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Performance evaluation of vacuum photovoltaic insulated glass unit

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Abstract

Although semi-transparent photovoltaic windows can generate electricity in situ, they also increase the cooling load of buildings significantly due to the waste heat as a byproduct. However, vacuum glazing, which has excellent thermal insulation, can effectively solve the above issues for PV windows. In order to take advantage of excellent thermal insulation performance of vacuum glazing, a novel vacuum photovoltaic insulated glass unit (VPV IGU) was presented. The electrical characteristics of the PV laminated glass were tested in laboratory under standard test conditions. Then power generation and thermal performances of the VPV IGU were evaluated through experiments. Results have indicated that the VPV IGU can not only generate electricity, but also help reduce the cooling load as well as improve the indoor thermal comfort.

Keywords: Building integrated photovoltaic (BIPV); vacuum PV glazing; energy performance; Solar heat gain coefficient

1. Introduction

Building-integrated photovoltaic (BIPV) system is already an option for today's building elements with numerous successful examples due to its novel integral function of power generation from solar energy resource and decoration, simultaneously serving as building envelope material [1]. In modern high rise structures, semi-transparent photovoltaic (STPV) panels, or PV windows, which admit a specific amount of daylight into an indoor space, have been widely used as portions of the façade [2]. However, despite the fact that PV windows absorb majority of incident solar irradiation, only a small part of

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absorbed energy will be converted into electricity, with the remaining energy converted into heat [3]. The waste heat not only reduce the energy conversion efficiency of PV windows but also increase the heat gain of indoors. In addition, the structure of conventional single pane PV glazing also result in higher U value [4, 5].

The vacuum glazing, initially proposed by Zoller in 1913, could minimize conductive and convective heat transfer to a negligible value via a vacuum gap [6]. The best U-value of the vacuum glazing was reported to be 0.86 $W/m^2 \cdot K$, much lower than that of air/argon filled double glazed windows [7]. Therefore, in this study a novel vacuum PV insulated glass unit (VPV IGU) which combined vacuum and PV glazing technologies was developed. The VPV IGU is expected to not only generate electricity in situ, but also improved the thermal insulation performance of conventional PV glazing.

So far, few studies have investigated the energy performance of VPV IGU. The objectives of this paper are to introduce a novel vacuum PV insulated glass unit (VPV IGU) and evaluate its power and thermal performances through experiments. The results are expected to provide a reference for the development of PV glazing applications.

2. Structure of VPV IGU

The novel VPV IGU was made by sandwiching a layer of polyvinyl butyral (PVB) between an external PV laminated glass with 20% transmittance and an internal vacuum glass with Low-E coating deposited on the third surface (toward outside). The U-value of the vacuum glass is as low as 0.8 $W/m^2 \cdot K$. The structure of the VPV IGU is shown in Fig. 1. The dimension of the VPV IGU is 1300 mm (width) ×1100 mm (height) × 20.87 mm (thickness), thinner than commonly used PV double glazed insulating glass units [4].

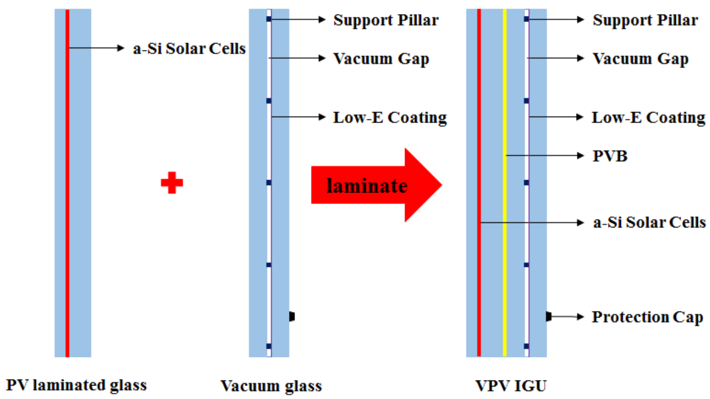

Fig. 1. Structure of VPV IGU

3. Experiment set-up

Before the outdoor testing, the electrical characteristics of the PV laminated glass were tested in laboratory under standard test conditions (STC, viz. air mass 1.5, solar irradiation 1000 W/m^2 and cell temperature 25 ˚C) using a triple A class solar simulator and results are listed in Table 1.

In order to evaluate the energy performance of the VPV IGU, an outdoor testing was conducted on the platform of Block Z in The Hong Kong Polytechnic University from June 2016. The VPV IGU was set up horizontally 0.4m above the floor on stilts so that the external temperatures of both side of the VPV IGU are approximately equal. Various parameters were measured during this test, including the ambient air temperature, the exterior and transmitted horizontal incident solar irradiation, the outer and inner surface temperature of VPV IGU as well as the I-V curve and the power generation from VPV IGU. All the data were logged at an interval of 1 minute. Power generation and thermal performances of the VPV IGU were analyzed based on the outdoor testing.

Table 1. Electrical characteristics of the VPV IGU under STC

Electrical characteristics	Value
Maximum power output (W)	74
Voltage at the maximum power point (V)	94
Current at the maximum power point (A)	0.78
Open circuit voltage (V)	120
Short circuit current (A)	0.98
Fill factor	0.62
Module efficiency	5.2%

4. Results and discussions

4.1. Power generation performance

The most prominent feature of VPV IGU is its ability to produce electricity. During the outdoor testing, the incident solar irradiation and power output were measured continuously. Fig. 2 presents the correlation between power generation from VPV IGU and incident solar radiation. It can be seen that the power generation from VPV IGU has a positive linear relation with incident solar radiation. Since the temperature coefficient of thin film solar cells is small, the photoelectric conversion efficiency of the VPV IGU will not decrease significantly with the increase of temperature.

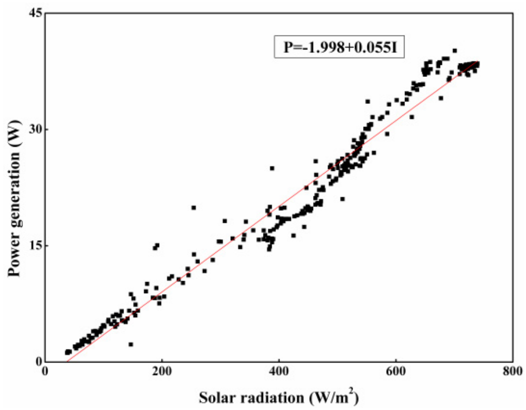

Fig. 2. Correlation between power generation from VPV IGU and incident solar radiation

4.2. Thermal performance

The solar irradiation received on the surface of VPV IGU is partly reflected by each glass surface, and partly absorbed by the glazing unit. The remainder transmitted through the glazing unit as solar heat gain directly. The absorbed solar irradiation is partly converted into electricity and partly transformed into waste heat which will indirectly contribute to the heat gain through the glazing unit.

Fig. 3 shows the exterior and transmitted incident solar irradiation. It can be seen that the average solar irradiation transmittance during the period is approximately 0.08. Such low transmittance means that vast majority of solar irradiation was blocked by the VPV IGU. Fig. 4 presents the outer and inner surface temperatures of the VPV IGU. It can be seen that the outer surface temperature was much higher than the inner surface temperature during the daytime. The maximum outer surface temperature was as high as 75.3 ˚C, 30 ˚C higher than the inner surface temperature. This indicates that most of the waste heat is dissipated from the outside surface of the VPV IGU and the heat transfers to the inside by convection will be mitigated. Thus, compared with conventional single-glazed PV glazing, the structure of VPV IGU can help reduce the cooling load and improve the indoor thermal comfort

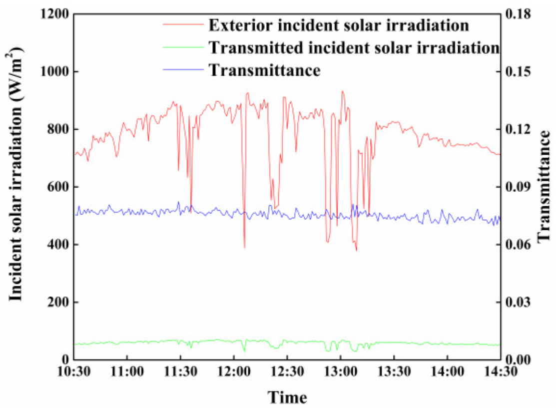

Fig. 3. Exterior and transmitted incident solar irradiation

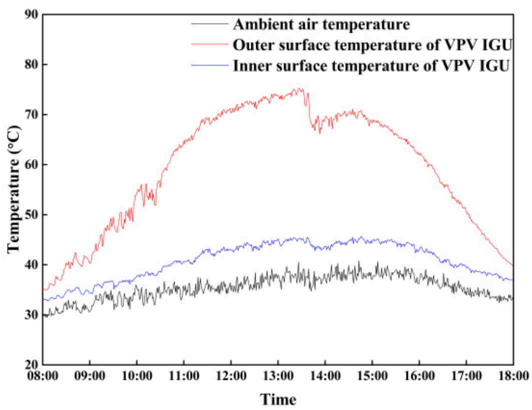

Fig. 4. Comparison of outer and inner surface temperatures of the VPV IGU

5. Conclusion

A novel VPV IGU has been introduced. Power generation and thermal performances of the VPV IGU have been studied via outdoor experiments. Due to the combination of PV laminate and vacuum glass, the VPV IGU can not only generate electricity, but also reduce air conditioning load as well as improve the indoor thermal comfort.

6. Copyright

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Biography

Dr. LU Lin is currently an Associate Professor in Department of Building Services Engineering at the Hong Kong Polytechnic University. Her research interests include renewable energy applications and technology development, green building nanomaterial development, fluid mechanics and heat/mass transfer related to building studies.