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CONFERENCE PAPER · LOW-CARBON BUILDINGS

Experimental study on the thermal and electrical performance of solar PV vacuum glazing skylights

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ABSTRACT

In Hong Kong, the building sector accounts for approximately 90% of total electricity consumption, driving over 60% of the city's carbon emissions. Within the building envelope, conventional skylights, constructed using single- or double-pane glass units, cause significant building energy consumption and induce indoor overheating. To address these challenges, this study proposes a solar photovoltaic vacuum glazing skylight (SPVGS) as a potential solution. The SPVGS enhances the thermal insulation performance by integrating a vacuum gap layer, while providing solar shading to mitigate excessive solar heat gains. Moreover, the integrated solar cells convert solar energy into clean electricity, thereby offsetting building energy demands. To comprehensively assess the overall energy performance of the SPVGS, an EnergyPlus model was developed to simulate its thermal performance, lighting energy use, and PV generation. The model was subsequently validated against outdoor test data to ensure simulation result reliability. Outdoor experimental results showed that the SPVGS outperformed vacuum glazing in both thermal insulation and energy performance. Specifically, it reduced indoor air temperature by 1.2 °C compared with a vacuum glass unit, while also reaching a maximum outer–inner surface temperature difference of 43.7 °C. Regarding PV generation, the peak power output reached 78.4 W/m2. Furthermore, using the validated model, a parametric study was conducted to optimize its energy performance by examining critical design variables. These variables include the PV coverage ratio, the skylight-to-roof area ratio, and the emittance of the low-emissivity coating. Overall, these insights provide practical guidance for PV skylight application and advance building decarbonisation.

KEYWORDS BIPV (building-integrated photovoltaic), Vacuum photovoltaics (PV) glass, Power generation, Energy saving

Nomenclature

Abbreviation	
BIPV	building-integrated photovoltaic
PV	photovoltaic
SPVGS	solar photovoltaic vacuum glazing skylight
VGS	vacuum glazing skylight
Low-E	low emittance
STPV	semi-transparent photovoltaic

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1. Introduction

In Hong Kong, buildings account for approximately 90% of total electricity consumption and 60% of associated carbon emissions. Consequently, reducing building energy consumption is both an urgent and essential measure for achieving Hong Kong's carbon neutrality target by 2050 (GovHK 2025).

Skylights are widely adopted in commercial buildings, including shopping malls, airport terminals, and railway stations, to enhance natural daylighting and aesthetic appeal. While skylights can reduce lighting energy demand by providing natural daylight, the transmitted solar irradiance leads to increased indoor heat gains, thereby elevating cooling loads (Pu *et al.* 2025). Moreover, high visible light transmittance (VLT) can cause visual discomfort. For instance, increasing the VLT from 0.4 to 0.8 raises the glare potential from 1.5%–7.2% to 2%–16.7% (El-Abd *et al.* 2018). To address this issue, an effective solution was provided by the semi-transparent photovoltaic (STPV) skylight.

Semi-transparent photovoltaic (STPV) skylights have emerged as an effective solution to these challenges. STPV skylights not only harvest solar energy to generate electricity for building operations but also provide inherent shading that reduces indoor heat gains. Compared with conventional skylights, STPV skylights achieve an energy-saving ratio exceeding 24% in Kunming and Xiamen, China (Fan *et al.* 2022). However, their relatively high thermal transmittance (U-value), ranging from 1.812–5.804 W/(m^2·K) (Fan *et al.* 2022), results in poor thermal insulation and significant heat losses through the skylight.

To overcome these limitations, this study proposes a cadmium telluride (CdTe)-based solar photovoltaic vacuum glazing skylight (SPVGS). The CdTe PV glazing is laminated onto vacuum glazing using a polyvinyl butyral (PVB) interlayer. The vacuum gap, maintained at a pressure below 0.1 Pa, suppresses gaseous heat transfer, while a low-emissivity (low-E) coating applied to the glazing surface minimizes radiative heat transfer (Zhou *et al.* 2024). To evaluate the energy-saving potential of the SPVGS, an outdoor experiment was conducted in Hong Kong to examine its thermal and energy performance. For comparison, a vacuum glazing skylight (VGS) was also tested to benchmark its thermal insulation performance against that of the SPVGS. Given Hong Kong's abundant solar resources and hot climate, this innovative skylight design has strong potential to reduce building energy consumption.

2. Experiment platform

To compare the thermal insulation performance of solar PV vacuum glazing skylight (SPVGS) with that of the vacuum glazing skylight (VGS) and to measure its PV power generation, an experimental test rig was constructed using wooden panels, as shown in Figure 1. The rig measured 1940 mm × 700 mm × 680 mm (length × width × height) and was equipped with a CdTe-based SPVGS (50% PV coverage ratio) and a VGS. Both skylights were identical in size, measuring 875 mm × 602 mm. To conduct the outdoor experiment, the test rig was placed on the sixth-floor outdoor platform of Building Z at The Hong Kong Polytechnic University. Testing was conducted on 7 June 2025, from 9:00 a.m. to 7:00 p.m.

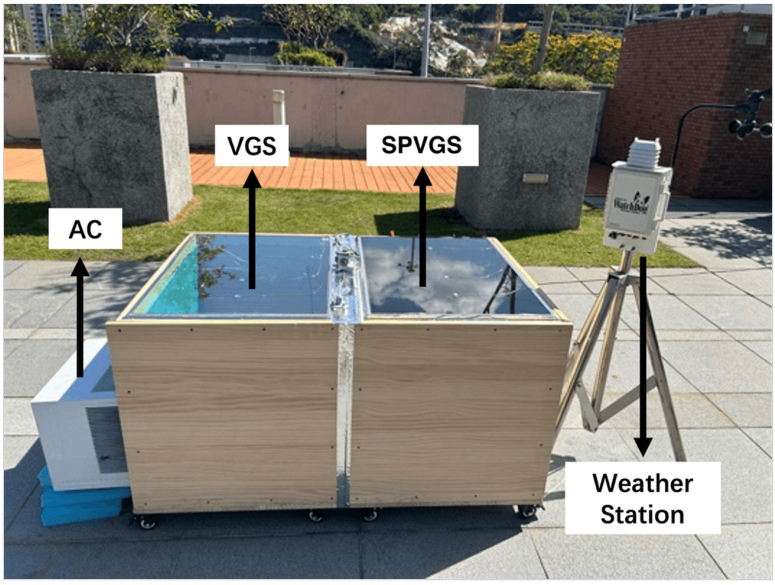

Figure 1. Outdoor experiment.

As shown in Figure 2, three K-type thermocouples were attached on each side of the skylights to measure inner and outer surface temperatures, with averaged values recorded as T_{in} and T_{out}. At the centre of the interior glazing surface, heat flux sensors (Captec, NHS-25 and HS-30) were installed to measure the heat flux density through the skylights into the indoor environment. Inside the test rig, two measurement points were selected for recording indoor air temperature, while a pyranometer (EKO, MS802) was placed at the bottom to quantify the transmitted solar irradiance of the skylight. An additional pyranometer was placed outside the experimental platform to measure incident solar irradiance, and a weather station was used simultaneously to record outdoor air temperature.

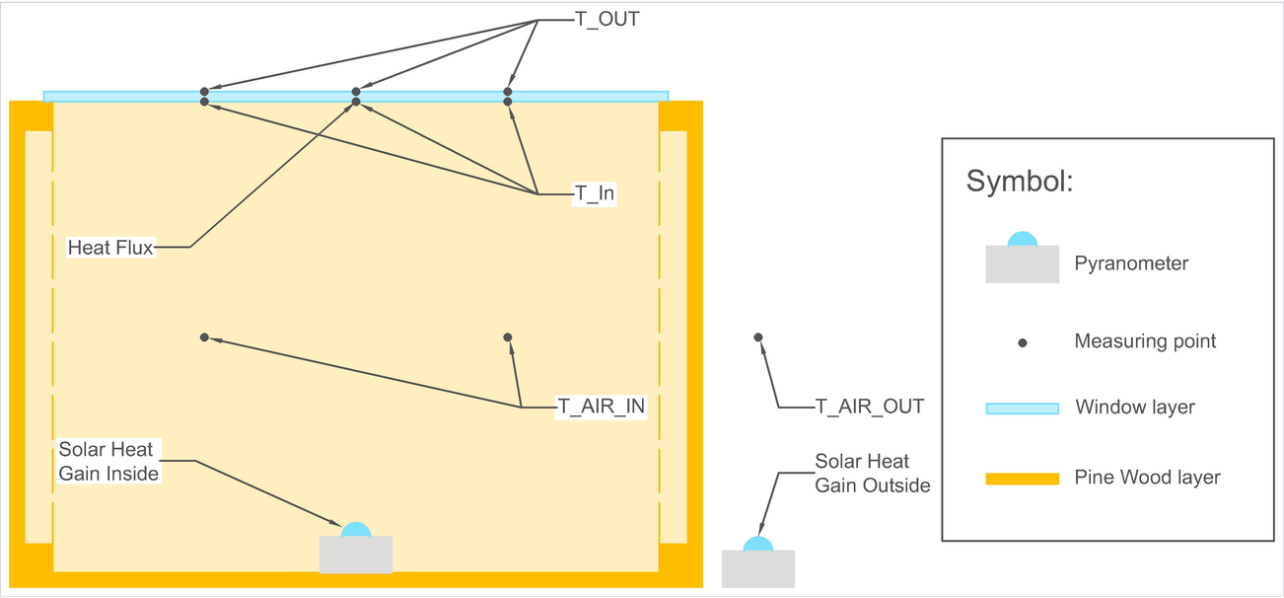

Figure 2. Schematic diagram of the experimental platform.

For data acquisition, two dataloggers (GRAPHTEC, GL840) were employed to record the inner and outer surface temperatures of the skylights, indoor air temperature, interior surface heat flux density, and transmitted solar irradiance. The photovoltaic (PV) performance of the SPVGS was monitored using an IV-checker, which tracked its maximum power point and recorded the

corresponding electrical data. All measurements were logged at one-minute intervals. The details of the instruments involved in the test are summarized in Table 1.

Table 1. Measuring equipment and their corresponding specifications.

Measuring equipment	Function	Manufacture and model	Accuracy
Heat flux sensor	Heat flux measuring	Captec (NHS-25 and HS-30)	< 3%
Thermocouple	Temperature measuring	K-type	±0.5 °C
Pyranometer	Incident solar irradiance measuring	EKO instrument (MS802)	Non-linearity < 0.2% (at 1000 W/m²)
Weather station	Outdoor air temperature measuring	Spectrum Technologies (model 2550)	±0.3 °C
Data logger	Data acquisition	GRAPHTEC (GL840)	—
IV-checker	PV power output collection	EKO instrument (MP-11)	—

3. Results and discussions

3.1. PV power generation

The primary distinction between SPVGS and VGS is that the former one can absorb solar radiation and convert it into electricity through photovoltaic processes. This enables SPVGS to provide clean electricity for powering buildings, thereby contributing to the reduction of energy consumption. As evidenced in Figure 3, the electrical output exhibits a positive correlation with increasing solar radiation, while the aggregate conversion efficiency of the solar photovoltaic coating approximates 8.1%. The maximum power output reached 78.4 W/m².

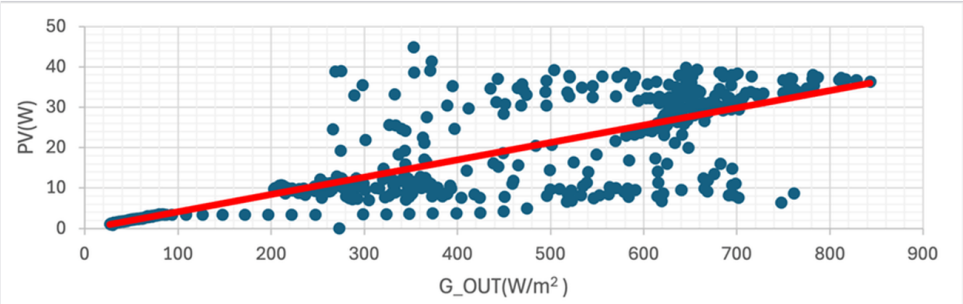

Figure 3. Relationship between power generation and solar radiation.

3.2. Thermal performance

Regarding thermal insulation performance, Figure 4 shows that the maximum temperature difference between the inner and outer surfaces of SPVGS reaches 43.7 °C (inner surface: 26.5 °C; outer surface: 70.2 °C). This value substantially exceeds the 22.3 °C of temperature difference observed in VGS (inner surface: 28.5 °C; outer surface: 50.8 °C). This comparative analysis demonstrates that the photovoltaic-integrated variant effectively obstructs greater thermal energy transfer into interior spaces, consequently mitigating indoor temperature elevation through conductive heat gain. This thermal behaviour can be attributed to the CdTe coating integrated within SPVGS, which absorbs incident solar radiation, thereby diminishing thermal energy transmission to the underlying glass layer and reducing resultant heat flux. During the power generation process, merely a minor fraction of solar energy undergoes conversion to clean electricity, whereas the residual portion transforms into waste heat. This energy distribution consequently elevates surface temperatures. Nevertheless, the vacuum interlayer's presence ensures minimal effect on inner surface temperature.

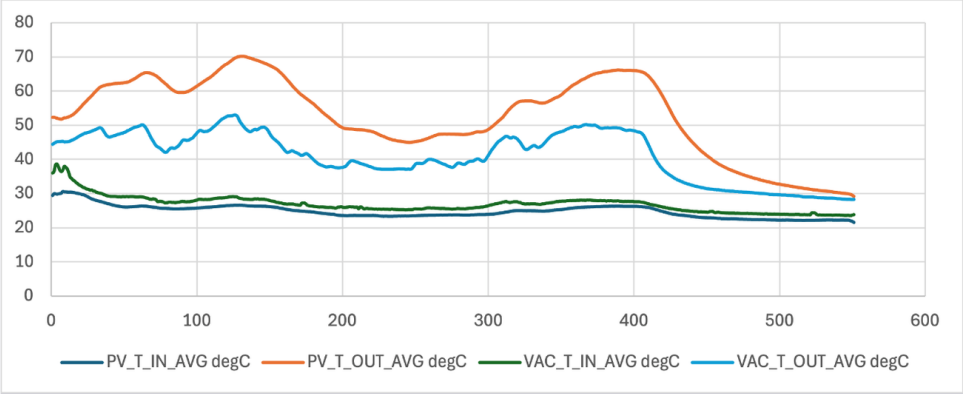

Figure 4. Internal and external surface temperatures of the glass.

As illustrated in Figure 5, the mean solar transmittance of SPVGS is 10.7%, whereas conventional VGS exhibits a transmittance of 32.5%. It is found that SPVGS demonstrates lower solar transmission due to the shading effect of the solar cells. This indicates that less solar energy is transmitted into interior spaces, thereby lowering the requisite indoor cooling load.

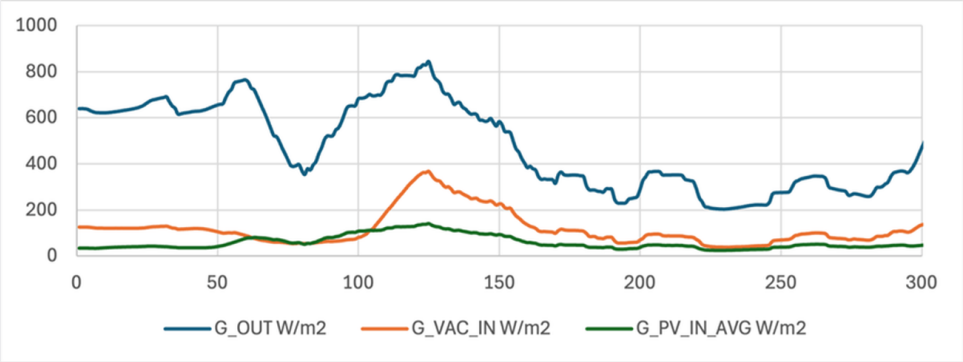

Figure 5. Indoor and outdoor solar radiation.

4. Future work

The experiments reported above were limited to a single prototype and a single measurement day in Hong Kong, so the results describe the instantaneous performance of the SPVGS rather than its annual behaviour. Three directions are being pursued to turn these measurements into design guidance.

First, a layer-resolved physical model of the SPVGS will be established. The model couples an optical sub-model for the CdTe and low-emissivity coatings, a one-dimensional thermal network for the glass panes, the vacuum gap, the polyvinyl butyral interlayer and the frame, and a single-diode electrical sub-model, so that the measured surface temperatures, heat flux density and power output can be reproduced without empirical fitting. The model will then be implemented in EnergyPlus and validated against the outdoor data reported in this study and against additional seasonal measurements, so that the whole-building model can be used with confidence for annual energy predictions.

Second, the validated model will be used to extend the assessment from a single day and a single city to a range of climates. Annual thermal, lighting and electrical performance will be simulated for representative locations, including hot-humid (Hong Kong, Singapore and Kuala Lumpur), hot summer–cold winter (Shanghai and Wuhan), cold (Beijing) and severe cold (Harbin) zones, and the trade-off between the PV coverage ratio, the skylight-to-roof area ratio and the cooling load reduction will be quantified region by region.

Third, the scope will be broadened to the issues that determine practical viability: the daylighting quality and visual comfort of the interior, the long-term stability of the vacuum edge seal under thermal cycling, and a life-cycle cost and carbon assessment of the SPVGS relative to conventional skylight glazing.

5. Conclusion

Experimental data indicate that the SPVGS can achieve a maximum photovoltaic power generation of 78.4 W/m^2 while lowering the solar transmittance to only 10.7%. These characteristics highlight its potential as an effective energy-saving solution. This study presents innovative applications of SPVGS in buildings, specifically focusing on its use as a replacement for traditional skylights to reduce building energy consumption and enhance thermal comfort.

Declarations

Author contributions. Wenhao Zhu: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing (original draft), Visualization, Validation, Software. Hao Zhou: Conceptualization, Writing (review and editing), Supervision, Project administration, Resources, Software, Validation. Hongxing Yang: Conceptualization, Writing (review and editing), Supervision, Project administration, Resources, Funding acquisition, Software.

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Conflicts of interest. The authors declare no competing interests.

Data availability. The data that support the findings of this study are available from the corresponding author upon reasonable request.

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