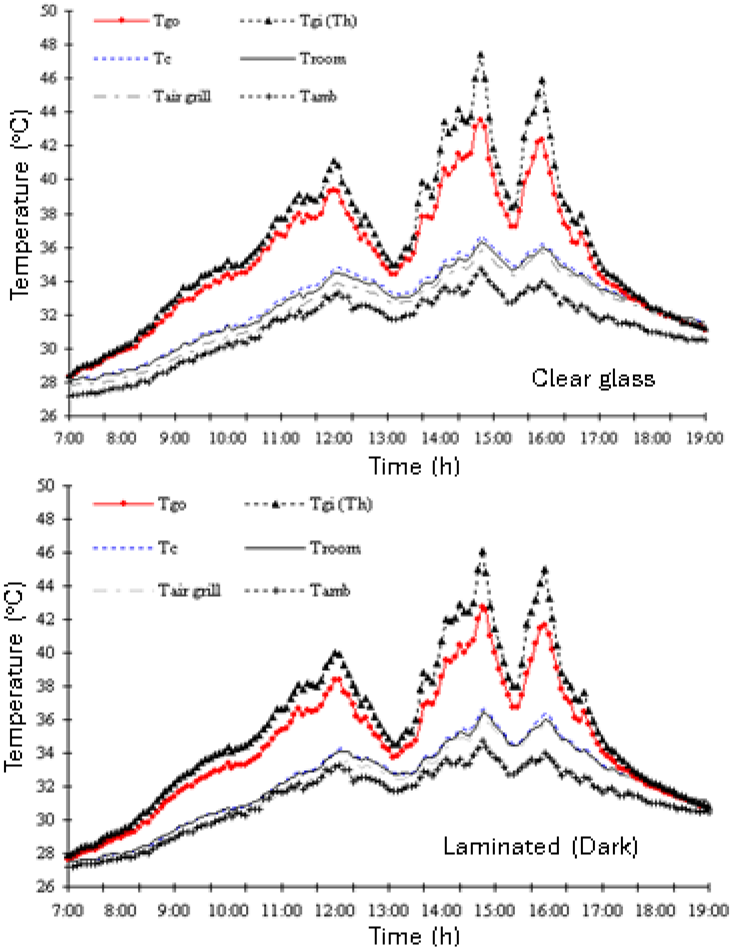


Figure 6. Hourly variation of different measured temperatures for the dark glass series: (9/06/2023): upper: Clear glass (Dark), lower: Laminated (Dark)

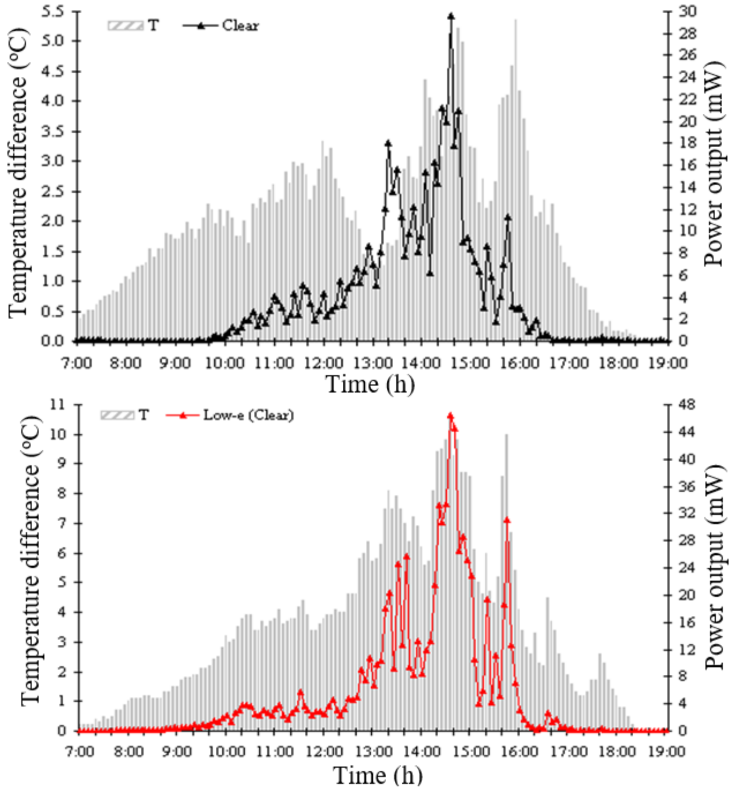


Figure 7. Comparison of power output and temperature difference between the hot and cold sides of TE module for the clear series test: (upper) clear glass, (lower): clear low-e (1/ 07/2023)

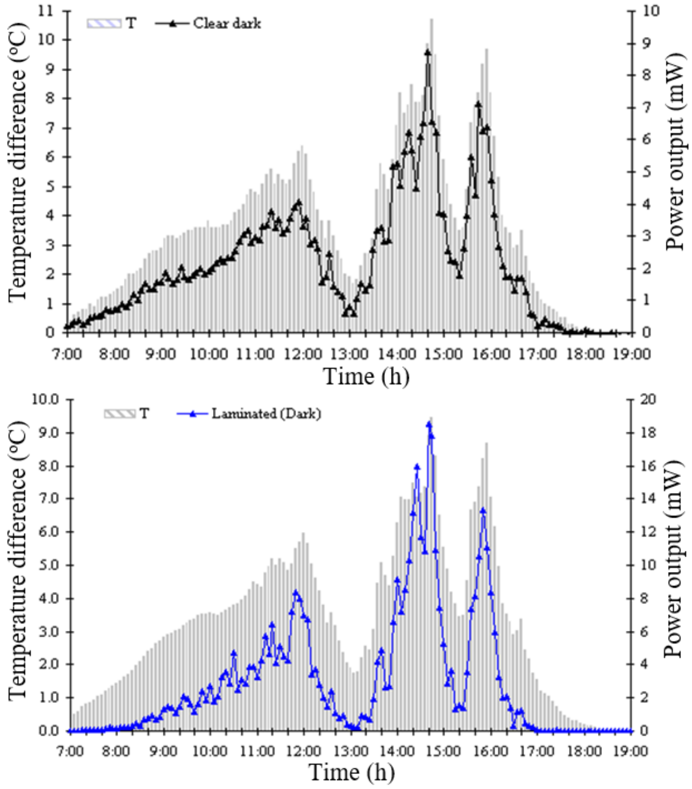


Figure 8. Comparison of power output and temperature difference between the hot and cold sides of TE module for the dark test series: (upper) clear dark, (lower): laminated dark (9/06/2023)

3.4 Generated electrical power

Figures 7-8 show the hourly variations of TE power generated compared to the temperature difference between the hot and cold sides (T) for the two-test series. Results showed that the generated power varied according to the ambient conditions and was dependent closely on the type of glass used: In the clear series tests, higher temperature difference between the hot and cold sides is observed compared to the clear glass and higher amount of power generated. The TE module on the low-e clear glass generates a maximum power of about 46 mW around 15:00, whereas that installed on the clear glass is about 29 mW. In the dark series test, the TE module installed on the laminated dark glass pane performed better than that on the clear dark glass as less incident heat from the solar radiation was transmitted (Figure 5 bottom); a maximum of 19 mW was obtained compared to 9 mW, respectively. These observations allow us to conclude that for practical application of TEGW, low-e clear glass will give the highest performance, however, its relatively expensive and wide use in the local sector is limited. The laminated dark glass gives good reasonable performance at relatively lower cost. The selection can be made upon designers' objectives and owners' expectation. To boost power generation, a combination of TE modules arrangements with parallel/series connections can be made depending on glazing surface and intendent purpose of application.

4. CONCLUSION

The type of window glazing affects thermoelectric power generation using diurnal temperature difference between ambient and indoor glazed windows (TEGW) considerably. Experimental investigation was conducted using two small houses 120 cm × 120 cm × 135 cm built from commercial materials available in the local market. A 50 cm × 100 cm glass pane 0.06 cm thick was installed on the south facing walls. Two test series were performed. In the first, clear transparent glass and clear low-emissivity glass were tested whereas in the second, clear dark glass and laminated dark glass were used. One Thermoelectric (TE) module (MT2-1, 6-127) 40 × 40 mm installed at the middle inner side of the glass pane and well insulated on the four sides.

Results showed that the generated power varied according to the ambient conditions and was dependent closely on the type of glass used: In the clear series tests, higher temperature difference between the hot and cold sides is observed compared to the clear glass and higher amount of power generated. The TE module on the low-e clear glass generates a maximum power of about 46 mW around 15:00 whereas that installed on the clear glass is about 29 mW. In the dark series test, the TE module installed on the laminated dark glass pane performed better than on the clear dark glass as less incident heat from the solar radiation was transmitted; a maximum of 19 mW was obtained compared to 9 mW respectively.

This first evaluation of TEGW using different types of glasng conducted under Thailand tropical climate without air conditioning is useful to draw guidance for practical integration of TEGW in building envelope. Low-e clear glass will give the highest performance, however, it's relatively expensive and may limit its wide use. The laminated dark glass gives reasonable performance at relatively lower cost. The selection can be made upon designers' objectives and owners' expectation.

REFERENCES

[1] Cucen, E., Riffat, S.B. (2015). A state-of-the-art review

on innovative glazing technologies. Renewable and Sustainable Energy Reviews, 41: 695-714. https://doi.org/10.1016/j.rser.2014.08.084

[2] Liu, X., Wu, Y.P. (2022). A review of advanced architectural glazing technologies for solar energy conversion and intelligent daylighting control. Architectural Intelligence, 1: 10. https://doi.org/10.1007/s44223-022-00009-6

[3] Rezaei, S.D., 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

[4] Lee, R., Kang, E., Lee, H., Yoon, J. (2022). Heat flux and thermal characteristics of electrically heated windows: A case study. Sustainability, 14(1): 481. https://doi.org/10.3390/su14010481

[5] Young, C.H., Chen, Y.L., Chen, P.C. (2014). Heat insulation solar glass and application on energy efficiency buildings. Energy and Buildings, 78: 66-78. http://doi.org/10.1016/j.enbuild.2014.04.012

[6] Somasundaram, S., Thangavelu, S.R., Chong, A. (2020). Improving building efficiency using low-e coating based retrofit double glazing with solar films. Applied Thermal Engineering, 171: 115064. https://doi.org/10.1016/j.applthermaleng.2020.115064

[7] Sharda, A., Kumar, S. (2014). Heat transfer through glazing systems with inter-pane shading devices: A review. Energy Technology & Policy, 1(1): 23-34. https://doi.org/10.1080/23317000.2014.969451

[8] 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

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

[10] Al-Fartoos, M.M.R., Roy, A., Mallick, T.K., Tahir, A.A. (2022). A short review on thermoelectric glazing for sustainable built environment. Energies, 15(24): 9589. https://doi.org/10.3390/en15249589

[11] 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: 111224. https://doi.org/10.1016/j.solmat.2021.111224

[12] Klochko, N.P., Klepikova, K.S., Kopach, V.R., Tyukhov, I.I., Starikova, V.V., Sofronov, D.S., Khrypunova, I.V., Zhadan, D.O., Petrushenko, S.I., Dukarov, S.V., Lyubov, V.M., Kirichenko, M.V., Khrypunova, A.L. (2019). Development of semi-transparent ZnO/FTO solar thermoelectric nanogenerator for energy efficient glazing. Solar Energy, 184: 230-239. https://doi.org/10.1016/j.solener.2019.04.002

[13] Hasan Nia, M., Abbas Nejad, A., Goudarzi, A.M., Valizadeh, M., Samadian, P. (2014). Cogeneration solar system using thermoelectric module and fresnel lens. Energy Conversion and Management, 84: 305-310. http://doi.org/10.1016/j.enconman.2014.04.041

[14] Koysal, Y., Ozdemir, A.E., Atalay, T. (2018). Experimental and modeling study on solar system using linear fresnel lens and thermoelectric module. Journal of Solar Energy Engineering, 140(6): 061003. https://doi.org/10.1115/1.4039777

[15] Indab, M.B.L., Ng, J.A.T., Reyeg, L.A.F.P., Tuppil, R.A.G., Umali, R., Manuel, M.C.E., Dela Cruz, J.C., Tud, R.C. (2021). Design, fabrication, and testing of thermoelectric generators integrated on a residential window frame. In 2021 IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS 2021), Shah Alam, Malaysia, pp. 197-202. https://doi.org/10.1109/I2CACIS52118.2021.9495851

[16] Thanthong, P., Chantawong, P., Khedari, J. (2022). Radiation-based thermoelectric power generation with finned heat absorber. International Journal of Renewable Energy Research, 12(1): 230-238. https://doi.org/10.20508/ijrer.v12i1.12409.g8401

[17] Thanthong, P., Chantawong, P., Khedari, J. (2024). Improved performance of a radiative-based thermoelectric power generator with vertical finned absorber: An experimental investigation. International Journal of Heat and Technology, 42(1): 353-357. https://doi.org/10.18280/ijht.420138

[18] Yang, S.Q., Qiu, P.F., Chen, L.D., Shi, X. (2021). Recent developments in flexible thermoelectric devices. Small Science, 1(7): 2100005. https://doi.org/10.1002/smsc.202100005

[19] Sateikis, I., Ambrulevicius, R., Lynikiene, S. (2010). Investigation of a micro power thermoelectric generator operating at a low temperature difference. Elektronika Ir Elektrotechnika, 106(10): 113-116.

[20] 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

[21] Souppornsingh, P., Chantawong, P., Khedari, J. (2024). Experimental investigation on thermoelectric power generation using diurnal temperature difference through glazed windows. International Journal of Heat and Technology, 42(2): 653-658. https://doi.org/10.18280/ijht.420232

[22] Energy conservation materials and equipment manual, 2017. Department of Alternative Energy Development and Energy Efficiency, Ministry of Energy, Thailand. https://2e-building.dede.go.th/.

[23] Cernea, B., Medved, S. (2007). Determination of transient two-dimensional heat transfer in ventilated lightweight low sloped roof using Fourier series. Building and Environment, 42(6): 2279-2288. https://doi.org/10.1016/j.buildenv.2006.04.022

[24] https://ennologic.com/wp-content/uploads/2018/07/Ultimate-Emissivity-Table.pdf, accessed on Nov. 11, 2022.

[25] Kiran Kumar, G., Saboor, S., Ashok Babu, T.P. (2017). Experimental and theoretical studies of window glazing materials of green energy building in Indian climatic zones. Energy Procedia, 109: 306-313. https://doi.org/10.1016/j.egypro.2017.03.072

[26] Construction materials manual, school of energy and materials. King Mongkut's University of Technology of Thonburi, 2001, p. 91.

[27] www.nationalglass.com.au/assets/main/Energy-Performance-Data-Jun23-V2-min.pdf, accessed on Oct. 15, 2024.