



TECHNICAL ARTICLE

Study on energy and economic performance of solar PV hollow vacuum glazing for high-rise hotel building in different climate zones

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ABSTRACT

To address the imperative for energy conservation and carbon reduction needs of high-rise hotel building in diverse climate zones, this study systematically evaluates the energy and economic performance of solar photovoltaic (PV) hollow vacuum glazing for application in five typical climate zones in China. For comparative analysis, three traditional glazing are also examined and compared including insulated glazing unit, PV hollow glazing and PV vacuum glazing based on the coupled glazing and EnergyPlus platform. The comprehensive performance of each glazing system is assessed across multiple dimensions: annual energy consumption, decarbonization potential, life-cycle economic viability, and visual comfort. The hotel model consists of thirteen floors, each with a height of 3.76 meters, and the total building area is 1,800 square meters. It is indicated that the PV hollow vacuum glazing exhibits optimal thermal performance with a thermal transmittance at $0.811 \text{ W/m}^2\cdot\text{K}$ and solar heat gain coefficient at 0.193. The net building energy consumption using the PV hollow vacuum glazing is reduced by 38.86% (Hefei) ~ 62.50% (Kunming) compared with the insulated glazing unit among the five climate zones. The decarbonation benefits using the PV hollow vacuum glazing are about 1265.52 tons (Hohhot) ~ 220.79 tons (Kunming) in five climate zones. The lifetime net present value of the PV hollow vacuum glazing is about 7.08 million CNY~10.10 million CNY in five climate zones, representing an increase of 10.69%~15.25% compared to PV vacuum glazing and an increase of 57.23% ~ 81.36% compared to PV hollow glazing. The maximum uncomfortable glare index of the PV hollow vacuum glazing ranges from 0.1717 (Hefei) to 0.1875 (Hohhot). This study provides detailed technical-economic-environmental performance data of the PV hollow vacuum glazing for application in different climate zones, which can be valuable reference for relative stakeholders for its practical application towards low-energy building.

KEYWORDS Solar photovoltaic hollow vacuum glazing (PVHVG), Energy performance, Building energy consumption, Lifetime economic evaluation, Decarbonization benefit

1. Introduction

1.1. Background

Against the dual backdrop of global energy shortages and the advancement of the carbon peaking and carbon neutrality strategy, the construction sector, as a core area of energy consumption and carbon emissions, its energy conservation and carbon reduction have become a key breakthrough for achieving sustainable development. According to the China Building Energy Development Report, the energy consumption of Chinese building operation stage accounts for over 21.8% of the national total energy consumption (Liu *et al.* 2022). Among them, public buildings exhibit notably high energy-use intensity due to their complex functional requirements and extended operating hours, thus offering substantial potential for energy optimization (Ortiz-Peña *et al.* 2025). In the future, wind power and photovoltaics are projected to account for approximately 70% of the energy mix. The State

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Grid is expected to achieve full zero-carbonization by 2050 (Zhu 2025). Building-integrated photovoltaics (BIPV) technology deeply integrates PV power generation functions with building envelopes, not only meeting basic building functions such as shading, thermal insulation, and daylighting but also realizing on-site generation and consumption, thereby establishing itself as a vital direction in the field of building energy efficiency (Shukla *et al.* 2016). As a core component of building envelopes, glazing thermal performance of thermal transmittance, solar heat gain coefficient and optical performance (visible light transmittance) directly affect building energy consumption and indoor thermal and visual comfort (Samuelson *et al.* 2025) (Yeom *et al.* 2023). Consequently, developing a new configuration of PV glazing with low energy consumption, high power generation, and excellent comfort has become a key technical path to address the high energy consumption and high carbon emissions of building (Chen *et al.* 2024).

To improve thermal insulation performance, with the development of BIPV technology, the energy and thermal performance of different configurations for PV glazing have been conducted, such as PV hollow glazing and PV vacuum glazing (Fthenakis *et al.* 2020). Hu *et al.* find that the illuminance of the indoor working surface in rooms with CdTe-PV glazing varies between 500–2200 lux, the requirements for human visual comfort are satisfied (Hu *et al.* 2024). Wang *et al.* evaluate the energy efficiency of semi-transparent CdTe thin-film PV glazing applied to commercial building. The results showed that CdTe PV glazing have significant energy-saving potential in Hong Kong, with an annual power generation of 52.3 kWh/m² per unit CdTe PV glazing. Compared with ordinary glazing and a-Si PV glazing, the net energy consumption savings are 19.6% and 15.3%, respectively (Meng *et al.* 2018). Qiu *et al.* use EnergyPlus to simulate the energy consumption of vacuum photovoltaic glazing in different climate zones. The result showed that the energy-saving potential of vacuum PV glazing in Harbin, Beijing, Wuhan, and Hong Kong is 43.4%, 66.0%, 48.8%, and 35.0%, respectively (Qiu and Yang 2020). Ke *et al.* proposed a new type of hybrid CdTe-PCM PV glazing module (CdTe-PCMG) and conducted manufacturing and testing. The results show that the annual net reductions of air-conditioning load were respectively 630.06 kWh, 1374.52 kWh, 142.42 kWh, 1241.11 kWh and 396.36 kWh (Ke *et al.* 2023). It is indicated that a single-structure PV glazing system is difficult to simultaneously meet the synergistic requirements of low energy consumption, high power generation, and excellent comfort, and the development of composite-structure PV glazing has become an important direction (Kyrrou *et al.* 2023).

The application of different configurations PV glazing in different climate zones have demonstrated excellent performance and energy-saving potential. Wang *et al.* simulated the thermal performance and energy consumption of CdTe PV glazing in tropical island regions using and reported that, relative to conventional insulated glazing units (IGU), SPVVG-IGU achieved reductions of 24.7% in heat gain, 4.4% in air-conditioning energy use, and 3% in total energy consumption (Wang *et al.* 2025). Tang experimentally compared PV-PCM glazing with ordinary clear glazing, PV glazing, and PCM-filled glazing under hot summer and warm winter conditions, observing respective reductions in indoor heat gain of 364.97 kJ, 265.96 kJ, and 301.10 kJ, while a 0.36 m² semi-transparent CdTe PV-PCM glazing unit generated daily electricity outputs of 548.33 kJ, 316.55 kJ, and 58.85 kJ (Tang *et al.* 2024). Wu *et al.* developed a comprehensive numerical model of PV double-skin façades (PV-DSF) for humid subtropical climates, showing that PV-DSF reduced heat gain by 30.4% and heat loss by 50.3% compared with single-layer semi-transparent PV (Wu *et al.* 2022). Roberts *et al.* assessed BIPV-DSF performance in UK office modules, finding that while maximum daylight illuminance decreased by 73% relative to a conventional DSF, building energy consumption increased by 8% (Roberts *et al.* 2023). Huang *et al.* experimentally and numerically evaluated hollow PV glazing, PV vacuum glazing, and hollow PV vacuum glazing, concluding that the latter two configurations offer superior heating and cooling energy savings compared with hollow PV glazing (Huang *et al.* 2021). Chen *et al.* investigated silicon PV glazing in Southwest China and identified Lhasa as achieving the highest absolute energy savings (983 kWh) and Kunming the highest energy-saving ratio (83%) (Chen *et al.* 2019). Despite these valuable contributions, the existing body of literature is predominantly

characterized by single-climate or site-specific assessments, with a conspicuous absence of systematic comparative analyses of the identical glazing system across multiple distinct climate zones. This limitation not only constrains the generalizability of individual findings but also obscures the delineation of climatic applicability boundaries for emerging glazing technologies. Consequently, there is a pressing and unmet need for comprehensive performance evaluation studies that span diverse climatic contexts, which are essential for informing region-specific design strategies and maximizing the energy-saving potential of advanced glazing systems in varied built environments (Huang *et al.* 2025).

From the literature review in the previous text, it can be seen that the composite structure of photovoltaic glazing still requires further research, and the adaptability to multiple climate zones should also be considered based on the research results (Table 1). This study adopted a systematic and comprehensive comparative analysis method covering various climate conditions, developed a new type of photovoltaic glass structure, and conducted configuration research. The study employed a unified simulation protocol, comprehensive performance indicators (energy, lighting, comfort, and power generation), and a novel climate adaptability zoning scheme. This approach not only achieved the first direct cross-regional comparison of the same glass technology but also established clear climate applicability ranges and regional-specific design guidelines.

Table 1. Citing references and comparing with this article

Reference	PV glazing configuration	zone	Energy saving
Hu et al. (2024)	PV glazing	Cold	/
Wang et al. (2018)	PV glazing	Hot summer warm winter	19.6%
Qiu et al. (2020)	Vacuum PV glazing	Severe cold, cold, hot summer cold winter and hot summer warm winter	43.4%, 66.0%, 48.8%, and 35.0%
Wang et al. (2025)	PV glazing	Tropical island regions	3 %
Tang et al. (2024)	PV-PCM glazing	Hot summer and warm winter climate	/
This study	Solar photovoltaic hollow vacuum glazing	Severe cold, cold, hot summer cold winter, moderate and hot summer warm winter	27.71% ~ 47.19%

1.2. Research objectives and contributions

This study evaluates the comprehensive performance of the solar PV hollow vacuum glazing for high-rise hotel building application in different typical climate zones including the annual energy performance, decarbonization potential, lifetime economy, and visual comfort. Three traditional types of glazing are compared including insulated glazing unit, PV hollow glazing and PV vacuum glazing based on the coupled WINDOW and EnergyPlus platform. It has filled the research gap in the application of solar photovoltaic hollow vacuum glazing in high-rise buildings across different climate zones. The research objectives and contributions are explicated as shown below:

- (1) The thermal, optical and electrical property of the PV hollow vacuum glazing is analyzed in comparison with three traditional glazings including insulated glazing unit, PV hollow glazing and PV vacuum glazing.
- (2) The high-rise hotel building energy model using different glazings is established for application in the typical cities of five major climate zones in China including Xiamen, Kunming, Hefei, Tianjin and Hohhot.
- (3) The detailed and comprehensive performance of the high-rise hotel building using different glazings is evaluated and compared including annual energy performance (i.e., total building energy

consumption, power generation), decarbonization potential (annual carbon emissions), lifetime economy (net present value), and visual comfort (daylight glare index).

2. Methodology

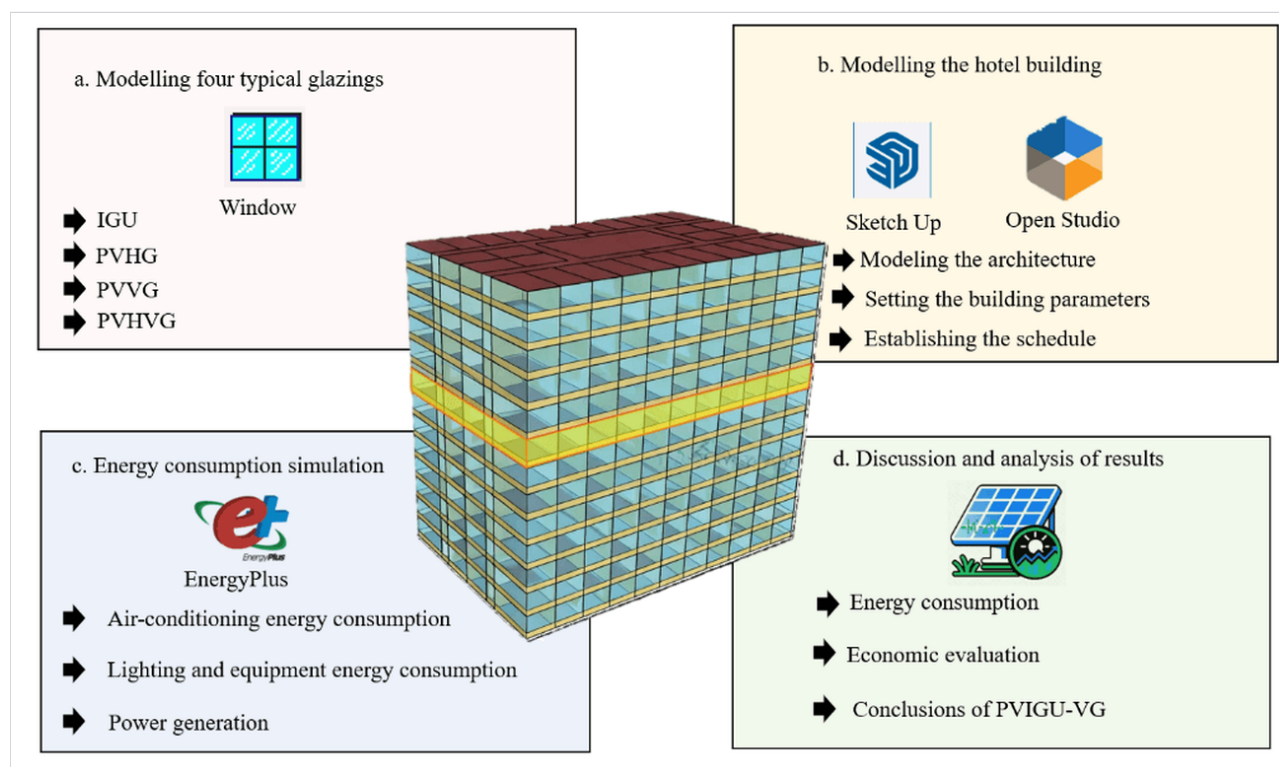


Figure 1. Framework on simulation research of CdTe PV hollow vacuum glazing (PVHVG) in high-rise hotel building across five typical climate zones

This research evaluates the technical-economic-environmental performance of the Solar photovoltaic hollow vacuum glazing (PVHVG) applied in an actual high-rise hotel in five typical climate zones as shown in Fig. 1. The annual energy performance, decarbonization potential, lifetime economy, and visual comfort of the PVHVG are analyzed through simulation and compared with those of PV hollow glazing (PVHG), PV vacuum glazing (PVVG) and insulated glazing unit (IGU) across five climate zones. The annual energy performance of the PVHVG applied in a high-rise hotel building is simulated by simulation platforms with WINDOW, SketchUp, Openstudio and EnergyPlus. The decarbonization and economic performance are evaluated through NPV analysis and carbon emission calculations. The daylight glare index is used to appraise the visual comfort of the PVHVG application in high-rise hotel building.

2.1. Modelling four typical glazings

Berkeley Lab WINDOW software is used to determine the optical and thermal properties of glazing, supporting the modeling of glazing products with multi-component combinations such as glazing layers, gas layers, and frames, and can realize vacuum glazing simulation. The photovoltaic (PV) layer is modeled in LBNL WINDOW as an equivalent thin-film coating with user-defined spectral optical properties. A one-dimensional steady-state heat transfer condition was assumed in accordance with ISO 15099 for U-factor calculation. The thermal analysis treats the PV layer as a passive, spectrally-selective shading component, with power generation calculated separately in EnergyPlus using the transmitted solar radiation. The spectral transmittance and reflectance data of CdTe PV are derived from relevant literature (Pan *et al.* 2025), covering the wavelength range required for the study, and have been imported into Berkeley Lab WINDOW software as glazing layers to provide key support for

the calculation of thermal performance indicators of PVHVG units. In Berkeley Lab WINDOW software, the PVHVG system is constructed. In the Layer Builder module, layers are added in the order of outer PV glazing / hollow layer / Low-E glazing / vacuum layer / inner clear glazing. Its structure is 16.2 mm CdTe PV glazing, 12 mm hollow layer, 5 mm Low-E glazing, 0.2 mm vacuum layer and 5 mm ordinary clear glazing. To form a horizontal comparison, three commonly used glazing systems (IGU, PVHG, and PVVG) are established simultaneously. The structure of each system and the optical-thermal parameters calculated by software simulation are shown in Figure 2 and Table 2.

Table 2. Optical-thermal parameters and structures of the four types of glazing

Glazing type	U-value	SHGC	T_{vis}	Structure
IGU	1.879	0.736	0.804	5 mm glazing + 12 mm air-gap + 5 mm Low-E with glazing
PVHG	1.764	0.358	0.338	16.2 mm CdTe PV glazing + 12 mm air-gap + 5 mm Low-E with glazing
PVVG	0.884	0.228	0.242	16.2 mm CdTe PV glazing + 0.2 mm vacuum-gap + 5 mm Low-E with glazing
PVHVG	0.811	0.193	0.219	16.2 mm CdTe PV glazing + 12 mm air-gap + 5 mm Low-E with glazing + 0.2 mm vacuum-gap + 5 mm glazing

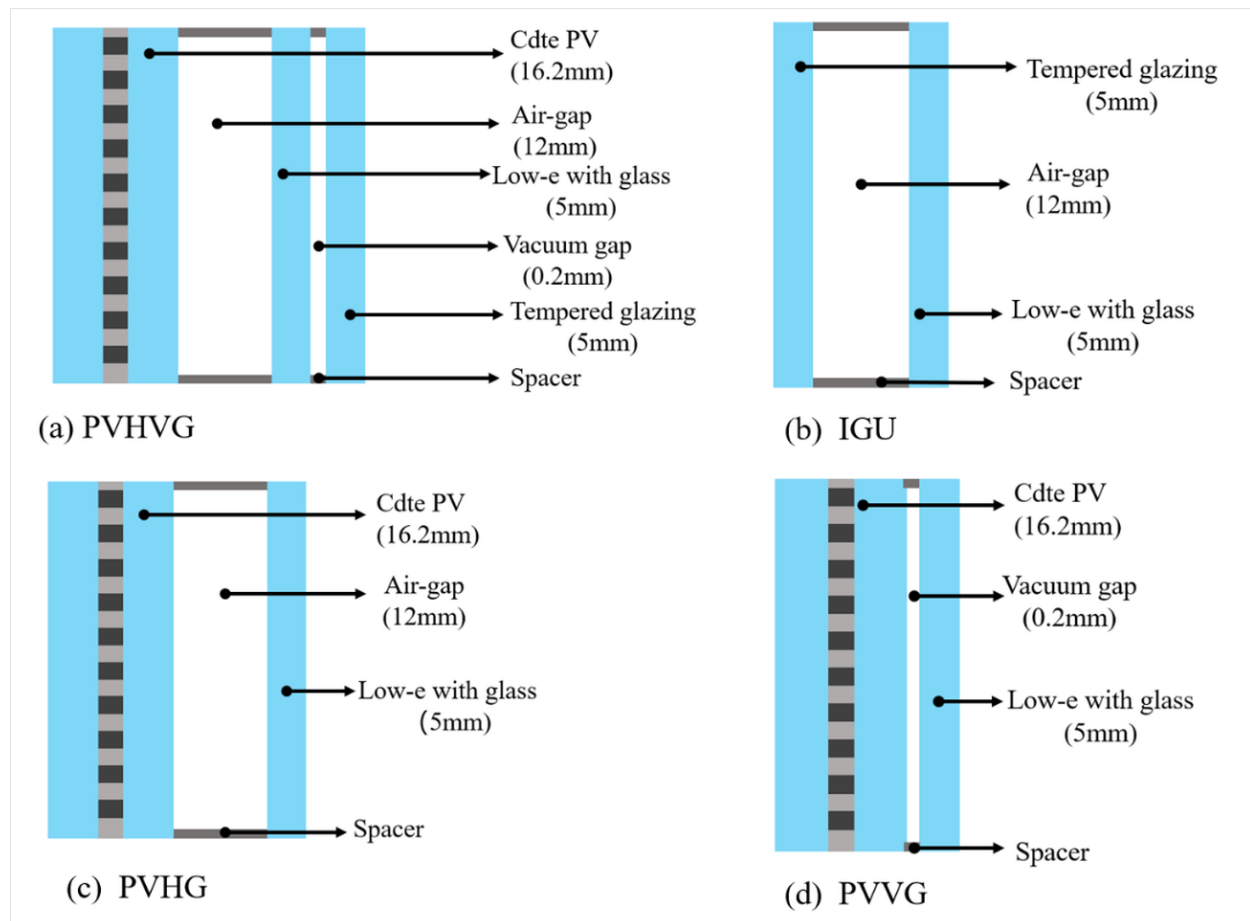


Figure 2. Structures of the four types of glazing

2.2. Climate and city selection

In the simulation, hourly Chinese standard meteorological data are adopted as boundary conditions to calculate building energy consumption and power generation. All weather datasets are sourced from the websites cited in References (US Department of Energy 2016). Five cities with diverse

climatic features are selected for analysis, whose names and geographic locations are presented in Table 3.

Table 3. Selection of climate zones and thermal transmittances of roofs and external walls in each climate zone

Climate	Location (City, Province)	Elevation (m)	Roof (W/m ² ·K)	Wall (W/m ² ·K)
Severe cold	Hohhot, Inner Mongolia	1063.00	0.40	0.35
Cold	Tianjin, Tianjin	3.00	0.40	0.35
Hot summer cold winter	Hefei, Anhui	27.00	0.90	0.673
Moderate	Kunming, Yunnan	1892.00	0.90	0.673
Hot summer warm winter	Xiamen, Fujian	139.00	0.90	0.673

2.3. Establishment of hotel building model

SketchUp is used to build the three dimensions structure of the high-rise hotel building, and Openstudio is utilized to set setting building parameters, which are cooperated to complete the basic model construction. Building geometry is simplified in SketchUp by omitting minor facade details with negligible thermal impact. Floors are aggregated into representative thermal zones by orientation and function. OpenStudio served solely as a preprocessor for EnergyPlus input file generation. The building models of the high-rise hotel building are established based on the practical investigation and statistical survey from over 200 sets of drawings of existing buildings in the Greater Bay Area (Lv *et al.* 2019). The hotel building has 13 floors, each with a floor height of 3.76 m, and a total floor area of 1800 square meters. As shown in Fig. 3, the red zones represent guest rooms of each area of 17.54 square meters, the cyan area is guest rooms with an area of 41.30 square meters, and the atrium area is 249.96 square meters. Considering the characteristics of the five major climate zones, the thickness of external wall and roof insulation materials is adjusted to match the envelope design standards of different climate zones. The thermal transmittances of external walls and roofs in severe cold and cold regions are set to 0.4 and 0.35 W/m²·K, in severe cold and cold regions, while the values for the other three climate zones are 0.9 and 0.673 W/m²·K (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2015). In SketchUp software, photosensitive points are arranged in each room of the hotel to monitor indoor illuminance and link to control artificial lighting, accurately simulating the difference in lighting energy consumption under different glazing systems. The uncomfortable glare index is simulated to quantify whether PV glazing would produce dazzling glare, ensuring indoor visual comfort and operational safety.

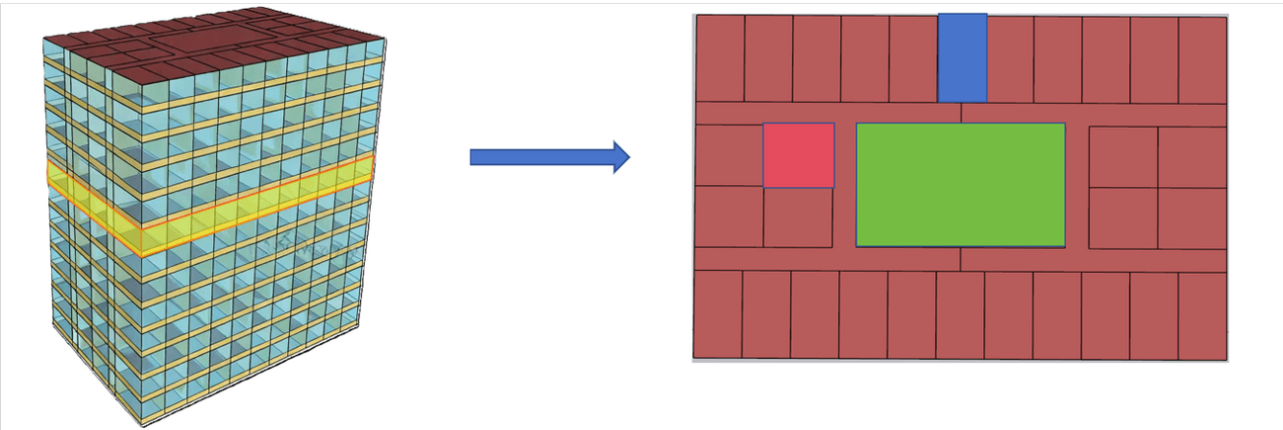


Figure 3. Hotel model diagram

EnergyPlus is adopted to simulate thermal performance, daylight performance, and power generation. It can accurately simulate complex glazing opening patterns, calculate the daylight illuminance at any arbitrary positions, formulate artificial light control strategies based on illuminance levels, and dynamically calculate the annual total power generation under different meteorological conditions by configuring parameters such as PV panel performance and installation parameters.

2.3.1. Air-conditioning system

In this simulation study, a water-cooled fan-coil unit system is applied in the hotel building to calculate heating load and cooling load. According to the code (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2015), the coefficients of performance (COP) of the refrigeration unit and the heating unit are set to 4.6 and 5, respectively, which are in line with the code and most current hotel systems (Fu 2025). Based on the operation mode of the hotel building, the air conditioning system is set to be always on, with constant temperature setpoints of 22°C for heating and 25°C for cooling, respectively. Heating is implemented during the heating period in different climate zones by setting the schedule accordingly. According to the code, days with an average daily temperature $\leq 8\text{ }^{\circ}\text{C}$ are defined as the heating period. The specific heating schedule settings for the five different climate zones are shown in Table 4, the air conditioning system is set to cooling mode by default for the rest of the time (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2012). For the terminal air of the air conditioning system, a constant air volume air supply device is adopted in this study to maintain a constant air supply volume. The fan is set to be always on and is adjusted automatically according to the occupant density (Zhao 2018).

Table 4. Heating period

Region	Xiamen	Kunming	Hefei	Tianjin	Hohhot
Heat period	-	12.17 - 1.12	11.24 - 3.06	11.06 - 3.27	10.12 - 4.13

2.3.2. Lighting

Table 5. Parameters of the hotel model

Building	Function area	Personnel density	Illumination power density	Equipment power density	Fresh air volume
Hotel	Bedroom	15 m ² /per	7 W/m ²	15 W/m ²	30 m ³ /(h·per)
	Corridor	50 m ² /per	4 W/m ²	0 W/m ²	30 m ³ /(h·per)
	Service area	4 m ² /per	7 W/m ²	13 W/m ²	20 m ³ /(h·per)

After defining the spatial layout and thermal parameters of the building envelope, the internal load parameters of the typical hotel building must be specified. In accordance with the building code, the personnel density, lighting power density, equipment power density, and fresh air volume per person are determined. These specific parameter values are listed in Table 5.

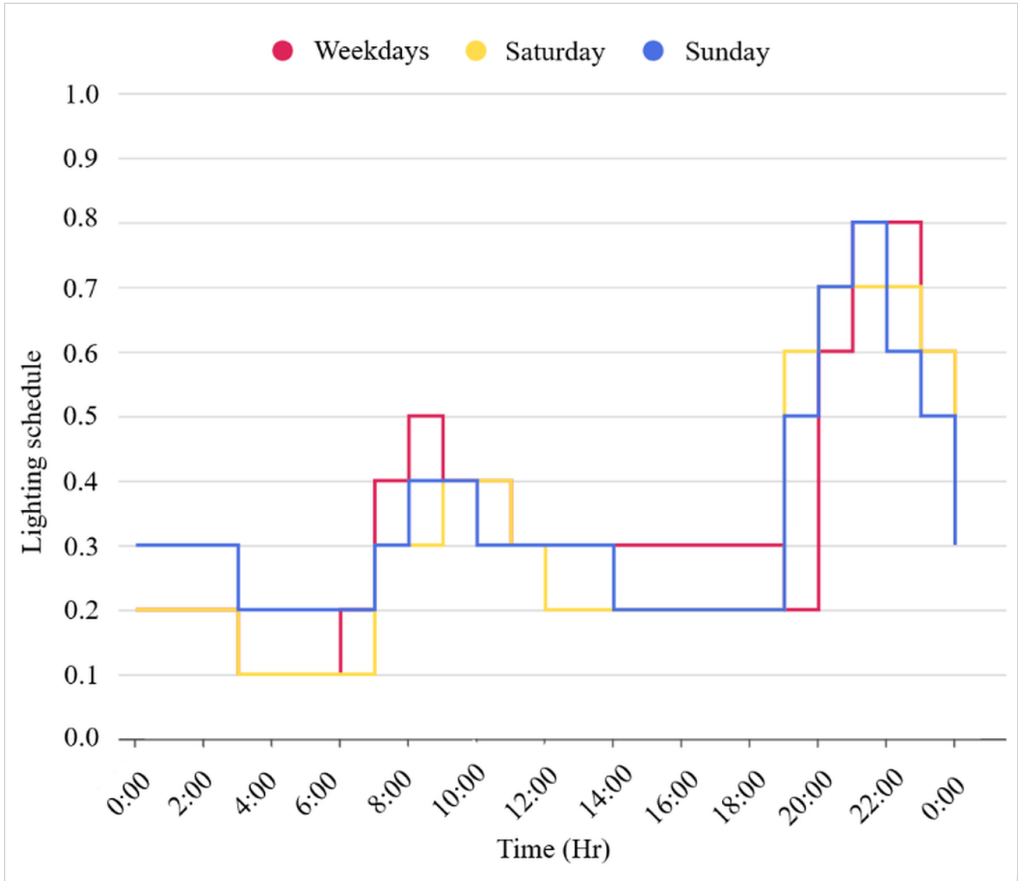


Figure 4. Lighting occupancy rate

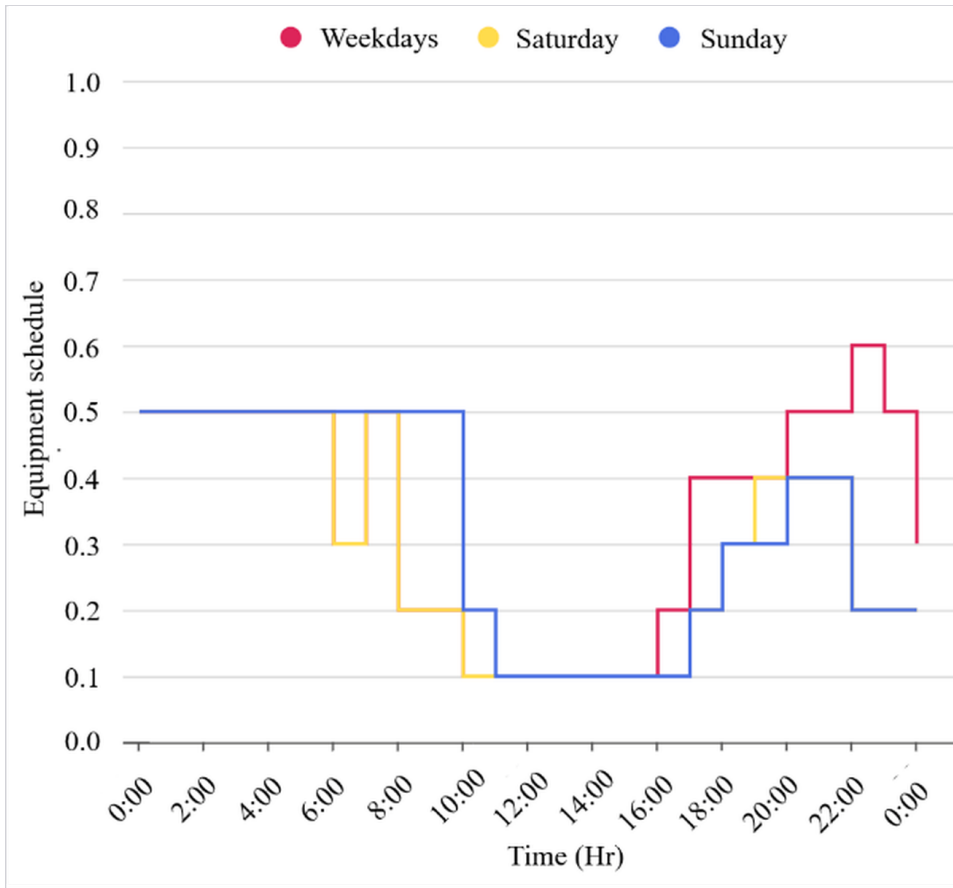


Figure 5. Equipment occupancy rate

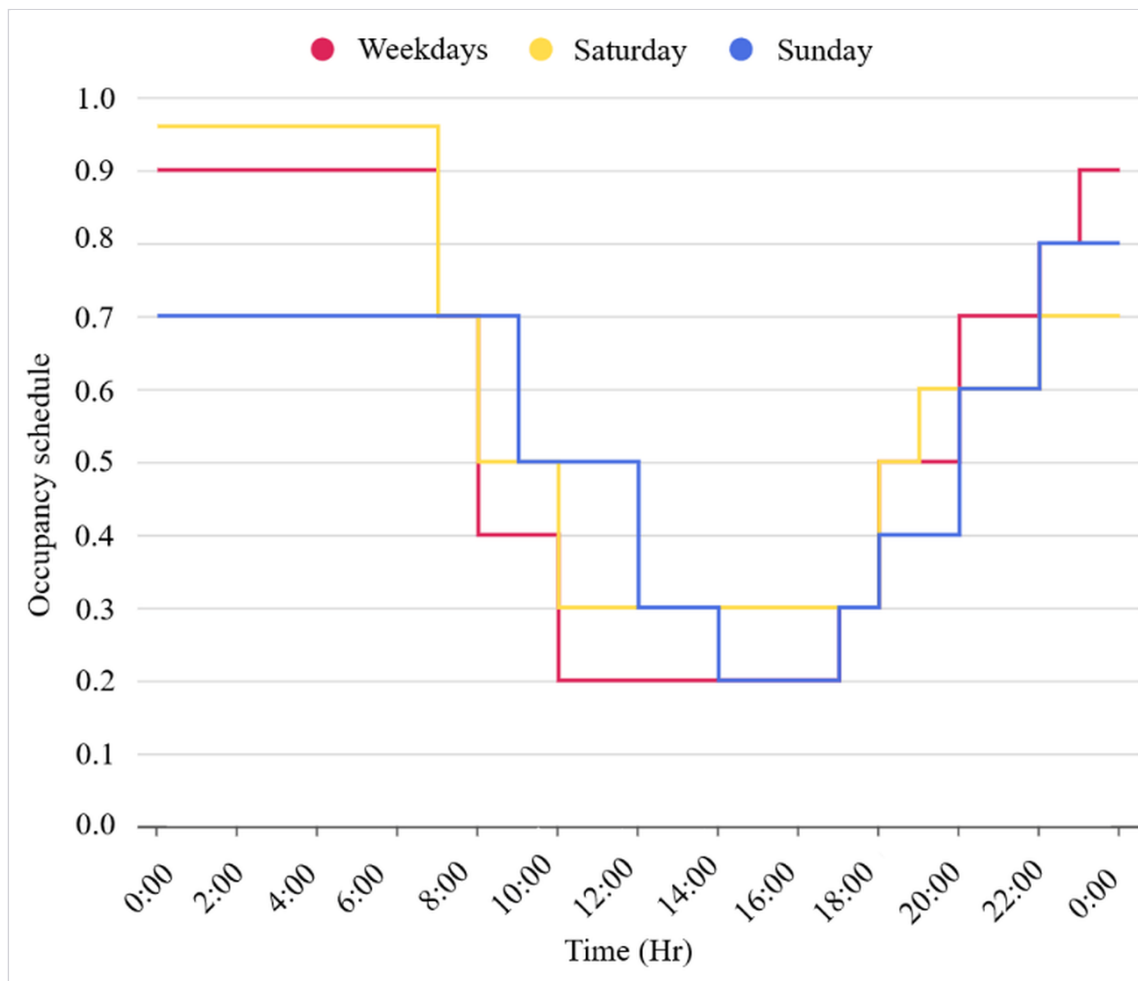


Figure 6. Personnel density

For the lighting control strategy, this study adopts continuous dimming, with different schedules applied for weekdays, Saturdays, and Sundays. In EnergyPlus, time-varying discrete parameters are first defined using Schedule: Interval objects, the corresponding settings and occupancy rate patterns are illustrated in Fig. 4, Fig. 5, and Fig. 6. Subsequently, the schedule for each representative week is constructed using Schedule: Daily objects. Since this study simulates a hotel building, the lighting and equipment are assumed to operate year-round, and the occupancy rate is defined to follow a weekly cycle repeated throughout the year.

2.3.3. Power generation model

In this study, to accurately simulate the actual operating characteristics and energy interaction mechanisms of the building-integrated photovoltaic (BIPV) system, the system is defined as a grid-connected photovoltaic system within the EnergyPlus building energy simulation platform. Considering the strong coupling between the electrical performance and thermal characteristics of PV modules, and given that the single-diode model can accurately describe the current-voltage output characteristics of PV cells through an equivalent circuit while effectively reflecting the influence of key factors such as solar irradiance and ambient temperature on power generation efficiency, this model is adopted as the core calculation model for the BIPV system (Schildt *et al.* 2025). Because the glazing surface of PV modules is prone to temperature rise under solar radiation, which directly leads to attenuation of the module's photoelectric conversion efficiency and consequently affects overall system performance and the building thermal environment, the study focuses on the coupling mechanism by which glazing surface temperature rise influences PV

modules. To achieve a refined coupled simulation of the thermal effects of PV modules and the heat transfer process of building envelopes, this study adopts the external surface integrated thermal coupling mode in EnergyPlus. This mode deeply integrates the heat generation and dissipation processes of PV modules with the convective, radiative, and conductive heat transfer processes of building surfaces.

2.4 System evaluation indicators

2.3.4. Net present value

The net present value (NPV) method is used to evaluate the economic performance of the PV hollow vacuum glazing system in hotel building in five major climate zones within a 25-year life cycle, which can be calculated by Eq. (1).

$$NPV = \frac{\sum_{i=0}^n (CI - CO)}{(1+i)^{yre}} - C_{ini} \quad (1)$$

where CI is cash inflow, CO is cash outflow, i is the discount rate (3%) (Wang *et al.* 2016), and y is the service life (≤ 25 years).

The difference between cash inflow and outflow can be calculated by Eq (2).

$$CI - CO = E_{pv}P_r + E_{pv}f_{ce}P_{ct} - C_{O\&M}(1+IR)^{yre} - C_{re}(1+IR)^{yre} \quad (2)$$

where E_{pv} is the annual power generation of PV glazing, and the annual degradation of PV glazing is considered for life cycle analysis. P_r is the local electricity price, which is 0.6725 CNY/kWh (Guangdong Provincial Development and Reform Commission 2021). P_{ct} is the local carbon emission factor, and the carbon trading price is 28.43 CNY/ton (The Standing Committee of Guangdong Provincial People's Congress 2023). $C_{O\&M}$ is the operation and maintenance cost of PV glazing, accounting for 0.5% of the initial investment (Gholami *et al.* 2020). IR is the inflation rate of 2% (Wang *et al.* 2016). C_{re} is the replacement cost of the inverter. yre represents the lifespan of the inverter and PVHVG, which is set at 25 years.

The initial investment C_{ini} is calculated by Eq. (3).

$$C_{ini} = C_{pv} + C_I - C_{eq} \quad (3)$$

where, C_{pv} is the material cost of PV glazing. C_I is the inverter cost of 857.14 CNY/KW (Liu *et al.* 2023). C_{eq} is the equivalent cost of the original glazing (Zhang *et al.* 2024).

Carbon emissions are calculated by Eq. (4).

$$CE = NEC \times CEF \quad (4)$$

Where, NEC is net energy consumption, CEF is carbon emission factor.

The cost of PV glazing and the carbon emission factors of the above five major climate zones are shown in Tables 6 and 7 (Ministry of Ecology and Environment of the People's Republic of China 2024).

Table 6. Costs of the four types of glazing

Glazing	IGU	PVHG	PVVG	PVHVG
Unit cost (CNY/m ²)	1200	1360	2050	2210

Table 7. Carbon emission factors of the five cities

Region	Hohhot	Tianjin	Hefei	Kunming	Xiamen
CEF (kgCO ₂ /KWh)	0.6849	0.7041	0.6782	0.1073	0.4092

2.3.5. Daylight glare index

The Daylight Glare Index (DGI) is a widely used metric for evaluating discomfort glare, especially in spaces dominated by daylight or large-area sources (such as glazing). The DGI formula combines the luminance and solid angle of each glare source, background luminance, and position index, thereby accounting for the intensity and apparent size of the glare source relative to the observer's field of view. Unnecessary or excessive light exposure is a major factor contributing to circadian rhythm disruption and other physiological abnormalities, including metabolic disorders, which can cause cardiovascular diseases, kidney diseases, and type 2 diabetes. Long-term exposure to excessive illumination from various indoor and outdoor sources can slowly disrupt the human biological clock (Fonken and Nelson 2014). In this study, the Daylight Glare Index was simulated using relevant modules energy and lighting simulation software. For shadow calculations, the average daily calculation method by frequency is adopted, and daylight reference points are defined. DGI values are calculated in accordance with Eq. (5) (Wienold and Christoffersen 2006), and the DGI performance of the four types of glazing across the five climate zones was evaluated with reference to applicable standards (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2013).

$$DGI=10\log_{10}[0.48\sum_{i=1}^n(\frac{L_s^{1.6}\Omega_s^{0.8}}{L_b+0.07\omega_s^{0.5}\cdot L_s})] \quad (5)$$

where Ω_s is the solid angle subtended by the glare source modified by the position of the source with respect to field of view and Goth's position index. L_s is glare source luminance (cd/m²). L_b is background luminance (cd/m²). ω_s is solid angle subtended by the source. L_s is glare source luminance (cd/m²)

3. Results and discussion

This section analyzes the total annual energy consumption and breakdown energy consumption indicators of PVHVG applied to high-rise hotel buildings across five climate zones, with comparisons against IGU, PVHG, and PVVG. Subsequently, the decarbonization potential and the net present value of the entire life cycle of PVHVG in high-rise hotel buildings in five climate zones are further investigated relative to the three reference glazing types. The visual comfort performance of PVHVG is assessed in comparison with the other three glazing options, so as to clarify the practical applicability of PVHVG.

3.1. Energy performance of the PV hollow vacuum glazing for high-rise hotel building in five climate zones

3.1.1. Total energy consumption

Fig. 7 shows that total building energy consumption of four types of glazing in high-rise hotel building in five climate zones which consists of air-conditioning energy consumption, lighting energy consumption, and equipment energy consumption to evaluate the energy-saving performance of glazing. The results indicate that the energy consumption of the high-rise hotel using PVHVG is lower by 27.71% (Hefei) ~ 47.19% (Kunming), 9.81 (Kunming) % ~ 14.45% (Hohhot), 2.37%

(Hohhot) ~ 4.59% (Kunming) compared with IGU, PVGH, PVVG in five climate zones, respectively. Among all cases, the energy consumption of the PVHVG applied in high-rise hotel is the lowest in Kunming, with reductions of 47.19%, 9.81% and 4.59%, compared with IGU, PVHG, and PVVG.

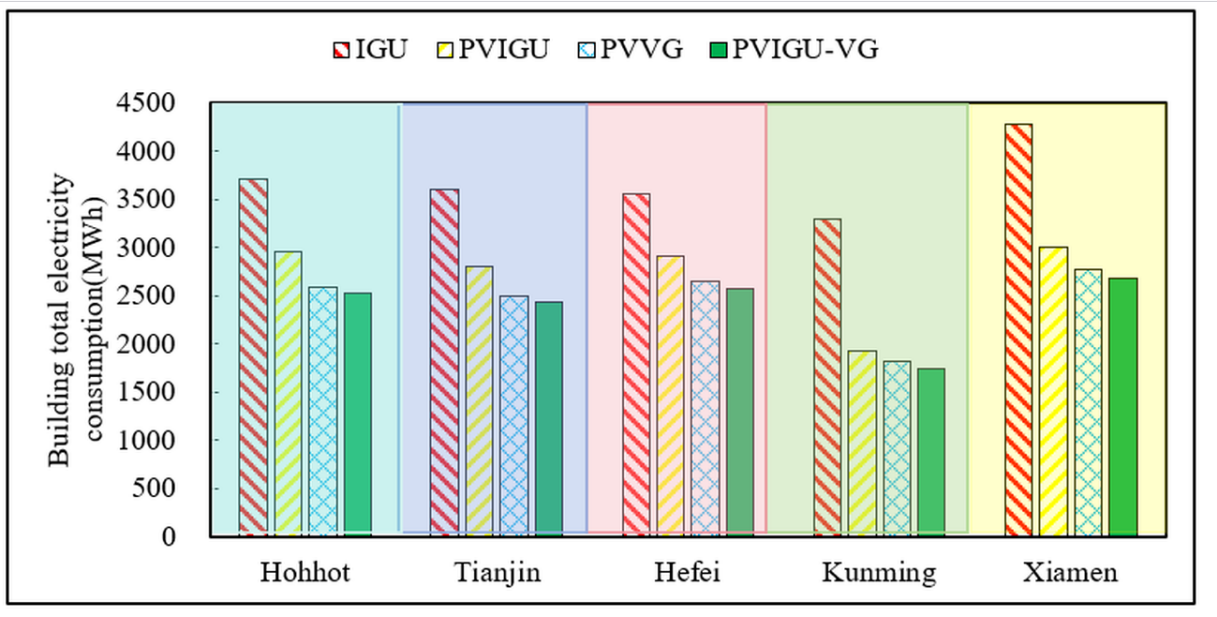


Figure 7. Total electricity consumption of four types of glazing in hotel building in five climate zones

Table 8. Total building electricity consumption with four types of glazing in five cities

Glazing	IGU	PVHG	PVVG	PVHVG
Hohhot	3701.72	2956.94	2591.12	2529.69
Tianjin	3597.36	2808.51	2492.93	2426.99
Hefei	3561.53	2916.36	2647.32	2574.65
Kunming	3292.25	1927.70	1822.14	1738.59
Xiamen	4277.48	2996.91	2768.68	2671.61

Table 8 shows the electricity consumption data of high-rise hotel building applying the four types of glazing in the five major climate zones. Compared with IGU, PVHVG reduces total energy consumption by 37.54% (1605.87 MWh) in Xiamen, 47.19% (1553.66 MWh) in Kunming, 27.71% (986.88 MWh) in Hefei, 32.53% (1170.37 MWh) in Tianjin, and 31.66% (1172.03 MWh) in Hohhot. Kunming achieves the highest energy-saving rate, while Hefei (hot summer and cold winter region) delivers the lowest rate. Compared with PVVG, PVHVG reduces total energy consumption by 3.50% (97.07 MWh), 4.70% (83.55 MWh), 2.75% (72.67 MWh), 2.65% (65.94 MWh), and 2.37% (61.43 MWh) across the five cities in sequence, respectively. Compared with PVHG, PVHVG reduces total energy consumption by 10.9% (325.30 MWh), 9.97% (189.11 MWh), 11.72% (341.71 MWh), 13.58% (430.20 MWh), and 14.45% (427.25 MWh), respectively. Although the energy-saving superiority of PVHVG over PVVG is less pronounced than that against IGU, performance enhancement can still be observed. These findings demonstrate that PVHVG possesses remarkable energy-saving strengths among various photovoltaic glazing types.

3.1.2. Air-conditioning energy consumption

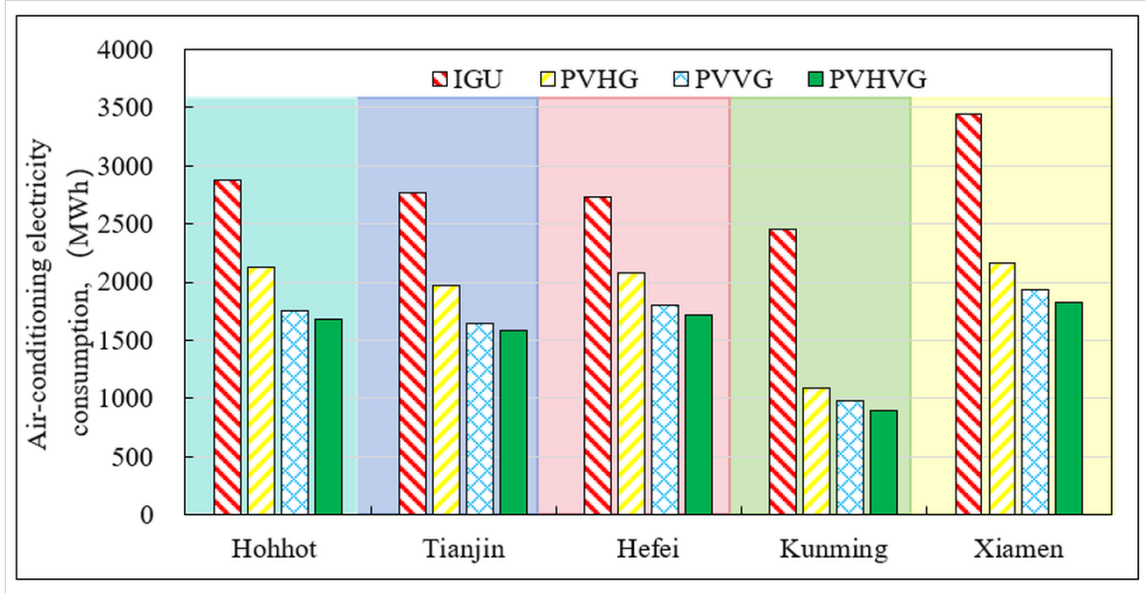


Figure 8. Air-conditioning electricity consumption of four types of glazing in hotel building in five climate zones

Fig. 8 shows the annual air-conditioning energy consumption of high-rise hotel building using four typical types of glazing (IGU, PVHG, PVVG and PVHVG) in five climate zones (Xiamen, Kunming, Hefei, Tianjin and Hohhot). Among the overall energy consumption, it can be seen that the energy consumption of air conditioners accounts for the majority. Therefore, it is of great significance to analyze the impact of glass curtain walls on the energy consumption of building air conditioning. It is found that air-condition energy consumption of PVHVG of the high-rise hotel building is lower by 36.86% (Hefei) ~ 63.75% (Kunming), 15.36 (Xiamen) ~ 20.52% (Hohhot), 3.62% (Hohhot) ~ 8.71% (Kunming), compared with IGU, PVHG, PVVG. The air-conditioning energy consumption of PVHVG applied in the high-rise hotel building is lowest in Kunming, decreased by 63.75%,18.00% and 8.71%, compared with IGU, PVHG and PVVG.

Table 9. Air-condition energy consumption of hotel building with four types of glazing in five climate zones (MWh)

Region	Hohhot	Tianjin	Hefei	Kunming	Xiamen
IGU	2876.87	2768.83	2729.77	2460.48	3451.41
PVHG	2123.71 (26.18%)	1971.69 (28.79%)	2075.47 (23.97%)	1087.68 (55.79%)	2163.64(37.31%)
PVVG	1751.37 (39.12%)	1650.01 (40.41%)	1800.50 (34.04%)	977.01 (60.29%)	1930.09(44.08%)
PVHVG	1687.92 (41.33%)	1582.18 (42.86%)	1723.51 (36.86%)	891.91 (63.75%)	1831.24 (46.94%)

Note: Compared with the proportion of energy consumption reduction by IGU

Table 9 lists the air-conditioning electricity energy consumption of hotel building with four types of glazing in five climate zones. Table 9 lists the air-conditioning energy consumption of the hotel building equipped with four glazing alternatives across the five climate zones. In Hohhot, the air-conditioning energy consumption of the high-rise hotel adopting PVHVG declines by 1188.95 MWh, 435.79 MWh and 63.45 MWh when compared with IGU, PVHG and PVVG, respectively. In Tianjin, the corresponding energy savings reach 1186.65 MWh, 389.51 MWh and 67.83 MWh. In Hefei, the reductions amount to 1006.26 MWh, 351.96 MWh and 76.99 MWh. In Kunming, the saved energy equals 1568.57 MWh, 195.77 MWh and 85.10 MWh. In Xiamen, the energy consumption drops by 1620.17 MWh, 332.40 MWh and 98.85 MWh.

Benefiting from its low solar heat gain coefficient (SHGC), PVHVG effectively blocks solar radiation from penetrating indoors during the summer cooling period, yielding a notable cut in cooling loads. This favorable performance improvement can be observed in all investigated climate zones. These findings confirm that PVHVG offers robust and climate-adaptive energy-saving potential, making it a highly promising solution for improving the energy efficiency of high-rise buildings nationwide (Liu *et al.* 2020).

3.1.3. Lighting energy consumption

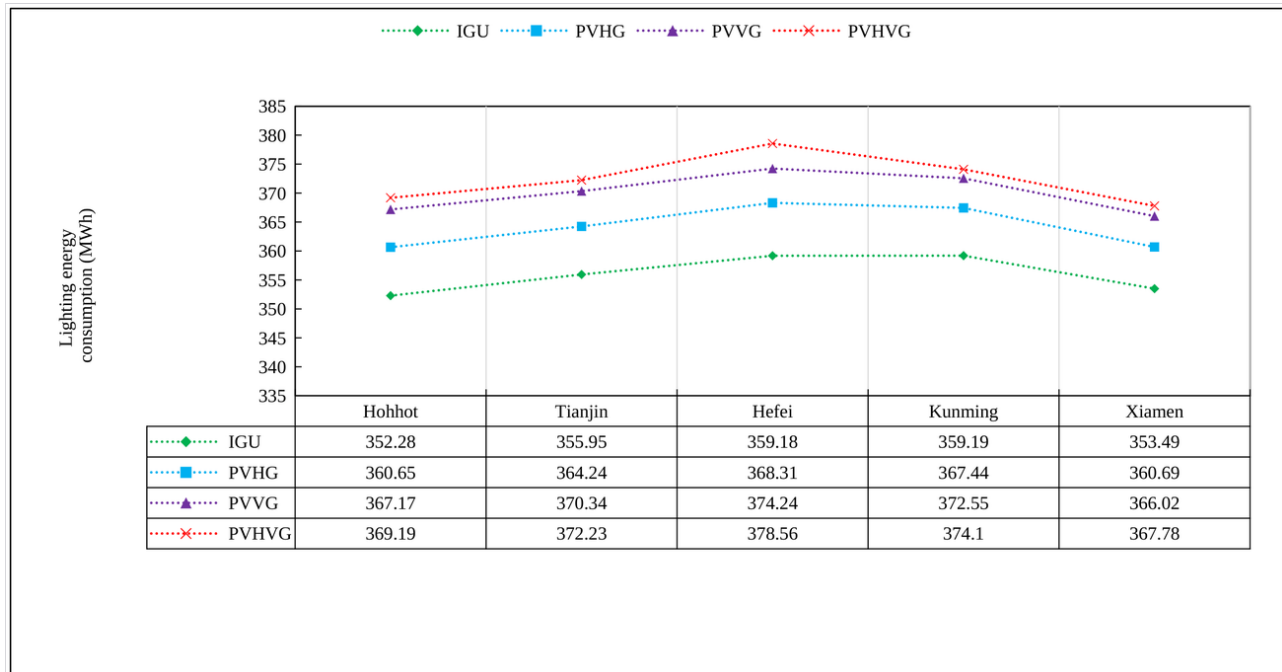


Figure 9. Lighting energy consumption of four glazings in the building in five climate zones

It can be seen that at every climate zone, the lighting energy consumption is highest for PVHVG, followed by PVVG, PVHG, and then IGU (Figure 9). The highest and lowest lighting energy consumption of PVHVG are reported in Hefei and Xiamen respectively, which are 378.56 MWh and 367.78 MWh. Furthermore, the lighting energy of PVHVG in high-rise hotel building is decreased by 5.12%, 2.71% and 1.14% in Hefei, compared with IGU, PVHG and PVVG, respectively. The lighting energy of PVHVG in high-rise hotel building is decreased by 3.89%, 1.93% and 0.48% in Xiamen, compared with IGU, PVHG and PVVG, respectively. It can be observed that while PVHVG reduces the energy consumption of air conditioning, it slightly increases the energy consumption of lighting in the hotel building. In this study, lighting energy consumption was controlled with daylight illuminance. Therefore, the performance parameters of different windows have an impact on lighting energy consumption, among which PVHG has the highest lighting energy consumption performance (Gündoğdu and Cilasun Kunduraci 2019).

3.1.4. Equipment energy consumption

Fig. 10 shows the equipment energy consumption of the building. Since equipment energy consumption has no significant correlation with the structure and parameters of glazing types (Li 2017), the equipment energy consumption of different glazing types in the five climate zones is consistent. The annual equipment energy consumption is 472.58 MWh.

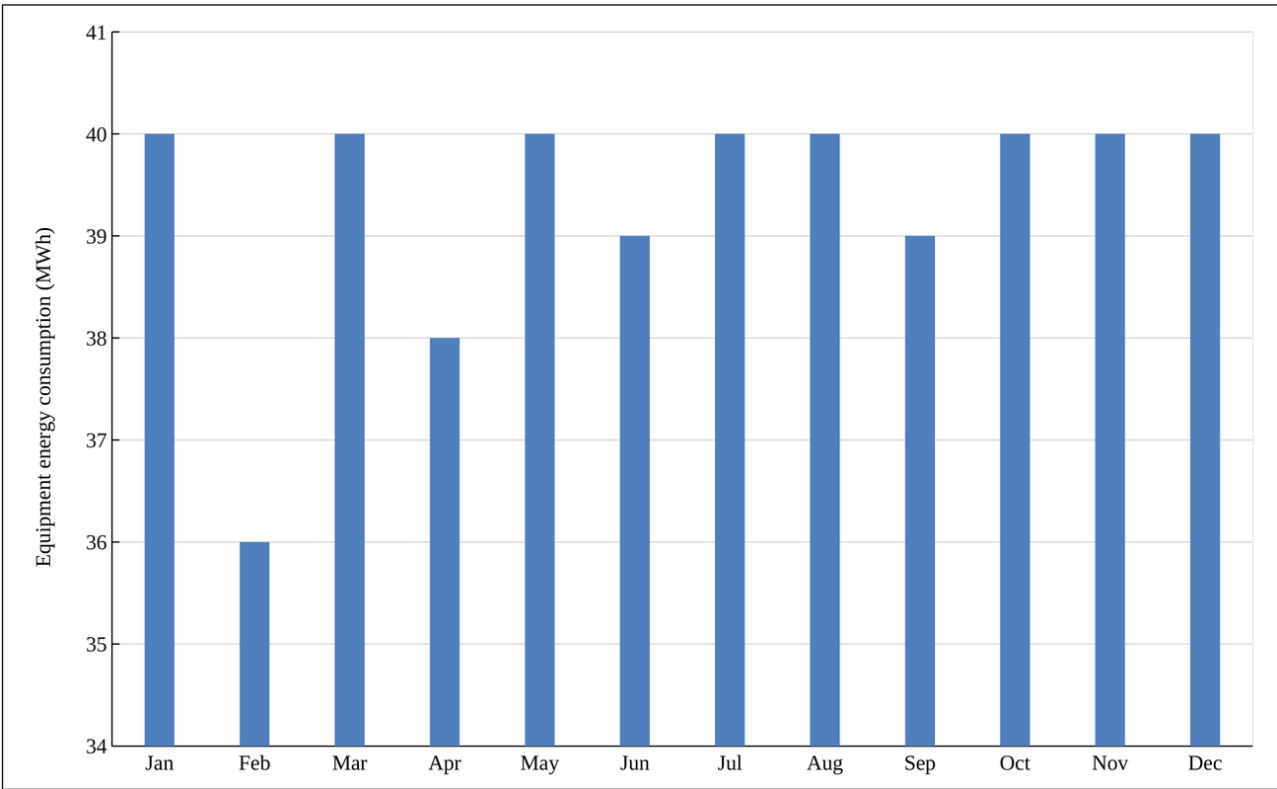


Figure 10. Equipment energy consumption of four types of glazing in hotel building in five climate zones

3.1.5. Power generation

Fig. 11 illustrates the power generation differences of three types of PV glazing applied to high-rise hotel building in the five major climate zones. The annual power generation of PVHVG of the five cities, sorted from highest to lowest, is 675.72 MWh (Hohhot), 504.00 MWh (Kunming), 495.25 MWh (Tianjin), 433.31 MWh (Xiamen), and 397.13 MWh (Hefei). Furthermore, the power generation of PVHVG has experienced a negative growth compared to PVHG, with the negative growth rate being 0.04 % in Xiamen. The underlying reason is that the low-temperature environment can lower the surface temperature of the photovoltaic glass, thereby reducing the loss of photoelectric conversion efficiency caused by high temperatures. Therefore, in cold climates, PVHVG achieves the highest power generation efficiency.

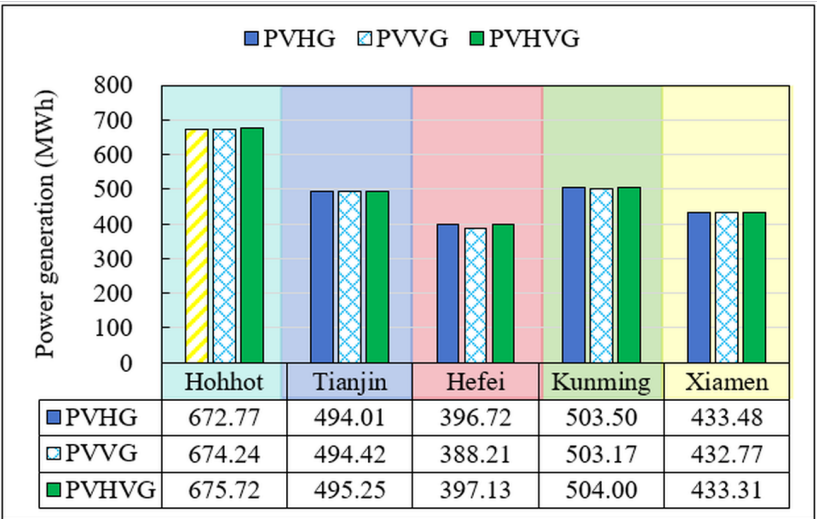


Figure 11. Power generation of three types of glazing in hotel building in five climate zones

Thanks to its outstanding thermal insulation capacity, PVHVG suffers considerable photovoltaic efficiency attenuation in hot cities such as Xiamen. Xiamen has a hot climate and the loss of battery photoelectric efficiency is high. The research finds that the power generation of the three types of glass is the highest in Hohhot and the lowest in Hefei. the energy generation of PVHVG in Hohhot increased by 0.435% and 0.22%, compared with PVHG and PVVG. These results indicate that the power generation performance of PVHVG is highly climate-dependent: it excels in cold regions due to lower cell temperatures, while its superior thermal insulation leads to a minor trade-off in electricity output under hot climates. However, when combined with the substantial cooling energy savings previously discussed, this slight reduction in power generation is far outweighed by the overall building energy efficiency gains. Therefore, PVHVG emerges as a versatile solution that maximizes total energy performance by balancing photovoltaic conversion and solar heat gain control across diverse climatic conditions.

3.1.6. Net energy consumption

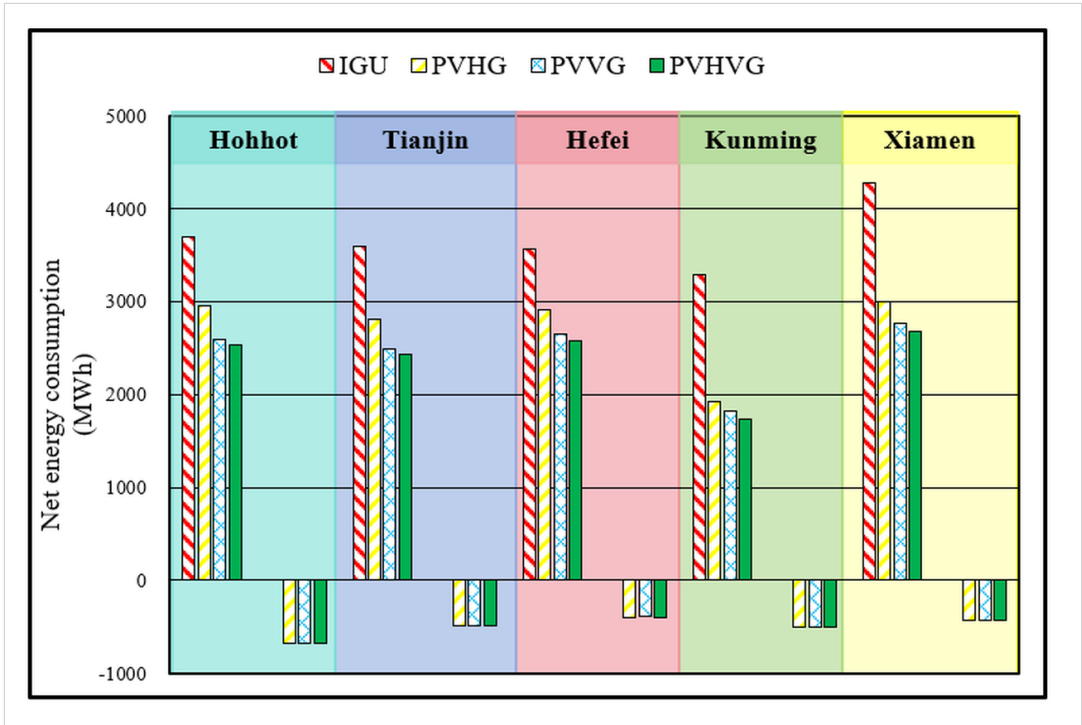


Figure 12. Net energy consumption of hotel building with four types of glazing

Net energy consumption is defined as the difference between total building energy consumption and photovoltaic power generation, which can more accurately quantify the net contribution of PV glazing to building energy balance. Fig. 12 presents the net energy consumption of hotel building applying the four types of glazing in the five major climate zones. When comparing the net energy consumption of four glazing types (IGU, PVHG, PVVG and PVHVG), the PVHVG yields the lowest net energy consumption in all five cities, demonstrating its optimal energy-saving performance.

Table 10. Net energy consumption of four types of glazing in hotel building in five climate zones

Glazing (MWh)	Hohhot	Tianjin	Hefei	Kunming	Xiamen
IGU	3701.72	3597.36	3561.53	3292.25	4277.48
PVHG	2284.14	2314.51	2519.66	1424.20	2563.41
PVVG	1916.92	1998.53	2259.12	1318.94	2335.88
PVHVG	1853.99	1931.69	2177.55	1234.59	2238.31

Table 10 lists the net energy consumption of four types of glazing in high-rise hotel building in five climate zones. The results indicate that relative to IGU, PVHVG achieves energy saving of up to 49.91%, 46.30%, 38.86%, 62.50% and 47.67% depending the location of Hohhot, Tianjin, Hefei, Kunming and Xiamen. Furthermore, PVHVG delivers greater energy saving in temperate and server cold climate zones. On the other hand, PVHVG outperforms both PVHG and PVVG in energy conservation. Compared with PVHG, PVHVG attains maximum energy saving rates of 18.83%, 16.54%, 13.58%, 13.31% and 12.68% for the hotel building in the five cities in sequence. When benchmarked against PVVG, the corresponding maximum saving rates reach 3.28%, 3.34%, 3.61%, 6.40% and 4.18%. Overall comparison with PVHG and PVVG confirms that PVHVG exhibits the most prominent energy-saving performance in Hohhot and Kunming. It is precisely this synergistic mechanism of heat insulation without hindering electricity, and power generation without generating heat that enables PVHVG to demonstrate the strongest comprehensive energy-saving

advantages in both extremely cold and mild climate zones, and provides a highly robust and economically feasible low-energy consumption enclosure structure solution for high-rise hotels under different climatic conditions.

3.2. Decarbonization potential of the hotel building using the PV glazing

Fig. 13 illustrates the carbon emissions of hotel building with four types of glazing. It can be seen from the broken line in Fig. 13 that the carbon emission reduction of PVHVG applied in high-rise hotel building is the largest in Hohhot, with the highest carbon reduction of 1265.52 tons, and the lowest reduction is in Kunming, with a carbon reduction of 220.79 tons, relative to IGU. Relative to PVHG, the carbon emission reductions brought by PVHVG in the five cities are 269.50 tons, 294.64 tons, 342.15 tons, 133.04 tons and 189.62 tons, respectively. Compared with PVVG, the corresponding carbon reductions reach 47.01 tons, 43.09 tons, 81.59 tons, 39.95 tons and 84.38 tons in sequence. The application of PVHVG shows certain advantages in different regions Temperate and severe cold climate zones endow this glazing system with greater energy-saving and emission-reduction potential Kunming has the lowest carbon emissions and the highest proportion (62.50%) of carbon emission reduction, the annual carbon emissions of PVHVG in high-rise hotel building are only 132.47 tons, because this region has low net energy consumption and a relatively low grid carbon emission factor.

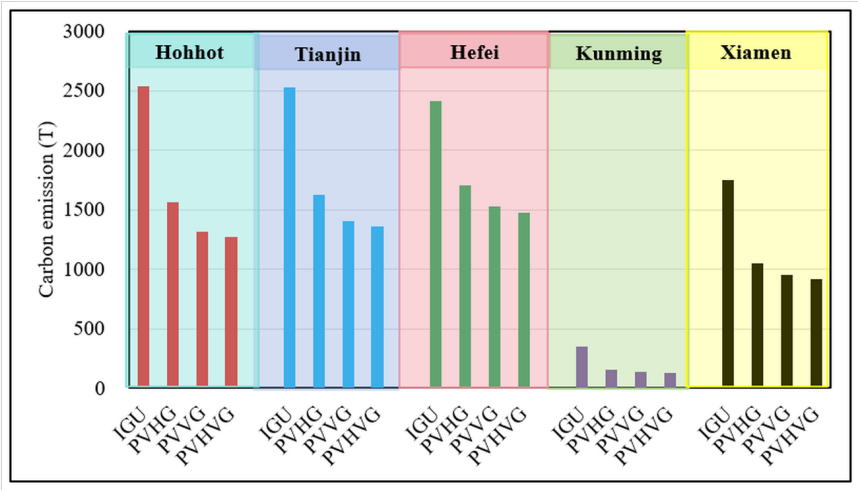


Figure 13. Carbon emissions of hotel building with four types of glazing

3.3. Lifetime economic performance of the hotel building using the PV glazing

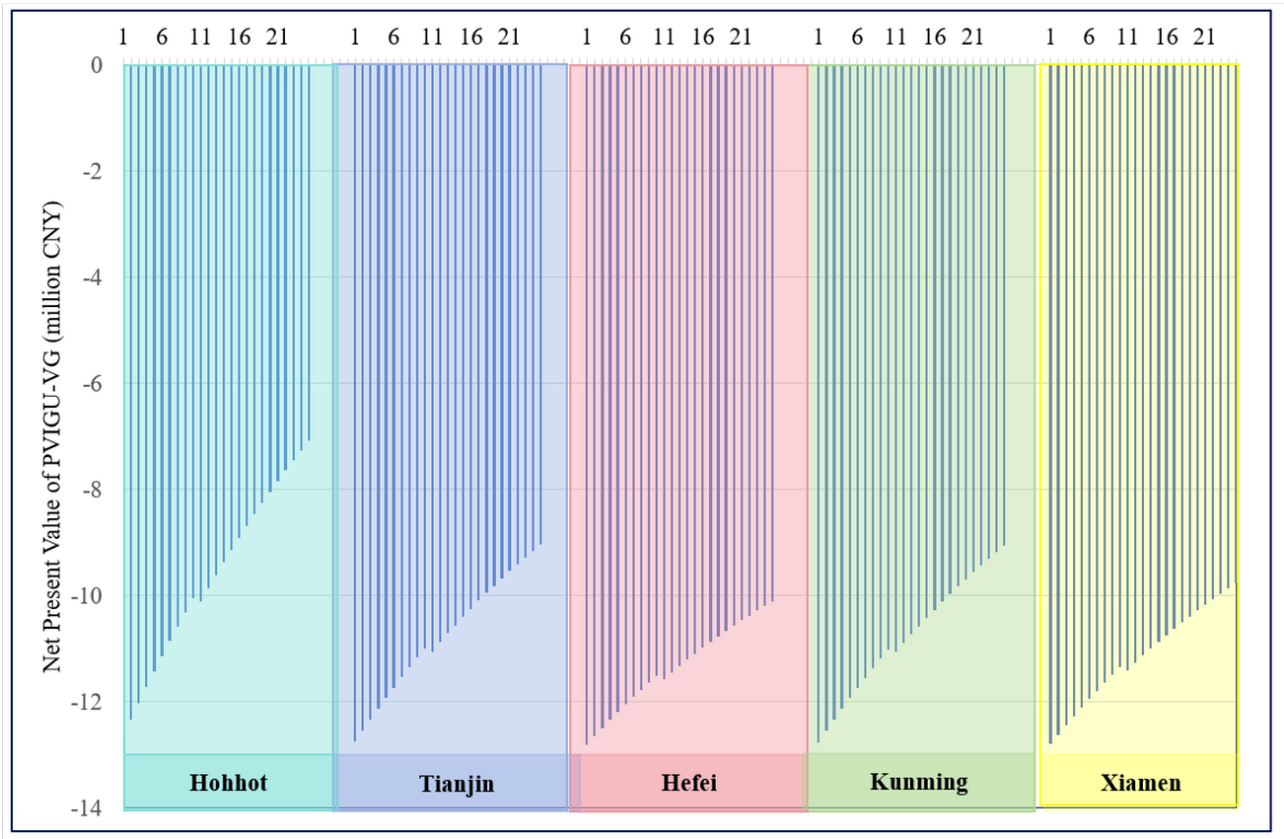


Figure 14. NPV of PVHVG in five cities

Fig. 14 shows the life-cycle net present value of PVHVG applied to hotel building in five climate zones. The study finds that the net present values of PVHVG in the five climate zones are 9.76 million CNY, 9.05 million CNY, 10.10 million CNY, 9.04 million CNY and 7.08 million CNY, at the market cost of 2210 CNY/m², respectively. It can be seen that during the life cycle, the application in Hohhot (severe cold region) has the optimal investment potential. Under this cost scenario, the PVHVG application is unable to achieve recovery in five climate zones.

Table 11. NPV of four types of PV glazing in five climate zones

NPV (Million CNY)	PVHG	PVVG	PVHVG
Xiamen	3.97	8.67	9.76
Kunming	3.27	7.97	9.05
Hefei	4.32	9.02	10.10
Tianjin	3.26	7.95	9.04
Hohhot	1.32	6.00	7.08

As summarized from the net present value data of the three types of PV glazing in Table 11, over the 25-year service life, PVHVG delivers the largest NPV across all five climate zones despite its highest upfront installation cost. PVVG ranks second, and PVHG ranks last. Across the five climate zones, the net present value of PVHVG applied to the high-rise hotel building in Hohhot was the lowest, at 7.08 million CNY, while the one applied to Hefei was the highest, at 10.10 million CNY. In addition, the net present value using the PV hollow vacuum glazing is increased by 57.23% (Hefei) ~ 81.36% (Hohhot) and 10.69% (Hefei) ~ 15.25% (Hohhot), compared with PVHG and PVVG among the

five climate zones. According to the study, the payback period of PV glazing is the best in severe cold regions. Although the higher initial investment in PVHVG leads to a greater net present value, this is offset by its superior energy-saving potential and carbon reduction capacity, particularly in severe cold regions where the payback period is found to be the most favorable. These findings indicate that the economic viability of PVHVG is strongly climate-dependent, with the best cost-benefit performance achieved in Hohhot, where the combination of high energy savings and a shorter payback period maximizes the long-term financial return. Therefore, PVHVG presents a compelling investment case in heating-dominated climates, as its enhanced thermal insulation not only reduces operational energy costs but also accelerates the recovery of the initial capital outlay.

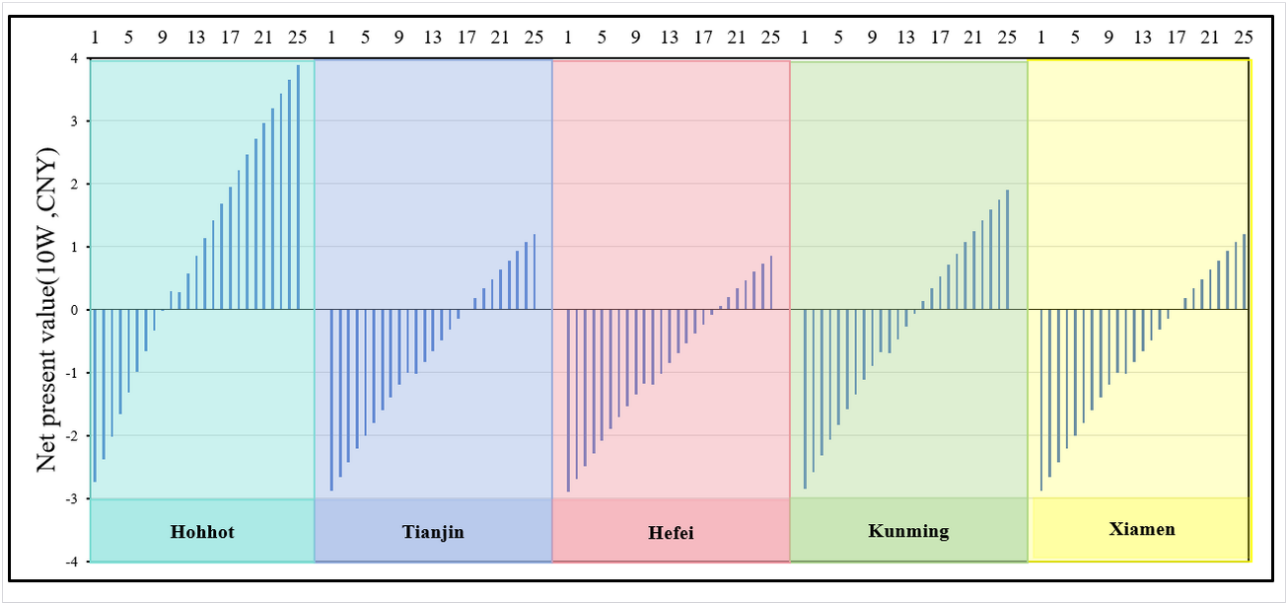


Figure 15. The NPV of PVHVG with a cost of 600 CNY in five climate zones

Fig.15 shows the lifecycle net present value (NPV) of the hotel building using the PVHVG. The results show that when PVHVG is installed on all exterior walls of the hotel building, with a cost of 2210 CNY, the net present value of the glass is higher. In five climate zones, with a lifespan of 25 years, the NPV is as high as 7.08 to 10.10 million (People's Republic of China 2026). Encouraging policy incentives and subsidies are proposed all over the world to accelerate the development pace of PV technologies with a decreasing initial cost. As the global leader in the photovoltaic industry, China's photovoltaic investment is expected to exceed 600 billion US dollars during the "13th Five-Year Plan" period. Through multiple policy tools such as special development funds, green fiscal and tax incentives, technology research and development subsidies, and grid connection and consumption guarantee mechanisms, the advantages of the entire industrial chain will be continuously consolidated. If the original price of the PVHVG is lowered to 600CNY/m², the PVHVG can shorten the investment payback period for hotel buildings in all five climate zones, and it can also extend the service life to 25 years. The results show that the NPV is the lowest in Hefei at 0.8578 million, and the investment can be recovered by the 19th year. The highest NPV was 3.8819 million in Hohhot, and the investment was recovered by the 10th year.

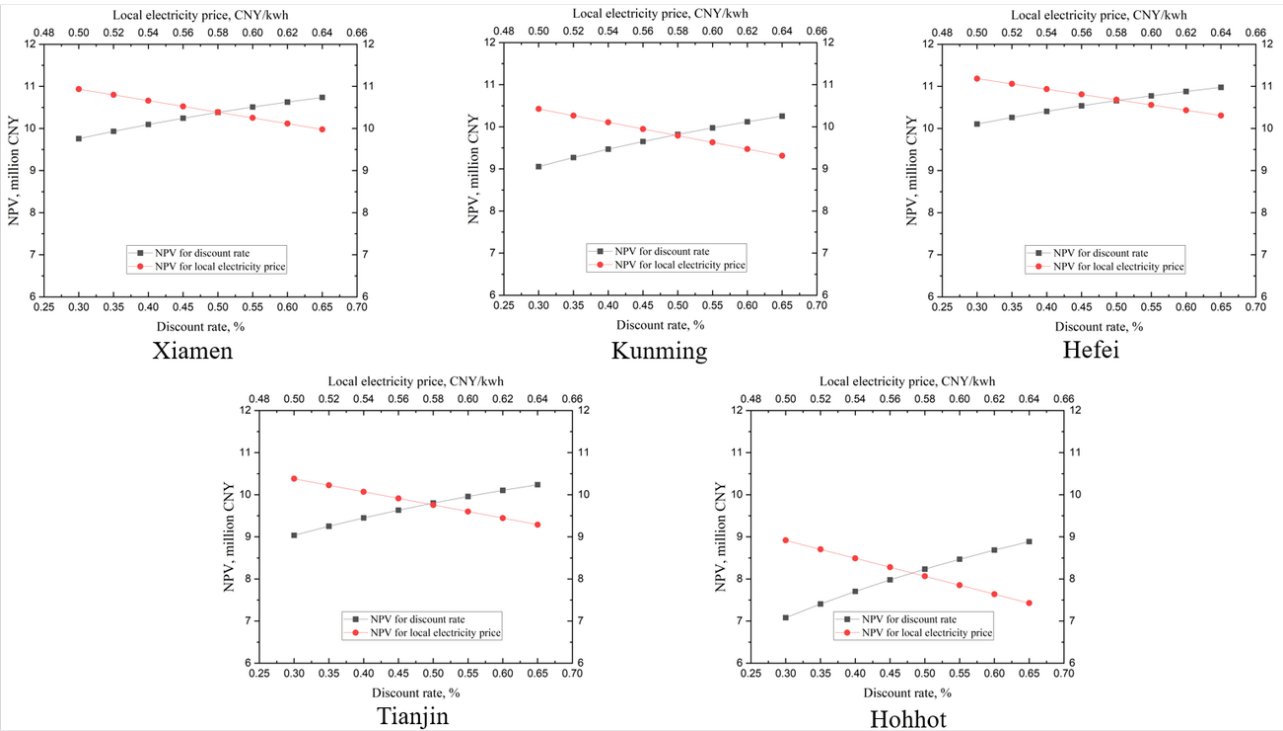


Figure 16. Sensitivity analysis of key variables affecting NPV of the PVHVG system.

Fig.16 presents the sensitivity analysis of key variables affecting NPV in five climate zones including discount rate and local electricity price. The local electricity price shows important impact on the NPV of the PVHVG system rising from 7.426 million CNY to 8.916 million CNY (+20.06 %, Hohhot), 9.289 million to 10.381 million CNY (+11.76%,Tianjin), 10.308 million to 11.184 million CNY (+8.50%, Hefei), 9.313 million to 10.424 million (+11.93%, Kunming), 9.978 million to 10.934 million CNY (+9.58%, Xiamen), when the local electricity price rises from 0.64 CNY/kWh to 0.50 CNY/kWh. The change in the discount rate also had a significant impact on the net present value. When the discount rate increased from 3% to 6.5%, the largest increase is approximately 25.52%, which occurred in Hohhot. The net present value rose from 7.080 million yuan to 8.887 million yuan. These results demonstrate that the economic viability of PVHVG is highly sensitive to both electricity pricing and financing conditions, with the greatest sensitivity observed in Hohhot. The substantial NPV response to electricity price variations highlights the importance of favorable tariff policies in improving project returns, particularly in severe cold regions. Moreover, the even stronger influence of the discount rate underscores that access to low-cost green financing could significantly enhance the investment attractiveness of PVHVG systems (Mohan *et al.* 2025).

3.4. Visual comfort evaluation of the PV glazing

Table 12. Standard values of maximum uncomfortable glare index in five cities

City	Xiamen	Kunming	Hefei	Tianjin	Hohhot
Standard value of glare index	≤27%	≤23%	≤27%	≤25%	≤23%

According to the provisions of Standard (GB 50033-2013) (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2013), the standard glare levels for cities in different climate zones are shown in Table 12.

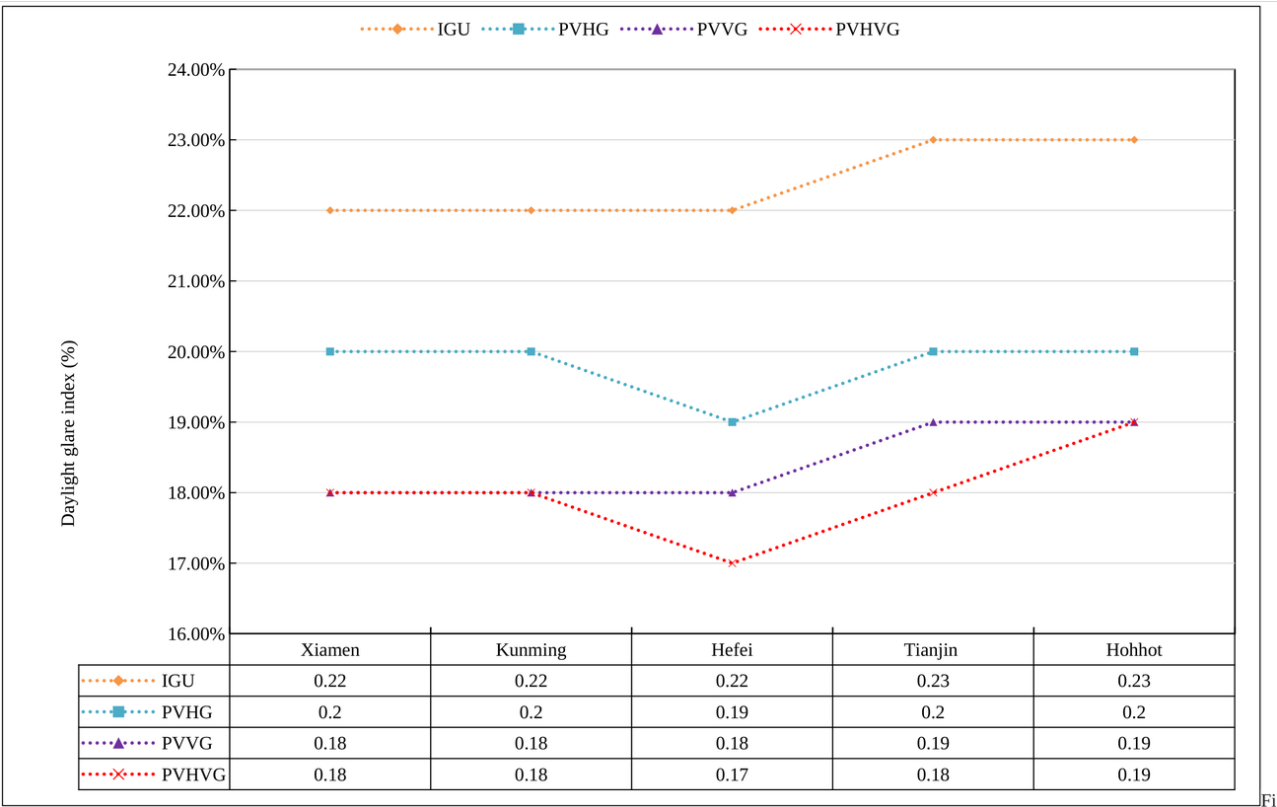


Figure 17. Maximum uncomfortable glare index of hotel building with four types of glazing

Based on the simulation results of the maximum uncomfortable glare index of the four types of glazing applied to hotels in different climate zones (Fig. 17) , PVHVG meets the daylighting design requirements in the application of hotel building in the five cities. Compared with IGU, PVHG and PVVG, PVHVG has the lowest DGI, which are 17.77%, 18.14%, 17.17%, 18.26%, and 18.75% in the five cities, respectively. This demonstrates that the low-glare characteristic of PVHVG can fully satisfy the long-term accommodation demands of hotel occupants and eliminate visual disturbances caused by screen reflections, without any design non-compliance risks. However, its low light transmittance will lead to indoor natural illuminance lower than the standard value, increasing lighting energy consumption.

3.5. The influence of orientation

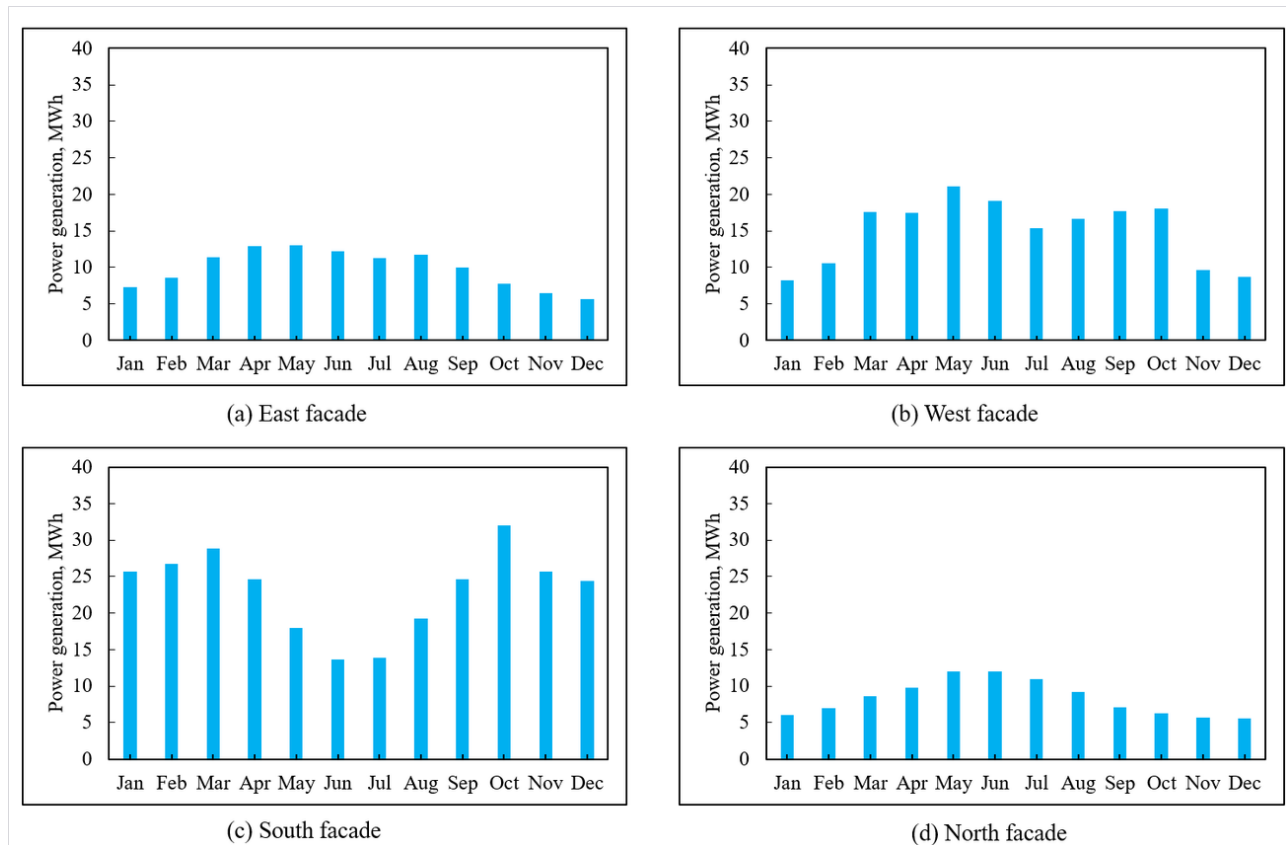


Figure 18. Energy production from the PVVG installed on various building sides.

Fig.18 illustrates the electricity production of the PVHVG used in different orientations of the hotel building. It is displayed that the PVHVG system in the south produces the most electricity with the most obvious monthly variation in electricity generation. In October, the southern orientation reaches a maximum generation of 31.95 MWh, while in June it drops to a minimum value of 13.59 MWh. The power generation on other facades reached its peak in May. Among them, the power generation on the north facade was 12.05 MWh, that on the east facade was 13.02 MWh, and that on the west facade was 21.12 MWh. This is mainly because the power generation on the south façade of the hotel building is most significantly affected by the direction of solar altitude. The southern PVHVG gets more solar radiation and produces more electricity during the winter months when the sun's altitude angle is low. As the sun's altitude angle increases in the summer, the PVHVG facade receives less solar radiation.

4. Conclusions

This study evaluates the comprehensive performance of the solar PV hollow vacuum glazing for high-rise hotel building application in different typical climate zones including the annual energy performance, decarbonization potential, lifetime economy, and visual comfort. Three traditional glazing is compared including insulated glazing unit, PV hollow glazing and PV vacuum glazing based on the coupled WINDOW and EnergyPlus platform. The main conclusions are as follows:

(1) The PV hollow vacuum glazing achieves the lowest U-value at $0.811 \text{ W}/(\text{m}^2 \cdot \text{K})$ (lower than insulated glazing unit at 1.879, PV hollow glazing at 1.764, and PV vacuum glazing at 0.884) and lowest SHGC at 0.193 (lower than IGU at 0.736, PVHG at 0.358, and PVVG at 0.228). The annual power generation of the PV hollow vacuum glazing is about 397.13 MWh (Hefei) ~ 675.72 MWh (Hohhot) in five climate zones. The net building energy consumption using the PV hollow vacuum glazing is

reduced by 38.86% (Hefei) ~ 62.5% (Kunming) compared with the insulated glazing unit among the five climate zones.

(2) The PV hollow vacuum glazing obtains the maximum decarbonization potential for 220.79 tons(Kunming)~ 1265.52 tons (Hohhot) among the five climate zones compared with other traditional glazings Even in Tianjin (cold) with a high carbon emission factor (0.7041 kgCO₂/kWh), the considerable carbon reduction of 1172.76 tons through reducing net energy consumption is still achieved, which confirms its application value in building under the double carbon goal.

(3) In terms of the lifecycle economy, the 25-year NPV of the PV hollow vacuum glazing ranges from 7.08 million CNY (Hefei) ~ 10.10 million CNY (Hohhot) in five climate zones. The maximum NPV is found in Hefei at 10.10 million CNY increased by 10.69% ~ 15.25% compared with PV vacuum glazing and 57.23% ~ 81.36% compared with PV hollow glazing. The maximum uncomfortable glare index of the PV hollow vacuum glazing ranges from 0.1717 (Hefei) to 0.1875 (Hohhot), which meets the requirements of indoor lighting codes and avoids indoor glare interference.

In summary, this study provides detailed technical-economic-environmental performance data of the PV hollow vacuum glazing for application in different climate zones, and it is considered the preferred solution for envelope upgrading of hotels and similar public building in diverse climate zones. In the future, long-term performance verification and multi-scenario expansion can further release its application potential.

Declarations

Author contributions. Yiweige Li, Jia Liu and Jialong Huang contributed to the conception and design of the study, to the analysis and interpretation of the results, and to the writing of the manuscript. All authors have read and approved the final version of the manuscript.

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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References

- Chen, Mo; Zhang, Wei; Xie, Lingzhi; Ni, Zhichun; Wei, Qingzhu; Wang, Wei; Tian, Hao (2019) 'Experimental and numerical evaluation of the crystalline silicon PV window under the climatic conditions in southwest China', *Energy*, 183, pp. 584-598. Available at: <https://doi.org/10.1016/j.energy.2019.06.146>
- Chen, Lin; Baghoolizadeh, Mohammadreza; Basem, Ali; Ali, Sadek Habib; Ruhani, Behrooz; Sultan, Abbas J.; Salahshour, Soheil; Alizadeh, As'ad (2024) 'A comprehensive review of a building-integrated photovoltaic system (BIPV)', *International Communications in Heat and Mass Transfer*, 159, pp. 108056. Available at: <https://doi.org/10.1016/j.icheatmasstransfer.2024.108056>
- Fonken, Laura K.; Nelson, Randy J. (2014) 'The Effects of Light at Night on Circadian Clocks and Metabolism', *Endocrine Reviews*, 35(4), pp. 648-670. Available at: <https://doi.org/10.1210/er.2013-1051>
- Fthenakis, Vasilis; Athias, Clement; Blumenthal, Alyssa; Kulur, Aylin; Magliozzo, Julia; Ng, David (2020) 'Sustainability evaluation of CdTe PV: An update', *Renewable and Sustainable Energy Reviews*, 123, pp. 109776. Available at: <https://doi.org/10.1016/j.rser.2020.109776>
- Fu, H (2025) 'Air Conditioning System Design Analysis and Application Cases', *Beijing: Chemical Industry Press*.
- Gholami, Hassan; Nils Røstvik, Harald; Manoj Kumar, Nallapaneni; Chopra, Shauhrat S. (2020) 'Lifecycle cost analysis (LCCA) of tailor-made building integrated photovoltaics (BIPV) façade: Solsmaragden case study in Norway', *Solar Energy*, 211, pp. 488-502. Available at: <https://doi.org/10.1016/j.solener.2020.09.087>
- Guangdong Provincial Development and Reform Commission (2021) *Report on Time-of-use Electricity Price in Guangdong Province*.
- Gündoğdu, E. and Cilasun Kunduraci, A (2019) *Effect of window glazings' visible transmittance to daylight factor and energy efficiency in an architecture studio*.

- Hu, Yilin; Xue, Qingwen; Wang, Haobo; Zou, Peng; Yang, Jinming; Chen, Shikeng; Cheng, Yuanda (2024) 'Experimental investigation on indoor daylight environment of building with Cadmium Telluride photovoltaic window', *Energy and Built Environment*, 5(3), pp. 404–413. Available at: <https://doi.org/10.1016/j.enbenv.2023.01.001>
- Huang, Junchao; Wang, Qiliang; Chen, Xi; Xu, Shiyuan; Yang, Hongxing (2021) 'Experimental investigation and annual overall performance comparison of different photovoltaic vacuum glazings', *Sustainable Cities and Society*, 75, pp. 103282. Available at: <https://doi.org/10.1016/j.scs.2021.103282>
- Huang, Mengyi; Chen, Yichen; Wu, Jindong; Luo, Xiaoyu; Fan, Yifan; Ge, Jian (2025) 'Quantify coupling effects between outdoor microclimate and building energy consumption for BIPV buildings in different local climate zones', *Energy and Buildings*, 347, pp. 116411. Available at: <https://doi.org/10.1016/j.enbuild.2025.116411>
- Ke, Wei; Ji, Jie; Zhang, Chengyan; Xie, Hao (2023) 'Modelling analysis and performance evaluation of a novel hybrid CdTe-PCM PV glass module for building envelope application', *Energy*, 284, pp. 129182. Available at: <https://doi.org/10.1016/j.energy.2023.129182>
- Kyrou, Evangelos; Goia, Francesco; Reith, András (2023) 'Current performance and future development paths of transparent PV glazing in a multi-domain perspective', *Energy and Buildings*, 292, pp. 113140. Available at: <https://doi.org/10.1016/j.enbuild.2023.113140>
- Li, R (2017) 'The correlation research of residential building indoor physical environment performance and energy consumption in hot summer and cold winter area', *MSc thesis*.
- Liu, Y., Zhao, H., Zhang, X., Zhang, C. and Yang, L (2020) 'Study on the solar heat gain coefficient and the air conditioning load of the external window shading system', *Nuantong Kongtiao/HV and AC*.
- Liu, Zhu; Deng, Zhu; He, Gang; Wang, Hailin; Zhang, Xian; Lin, Jiang; Qi, Ye; Liang, Xi (2022) 'Challenges and opportunities for carbon neutrality in China', *Nature Reviews Earth & Environment*, 3(2), pp. 141–155. Available at: <https://doi.org/10.1038/s43017-021-00244-x>
- Liu, Jia; Wu, Huijun; Huang, Huakun; Yang, Hongxing (2023) 'Renewable energy design and optimization for a net-zero energy building integrating electric vehicles and battery storage considering grid flexibility', *Energy Conversion and Management*, 298, pp. 117768. Available at: <https://doi.org/10.1016/j.enconman.2023.117768>
- Lv, Yajun; Peng, Huiwang; He, Manning; Huang, Yu; Wang, Junwei (2019) 'Definition of typical commercial building for South China's Pearl River Delta: Local data statistics and model development', *Energy and Buildings*, 190, pp. 119–131. Available at: <https://doi.org/10.1016/j.enbuild.2019.02.035>
- Meng, Wang; Jinjing, Peng; Hongxing, Yang; Yimo, Luo (2018) 'Performance evaluation of semi-transparent CdTe thin film PV window applying on commercial buildings in Hong Kong', *Energy Procedia*, 152, pp. 1091–1096. Available at: <https://doi.org/10.1016/j.egypro.2018.09.131>
- Ministry of Ecology and Environment of the People's Republic of China (2024) *Carbon Emission Factor Data*.
- Ministry of Housing and Urban-Rural Development of the People's Republic of China (2012) 'Design Code for Heating, Ventilation and Air Conditioning of Civil Building (GB 50736-2012)', *Beijing: China Architecture and Building Press*.
- Ministry of Housing and Urban-Rural Development of the People's Republic of China (2013) *Standard for Daylighting Design of Building (GB 50033-2013)*.
- Ministry of Housing and Urban-Rural Development of the People's Republic of China (2015) 'Design Standard for Energy Efficiency of Public Building (GB 50189-2015)', *Beijing: China Architecture and Building Press*.
- Mohan, Siddhika; Sharma, Bharat Bhushan; Mishra, Seema; Kumarasamy, Sudhakar (2025) 'Environmental and social impact of solar farms: Insights and perspectives from solar professionals', *Green Technology & Innovation*, 1(2), pp. 1–12. Available at: <https://doi.org/10.36922/gti025280008>
- Ortiz-Peña, Aarón; Honrubia-Escribano, Andrés; Gómez-Lázaro, Emilio (2025) 'Electricity Consumption and Efficiency Measures in Public Buildings: A Comprehensive Review', *Energies*, 18(3), pp. 609. Available at: <https://doi.org/10.3390/en18030609>
- Pan, Zhongjie; Liu, Jia; Wu, Huijun; Luo, Diqian; Huang, Jialong (2025) 'Theoretical-experimental-simulation research on thermal-daylight-electrical performance of PV glazing in high-rise office building in the Greater Bay Area', *Applied Energy*, 378, pp. 124739. Available at: <https://doi.org/10.1016/j.apenergy.2024.124739>
- People's Republic of China (2026) *Outline of the 15th Five-Year Plan for National Economic and Social Development of the People's Republic of China*.

- Qiu, Changyu; Yang, Hongxing (2020) 'Daylighting and overall energy performance of a novel semi-transparent photovoltaic vacuum glazing in different climate zones', *Applied Energy*, 276, pp. 115414. Available at: <https://doi.org/10.1016/j.apenergy.2020.115414>
- Roberts, Frank; Yang, Siliang; Du, Hu; Yang, Rebecca (2023) 'Effect of semi-transparent a-Si PV glazing within double-skin façades on visual and energy performances under the UK climate condition', *Renewable Energy*, 207, pp. 601–610. Available at: <https://doi.org/10.1016/j.renene.2023.03.023>
- Samuelson, Holly; Srivastava, Charu; Baniassadi, Amir (2025) 'Optimizing window solar heat gain coefficient for energy and carbon performance in a changing context of electrification and decarbonization', *Energy Reports*, 13, pp. 1450–1466. Available at: <https://doi.org/10.1016/j.egyr.2025.01.013>
- Schildt, Maximilian; Ferrando, Martina; Nardelli, Chiara; Causone, Francesco; van Treeck, Christoph; Frisch, Jérôme (2025) 'Cross-examination of country-specific archetypes generation for urban building energy modelling (UBEM)', *Sustainable Cities and Society*, 135, pp. 106940. Available at: <https://doi.org/10.1016/j.scs.2025.106940>
- Shukla, Akash Kumar; Sudhakar, K.; Baredar, Prashant (2016) 'A comprehensive review on design of building integrated photovoltaic system', *Energy and Buildings*, 128, pp. 99–110. Available at: <https://doi.org/10.1016/j.enbuild.2016.06.077>
- Tang, Haida; Long, Qihao; Li, Cuimin; Li, Chunying (2024) 'Experimental study of a PV-PCM window under hot summer and warm winter climate', *Journal of Energy Storage*, 96, pp. 112724. Available at: <https://doi.org/10.1016/j.est.2024.112724>
- The Standing Committee of Guangdong Provincial People's Congress (2023) *Report on the State of Guangdong Provincial Ecology and Environment*, 2023.
- US Department of Energy (2016) *Weather Data*. EnergyPlus. Available at: <https://energyplus.net/weather>
- Wang, Wenli; Liu, Yongsheng; Wu, Xinfang; Xu, Yan; Yu, Wenying; Zhao, Chunjiang; Zhong, Yunbo (2016) 'Environmental assessments and economic performance of BAPV and BIPV systems in Shanghai', *Energy and Buildings*, 130, pp. 98–106. Available at: <https://doi.org/10.1016/j.enbuild.2016.07.066>
- Wang, Qiankun; Wu, Haodong; Bai, Shuo; Wang, Lijun (2025) *Towards Net Zero Energy Buildings: Thermal and Energy Performance of CdTe Pv Glazing in Tropical Island Regions*. Elsevier BV. Available at: <https://doi.org/10.2139/ssrn.5251206>
- Wienold, Jan; Christoffersen, Jens (2006) 'Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras', *Energy and Buildings*, 38(7), pp. 743–757. Available at: <https://doi.org/10.1016/j.enbuild.2006.03.017>
- Wu, Zhenghong; Zhang, Ling; Su, Xiaosong; Wu, Jing; Liu, Zhongbing (2022) 'Experimental and numerical analysis of naturally ventilated PV-DSF in a humid subtropical climate', *Renewable Energy*, 200, pp. 633–646. Available at: <https://doi.org/10.1016/j.renene.2022.09.108>
- Yeom, Seungkeun; An, Jongbaek; Hong, Taehoon; Kim, Sungchul (2023) 'Determining the optimal visible light transmittance of semi-transparent photovoltaic considering energy performance and occupants' satisfaction', *Building and Environment*, 231, pp. 110042. Available at: <https://doi.org/10.1016/j.buildenv.2023.110042>
- Zhang, Chengyan; Ji, Jie; Wang, Chuyao; Ke, Wei (2024) 'Annual analysis and comparison of the comprehensive performance of a CdTe PV ventilated window integrated with vacuum glazing in different climate regions', *Renewable Energy*, 223, pp. 120029. Available at: <https://doi.org/10.1016/j.renene.2024.120029>
- Zhao, Y (2018) 'Calculation analysis and optimization of air distribution in a hotel lobby', *Journal of Yangzhou University*, 41(2), pp. 45–50.
- Zhu, Y (2025) 'Carbon Neutrality Strategy and Advancements in China's Building Sector', *Global Decarbonization*, 1(1), pp. 1–19.

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