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Research Article

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Posted Date: November 20th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11787951/v1

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Additional Declarations: The authors declare no competing interests.

Simulation-Based Optimization of Semi-Transparent Photovoltaic Solar Glass for Energy-Efficient Commercial Buildings in Bangladesh

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Abstract

Façades with large glazed areas are common in commercial buildings in Dhaka, where a hot-humid climate makes cooling a major energy end use. Semi-transparent photovoltaic (STPV) glazing can generate electricity while admitting daylight, but it also reduces daylight availability and changes solar heat gain, so its net benefit is not obvious, and studies for Bangladesh that combine glazing transmittance, glazed fraction, façade orientation and cost are limited. This study uses EnergyPlus 24.2 with a Dhaka typical-year weather file to evaluate five glazing systems (clear double glazing, solar-control Low-E double glazing, and STPV double glazing with visible light transmittance (VLT) of 40%, 30% and 20%) on a 20 m × 15 m single-floor office with window-to-wall ratios (WWR) of 20%, 40% and 60% on north-, east-, south- and west-facing façades, giving 60 annual simulations. The performance metric is net annual electricity use: cooling, lighting with daylight dimming and equipment, minus STPV generation. STPV gave the lowest net electricity in 6 of the 12 WWR–orientation combinations, all at WWR of 40% or more. The best case was a south-facing façade with 60% WWR and VLT 20%, at 63.3 kWh/m²·yr, which is 17.1% below clear glazing and 9.3% below Low-E glazing. At 20% WWR, STPV increased net electricity by 2.3–6.3% relative to Low-E glazing because the lighting penalty outweighed the small generation area. The glazing properties, STPV efficiencies and costs are assumed representative values. A sensitivity analysis over STPV output (×0.25 to ×2.5) shows that the energy conclusions depend strongly on STPV efficiency. The model was verified (geometry, generator calculation, and an independent solar-radiation calculation agreeing within 0.31%) and benchmarked against published office energy-use figures, but it was not validated because no measured data were available. An economic analysis with assumed installed costs and the June 2026 BERC tariffs found no case in which STPV had a positive net present value or a payback within 25 years at mid-range cost against Low-E glazing. A Monte Carlo analysis of the economic inputs gave a positive net present value in 0.02% of 20,000 draws for the best case; for the best case to break even, STPV would need an installed cost of about 1.7 to 2.6 times that of Low-E glazing.

Keywords: semi-transparent photovoltaics; building-integrated photovoltaics; EnergyPlus; window-to-wall ratio; Dhaka; commercial buildings; daylighting; economic analysis; sensitivity analysis

1. Introduction

1.1 Background

Commercial buildings in Bangladesh increasingly use glazed façades, and the climate of Dhaka, with a high annual mean air temperature, high humidity and strong solar radiation, means that much of the electricity used in these buildings goes to space cooling. Glazing is the weakest part of the thermal envelope: it admits solar heat gain in the cooling season, but it also supplies daylight that can displace

electric lighting. Design decisions about glazing type, glazed fraction and façade orientation therefore interact.

Semi-transparent photovoltaic (STPV) glass replaces part of the conventional glazing function with thin-film solar cells laminated in the glass. It turns part of the incident solar radiation into electricity, reduces the solar heat reaching the interior, and still transmits some visible light. These benefits come with costs: lower transmitted daylight raises artificial lighting demand, and the electrical output of a vertical façade is lower than that of an optimally tilted roof array. Whether STPV reduces total building electricity use therefore depends on the balance between generation, cooling and lighting, and that balance varies with climate, orientation and glazed area. Uddin et al. (2023) provide the starting reference for this study.

1.2 Previous studies

STPV glazing has been studied for office buildings for more than two decades, mostly by simulation. Miyazaki et al. (2005) used EnergyPlus to model a standard office floor in Japan, combining heating and cooling loads, daylighting and electricity production, and presented the optimum solar-cell transmittance for different orientations; window-to-wall ratio was also a study variable. Li et al. (2009) combined measurements on a semi-transparent PV panel with case studies of a generic reference office building with daylight-linked lighting control and a cost analysis, and concluded that such an integrated system could produce electricity and reduce lighting and cooling requirements. Didoné and Wagner (2013) simulated semi-transparent PV windows in Brazilian office buildings, and Xu et al. (2014) determined the optimal PV cell coverage ratio of office façades in central China, noting that the benefit of STPV varies between climates. Olivieri et al. (2014) compared STPV elements with a conventional solar-control glass that met the local technical standard, which is a more demanding comparator than plain glass and is the approach followed here with Low-E glazing. Other work addresses PV insulated glazing units under different climates (Zhang and Lu, 2019), single-glazed PV windows for offices in Hong Kong (Lu and Law, 2013), BIPV windows with semi-transparent cells (Chae et al., 2014) and the daylight performance of window-integrated STPV (Liu et al., 2020).

For Bangladesh, Uddin et al. (2023) assessed three configurations of semi-transparent CdTe window systems in an office building under Bangladesh's climate and concluded that such windows can conserve energy while providing daylight; they also noted that Bangladesh lacks policies and guidelines for BIPV in buildings. Refat and Sajjad (2020) discuss the potential of STPV for net-zero energy buildings from device to system level.

1.3 Research gap and contribution

These studies show that STPV can reduce building energy use, but that the outcome depends on climate, orientation, glazed fraction and transmittance, so results from Japan, Hong Kong, Brazil or China cannot be transferred directly to Dhaka. In the literature reviewed for this paper, we did not find a study that, for Dhaka, (i) varies WWR, façade orientation and VLT together while modelling daylight-controlled lighting; (ii) compares STPV against both clear glazing and solar-control Low-E glazing; (iii) states explicitly what has been verified and what has not been validated; and (iv) converts the result into payback, net present value and break-even cost under current tariffs, with an uncertainty analysis. This paper addresses these four points for a typical office floor.

The numerical results depend on assumed glazing properties and installed costs (Sections 2.3 and 6.1), because no product data or quotations were available. The contribution is therefore a transparent

comparison framework for Dhaka, with conclusions that are conditional on stated assumptions and tested over wide ranges of those assumptions, rather than product-specific predictions.

1.4 Aim and objectives

This paper quantifies that balance for a typical office floor in Dhaka. The objectives are to:

(1) quantify annual cooling, lighting and STPV generation for clear, Low-E and STPV glazing at WWR of 20%, 40% and 60% on four orientations;

(2) identify the glazing, WWR and orientation combination with the lowest net electricity use;

(3) determine in which combinations STPV is beneficial relative to conventional glazing, and in which it is not;

(4) test how sensitive the conclusions are to the assumed STPV efficiency and cooling system efficiency;

(5) verify and benchmark the simulation model, stating clearly what has and has not been validated;

(6) assess whether the energy saving justifies the cost, using payback, net present value and break-even cost under several tariff and cost scenarios; and

(7) quantify how far the conclusions change over wider ranges of STPV output and economic inputs, including a Monte Carlo uncertainty analysis of the economic results.

2. Methodology

2.1 Location and climate data

Simulations use the SWERA typical-year weather file for Dhaka (Tejgaon, 23.77° N, 90.38° E, 9 m elevation; file BGD_Dhaka.419230_SWERA.epw), produced under the UNEP Solar and Wind Energy Resource Assessment project with NREL. The file has 8,760 hourly records with an annual mean dry-bulb temperature of 25.8 °C (minimum 8.2 °C, maximum 39.4 °C), mean relative humidity of 75%, and annual global horizontal, direct normal and diffuse horizontal radiation of 1,754, 1,287 and 912 kWh/m² respectively. This is an older typical-year dataset rather than a recent TMY, which is noted as a limitation.

2.2 Building model

The model is a single thermal zone of 20 m × 15 m floor area (300 m²) and 3.0 m floor-to-ceiling height, representing a typical intermediate office floor. Floor and ceiling are adiabatic. Only one 20 m façade is glazed, and the other three façades are opaque brick walls (12.5 mm plaster, 230 mm brick, 12.5 mm plaster; $U \approx 2.1$ W/m²·K). Orientation is varied by rotating the building so that the glazed façade faces north, east, south or west, which isolates the effect of orientation on that façade. The window is a 19 m wide ribbon with its centre line 1.6 m above the floor; its height is set to obtain the target WWR on the 20 m × 3 m façade (12, 24 and 36 m² of glazing for WWR of 20%, 40% and 60%). No external shading devices are included.

Table 1. Main model inputs

Parameter	Value	Basis
Occupancy and schedule	18 m²/person, 120 W/person; Sunday–Thursday, 09:00–17:00 (lunch hour at half occupancy)	Assumed; Sunday–Thursday working week, typical office pattern
Lighting and equipment	10 W/m² lighting, 10 W/m² plug loads; weekday schedule 0.9 in occupied hours, small standby otherwise	Assumed; compared with the SREDA guideline in Section 5.3

Parameter	Value	Basis
Daylight control	Two reference points (3 m and 9 m from the window, 0.8 m height), 500 lux set point, continuous dimming to 10% minimum power, each point controlling half of the lighting	500 lux: general office illuminance in ISO 8995-1; layout assumed
Infiltration and ventilation	0.3 air changes per hour; outdoor air 2.5 L/s per person plus 0.3 L/s per m²	Ventilation rates: ASHRAE 62.1, Table 6-1 (office space); infiltration assumed
HVAC	EnergyPlus ideal loads air system, 08:00–17:00 Sunday–Thursday; cooling set point 24 °C, heating set point 20 °C; cooling COP 3.0, heating COP 1.0 (used to convert thermal loads to electricity)	Assumed; cooling COP varied from 2.5 to 3.5 in Section 4
Simulation	EnergyPlus 24.2.0, 4 time steps per hour, full-year run, SplitFlux daylighting	Crawley et al. (2001); U.S. DOE (EnergyPlus 24.2.0)

2.3 Glazing systems

Five double-glazed unit (DGU) systems were modelled using whole-unit properties in the EnergyPlus simple glazing model (U-factor, solar heat gain coefficient (SHGC) and visible transmittance). The clear and Low-E systems are typical commercial values. The STPV values, including module efficiency, are assumed representative values for amorphous-silicon-type semi-transparent modules, chosen so that SHGC and efficiency change consistently with VLT: a more transparent module has higher VLT and lower efficiency. They were not taken from a single measured product, and they are collected in one configuration file so they can be replaced by Uddin et al. (2023) or manufacturer data.

Table 2. Glazing properties used in the simulations (assumed representative values)

Glazing system	U (W/m²·K)	SHGC	VT	STPV module efficiency
Clear DGU	2.70	0.70	0.78	–
Solar-control Low-E DGU	1.90	0.38	0.68	–
STPV DGU, VLT 40%	2.30	0.38	0.40	4.0%
STPV DGU, VLT 30%	2.30	0.32	0.30	5.0%
STPV DGU, VLT 20%	2.30	0.26	0.20	6.0%

2.4 STPV generation model

STPV electricity is calculated with the EnergyPlus Generator:Photovoltaic object (simple performance model, fixed conversion efficiency) attached to the window surface, which uses the solar radiation incident on the glass, including shading, calculated hourly. Ninety per cent of the glazed area is taken as active cell area, and a simple inverter with 95% efficiency converts to AC. The photovoltaic model is decoupled from the thermal model: the effect of the cells on heat gain and daylight is represented through the SHGC and VT values in Table 2, and cell temperature effects on efficiency are not modelled.

2.5 Parametric matrix and performance metric

The study covers 5 glazing systems × 3 WWR × 4 orientations = 60 annual simulations. For each case the net annual electricity use is

$$E_{net} = E_{cool} / COP_c + E_{heat} / COP_h + E_{light} + E_{equip} - E_{PV} \qquad (1)$$

where E_cool and E_heat are the thermal cooling and heating loads from the ideal loads system (cooling includes the ventilation load), E_light is lighting electricity after daylight dimming, E_equip is plug-load electricity and E_PV is the AC output of the STPV. Equipment electricity is the same in every case, so differences between cases come from cooling, lighting and generation. Results are also

expressed per unit floor area (kWh/m²·yr). All STPV output is credited at full value in this metric; Section 6 examines how much of it is used on site. Absolute values are not calibrated against metered data (Section 5), so the study should be read as a comparison between glazing options.

2.6 Sources and status of model inputs

The inputs fall into three groups. (a) Inputs with an external basis: the SWERA weather file, the ventilation rates (ASHRAE 62.1, Table 6-1, office space: 2.5 L/s per person plus 0.3 L/s per m²), the 500 lux design illuminance (ISO 8995-1), the electricity tariffs (BERC, June 2026) and the exchange rate, and the simulation engine (Crawley et al., 2001). (b) Typical values assumed by the authors and cross-checked against published figures: internal gains, schedules, set points, cooling COP and the wall construction; the model output is compared with published energy-use figures in Section 5.3 and the wall U-factor is verified by hand calculation in Section 5.2. (c) Values assumed without product data: the glazing properties, the STPV module efficiencies and the installed costs. Group (c) is the main source of uncertainty and is tested in Sections 4 and 6.3. Any input in Tables 1, 2 and 12 without a cited basis is an assumption of this study.

3. Results and discussion

3.1 Incident solar radiation

The annual solar radiation incident on the glazed façade differs strongly by orientation: 1,141 kWh/m² on the south façade, 949 on the west, 941 on the east and 522 on the north. This ordering controls both the heat gain through the glass and the potential STPV output, and explains much of the orientation dependence below.

3.2 Effect of glazing on cooling, lighting and generation

Table 3 gives the average over all 12 WWR–orientation combinations. Cooling electricity falls from 12,028 kWh/yr with clear glazing to 11,006 kWh/yr with Low-E glazing (8.5% lower) and to between 11,034 and 11,146 kWh/yr with STPV. STPV therefore reduces cooling about as much as Low-E glazing, but it raises lighting electricity from 1,645 kWh/yr (clear) to 2,373, 2,828 and 3,540 kWh/yr for VLT of 40%, 30% and 20%. The generation of 729–1,094 kWh/yr offsets only part of this lighting increase on average, so across all 12 combinations the mean net electricity of STPV (VLT 40%) is about equal to Low-E glazing, and lower VLT is worse on average. The averages hide large differences between façades, which are examined next.

Table 3. Mean annual electricity by glazing system over all 12 WWR–orientation combinations

Glazing system	Cooling (kWh/yr)	Lighting (kWh/yr)	STPV output (kWh/yr)	Net electricity (kWh/yr)	Net change vs clear (%)
Clear DGU	12,028	1,645	0	21,312	–
Low-E DGU	11,006	1,776	0	20,420	−4.2
STPV, VLT 40%	11,146	2,373	729	20,429	−4.1
STPV, VLT 30%	11,053	2,828	911	20,608	−3.3
STPV, VLT 20%	11,034	3,540	1,094	21,120	−0.9

Cooling is thermal cooling load divided by COP 3.0. Equipment electricity (7,639 kWh/yr in all cases) is included in net electricity.

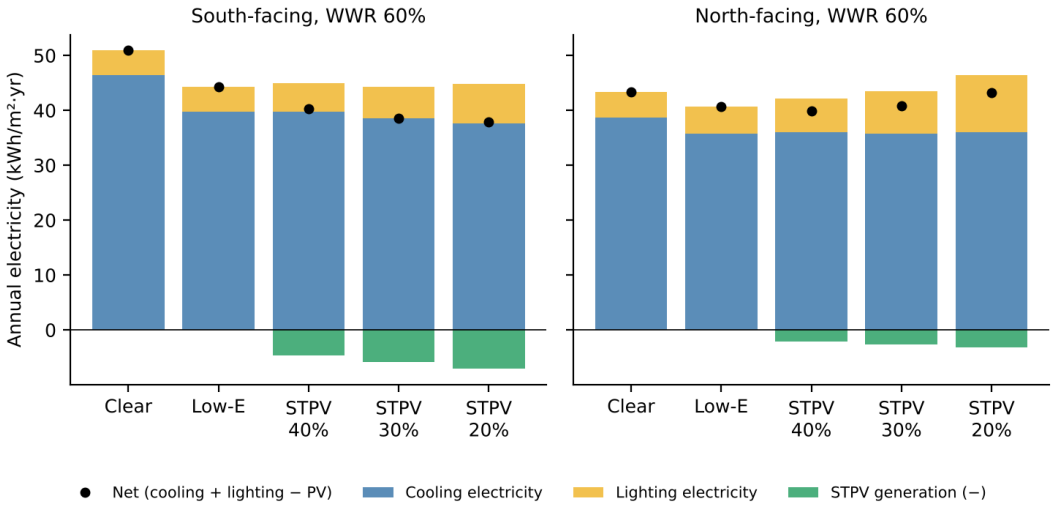

Figure 1. Annual cooling, lighting and STPV generation per m² of floor area for the south-facing (left) and north-facing (right) façade at WWR 60%. Equipment electricity is identical in all cases and is not shown.

3.3 Net electricity by WWR and orientation

Figure 2 and Table 4 give net electricity for all 60 cases. With clear glazing, net electricity rises with WWR on the east, south and west façades, because added glazing mainly adds solar heat gain: on the south façade it increases from 68.9 kWh/m²·yr at WWR 20% to 76.4 kWh/m²·yr at WWR 60%. On the north façade the dependence on WWR is weak because little direct sun reaches the glass. Low-E glazing limits this increase, and STPV limits it further when the glazed area is large enough to generate a useful amount of electricity.

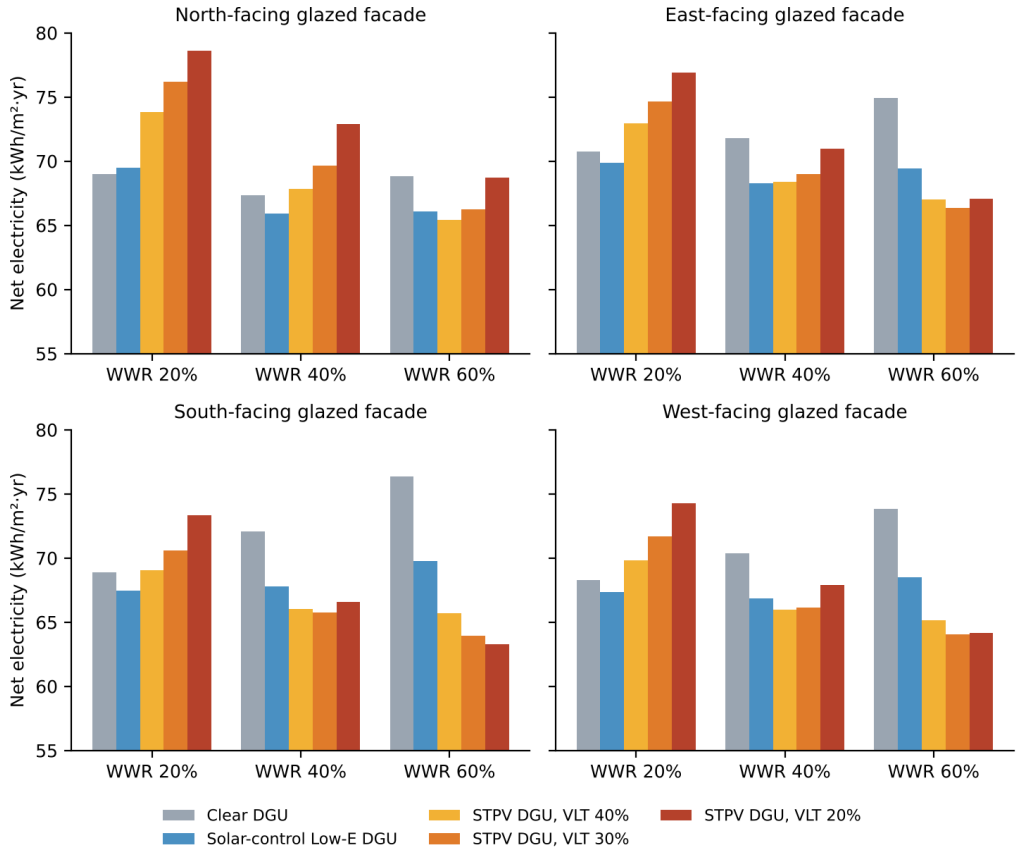

Figure 2. Net annual electricity use per m² of floor area for the five glazing systems at WWR 20%, 40% and 60% on each orientation. The vertical axis starts at 55 kWh/m²·yr to show differences between systems.

Table 4. Net annual electricity use (kWh/m²·yr); lowest value in each row in bold

WWR (%)	Façade	Clear DGU	Low-E DGU	STPV 40%	STPV 30%	STPV 20%
20	North	69.0	69.5	73.8	76.2	78.6
20	East	70.8	69.9	72.9	74.7	76.9
20	South	68.9	67.5	69.0	70.6	73.3
20	West	68.3	67.3	69.8	71.7	74.3
40	North	67.3	65.9	67.9	69.6	72.9
40	East	71.8	68.3	68.4	69.0	71.0
40	South	72.1	67.8	66.0	65.8	66.6
40	West	70.4	66.9	66.0	66.2	67.9
60	North	68.8	66.1	65.4	66.3	68.7
60	East	74.9	69.4	67.0	66.4	67.1
60	South	76.4	69.8	65.7	64.0	63.3
60	West	73.8	68.5	65.2	64.1	64.2

At 20% WWR the lowest net electricity is obtained with clear or Low-E glazing in every orientation. The glazed area (12 m²) is too small for STPV to generate much, while the daylight lost is relatively costly: in the 15 m deep plan, lighting electricity for STPV (VLT 20%) at WWR 20% is 4,649 kWh/yr on average, against 2,075 kWh/yr for clear glass. At WWR 60% the same VLT 20% glass needs 2,624 kWh/yr against 1,376 kWh/yr for clear glass, so the lighting penalty is smaller in absolute terms, while the glazing area available for generation is three times larger. This is why STPV becomes attractive as WWR increases.

3.4 Optimal configurations

Table 5 gives the best glazing for each combination. Clear or Low-E glazing is best in 6 of 12 combinations (all at WWR 20%, and the north and east façades at WWR 40%), and STPV is best in the other 6. At WWR 60% STPV is best on all four orientations: VLT 20% on the south façade (63.3 kWh/m²·yr, 17.1% below clear glazing and 9.3% below Low-E), VLT 30% on the west and east façades (13.2% and 11.4% below clear glazing), and VLT 40% on the north façade, where the benefit over Low-E is only 1.0%. The best VLT thus depends on solar exposure: façades with more incident radiation justify a lower VLT and higher efficiency, whereas on the north façade the generation is too small to justify the loss of daylight.

Table 5. Lowest-energy glazing for each WWR and orientation

WWR (%)	Façade	Best glazing	Net (kWh/m²·yr)	Saving vs clear (%)	Saving vs Low-E (%)	Best STPV vs Low-E (%)
20	North	Clear DGU	69.0	0.0	0.7	−6.3
20	East	Low-E DGU	69.9	1.2	0.0	−4.4
20	South	Low-E DGU	67.5	2.1	0.0	−2.3
20	West	Low-E DGU	67.3	1.4	0.0	−3.7
40	North	Low-E DGU	65.9	2.1	0.0	−3.0
40	East	Low-E DGU	68.3	4.9	0.0	−0.2
40	South	STPV 30%	65.8	8.8	2.9	+2.9
40	West	STPV 40%	66.0	6.2	1.4	+1.4
60	North	STPV 40%	65.4	4.9	1.0	+1.0
60	East	STPV 30%	66.4	11.4	4.4	+4.4
60	South	STPV 20%	63.3	17.1	9.3	+9.3

WWR (%)	Façade	Best glazing	Net (kWh/m²·yr)	Saving vs clear (%)	Saving vs Low-E (%)	Best STPV vs Low-E (%)
60	West	STPV 30%	64.1	13.2	6.5	+6.5

Positive values in the last column mean the best STPV option uses less electricity than Low-E glazing; negative values mean it uses more.

3.5 STPV generation

The annual AC output per m² of window area, averaged over the three WWR values, is 48.8 kWh/m² for the south façade, 40.6 for the west, 40.2 for the east and 22.3 for the north (STPV with VLT 30%). Lower-VLT glass produces more per m² because of its higher efficiency (Table 6). Output on the north façade is roughly half that of the south, in line with the incident radiation. Figure 3 shows the monthly pattern for VLT 30% at WWR 40%. The south façade has a strong seasonal swing: generation is highest from November to January (136–157 kWh/month) when the sun is low in the sky, and lowest in June and July (about 50 kWh/month) when the sun is high. The north façade shows the reverse pattern, with a maximum of about 60 kWh/month in May and June and a minimum of about 31–34 kWh/month in November to January. The east and west façades are the most uniform, between about 72 and 95 kWh/month throughout the year.

Table 6. Annual STPV AC output per m² of window area (kWh/m²·yr), mean of three WWR values

STPV glazing	North	East	South	West
STPV, VLT 40%	17.9	32.2	39.0	32.5
STPV, VLT 30%	22.3	40.2	48.8	40.6
STPV, VLT 20%	26.8	48.3	58.5	48.7

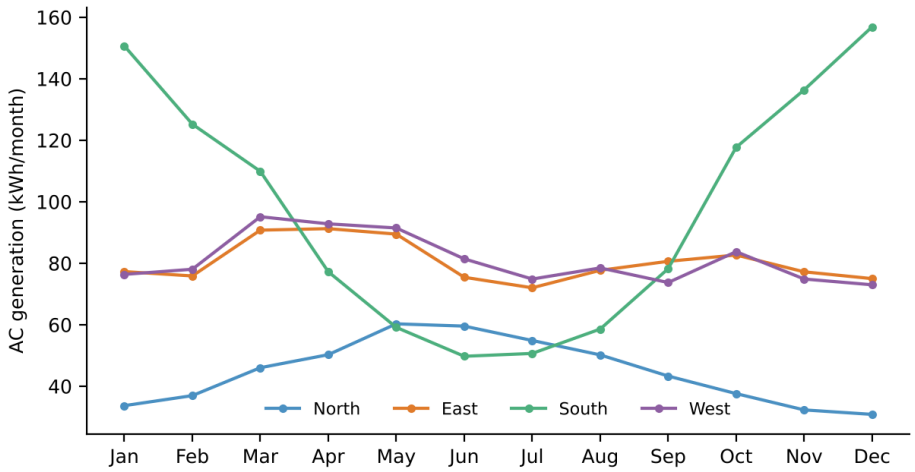

Figure 3. Monthly STPV AC generation for VLT 30% glazing at WWR 40%, by orientation.

4. Sensitivity analysis

4.1 STPV output and cooling COP

Because the STPV efficiency and glazing properties are assumed, the results were tested by scaling STPV output by 0.5, 1.0 and 1.5 and by varying the cooling COP from 2.5 to 3.5 (Table 7). With the assumed efficiencies the best STPV option beats Low-E glazing in 6 of 12 combinations. If STPV output is 50% lower, that falls to 4 of 12, and if it is 50% higher it rises to 7 of 12. The cooling COP has almost no effect on this count over the range tested, because STPV and Low-E glazing give similar cooling loads, so the comparison between them is decided by lighting and generation. Figure 4 shows the same effect for VLT 30% at WWR 60%: on the south, west and east façades STPV remains

better than Low-E glazing even at the lower efficiency, but on the north façade it needs an efficiency about the assumed value or higher to break even.

Table 7. Number of the 12 WWR–orientation combinations in which the best STPV option uses less net electricity than Low-E glazing

STPV output multiplier	COP 2.5	COP 3.0	COP 3.5
×0.5 (lower)	4 of 12	4 of 12	4 of 12
×1.0 (assumed)	6 of 12	6 of 12	6 of 12
×1.5 (higher)	7 of 12	7 of 12	7 of 12

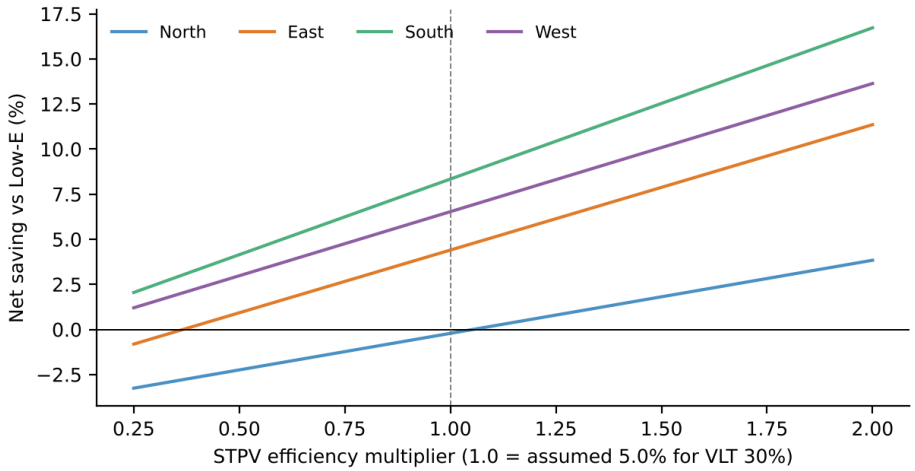

Figure 4. Net electricity saving of STPV (VLT 30%) relative to Low-E glazing at WWR 60% as a function of the STPV efficiency multiplier. The dashed line marks the assumed efficiency.

4.2 Extended range and break-even STPV output

The STPV output multiplier in Table 7 was extended from ×0.5–×1.5 to ×0.25–×2.5, and for every combination the multiplier at which the best STPV option uses the same net electricity as Low-E glazing was calculated (Table 8). The multiplier scales only the generation term of Equation (1); cooling, lighting and equipment electricity are those of the simulations, so these calculations rescale the results of the 60 runs and do not need new simulations. They reproduce the counts in Table 7 (4, 6 and 7 of 12 combinations at ×0.5, ×1.0 and ×1.5) and the first-year savings in Table 13 to within 24 kWh/yr, which is the effect of rounding in Tables 4 and 6.

Table 8. Output multiplier at which the best STPV option equals Low-E glazing in net electricity

WWR (%)	Façade	Best STPV VLT at ×1.0	Saving vs Low-E at ×1.0 (kWh/m²·yr)	Break-even output multiplier	VLT at break-even
20	North	40%	−4.3	7.01	40%
20	East	40%	−3.0	3.33	40%
20	South	40%	−1.5	1.96	40%
20	West	40%	−2.5	2.92	40%
40	North	40%	−2.0	2.40	40%
40	East	40%	−0.1	1.04	40%
40	South	30%	+2.0	0.42	40%
40	West	40%	+0.9	0.65	40%
60	North	40%	+0.7	0.67	40%
60	East	30%	+3.0	0.38	30%
60	South	20%	+6.5	0.01	30%

WWR (%)	Façade	Best STPV VLT at ×1.0	Saving vs Low-E at ×1.0 (kWh/m²·yr)	Break-even output multiplier	VLT at break-even
60	West	30%	+4.4	0.10	30%

A multiplier below 1 means STPV still beats Low-E glazing if its output is lower than assumed; a multiplier above 1 means the output must be higher than assumed. Calculated from Tables 4 and 6.

Figure 5a shows that the number of combinations in which STPV beats Low-E glazing is 2 at ×0.25, 4 at ×0.5, 6 at ×0.75 and ×1.0, 7 at ×1.25, 8 at ×2.0 and 9 at ×2.5. Table 8 shows two groups. For the south and west façades at WWR 60% the break-even multiplier is close to zero (0.01 and 0.10): with VLT 30%, cooling and lighting electricity together are within 0.5 kWh/m²·yr of Low-E glazing, so the saving comes almost entirely from generation. At the other end, the 20% WWR cases need about 2 to 7 times the assumed output; the north façade needs ×7.0, equivalent to an efficiency of about 28% at VLT 40% against the assumed 4%. The finding that STPV is not advantageous at small glazed areas is therefore not a consequence of the assumed efficiencies. The north façade at WWR 60% (0.67) and the west and east façades at WWR 40% (0.65 and 1.04) are marginal, with savings smaller than the uncertainty in the assumed efficiencies.

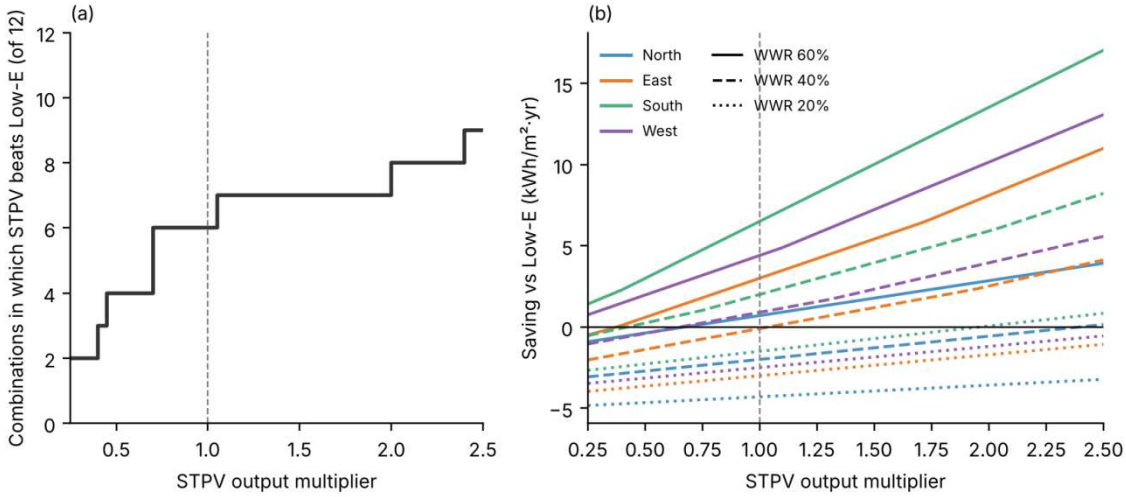

Figure 5. (a) Number of the 12 WWR–orientation combinations in which the best STPV option uses less net electricity than Low-E glazing, as a function of the STPV output multiplier. (b) Saving of the best STPV option relative to Low-E glazing for all 12 combinations (line colour: façade; line style: WWR).

4.3 Parameters not varied

Several inputs were not varied because they require new EnergyPlus runs: the glazing U-factor, SHGC and VT, the lighting power density and daylight set point, the building depth, and WWR values between 20% and 60%. The lighting penalty of low-VLT glass drives the result at small WWR (Section 3.3), so the assumed VT values and the lighting power density (Section 5.3) are likely to matter most among these. The extended range above therefore tests the uncertainty in STPV efficiency but not in the optical and thermal properties of the glass, and the sensitivity analysis should be read as partial.

5. Model verification and benchmarking

5.1 What is and is not claimed

No measured energy data from an office building in Dhaka, and no measured output from an STPV façade, were available for this study. The model is therefore not validated: no agreement between simulated and measured values is claimed. This section instead reports two separate things.

Verification checks that the model was built and solved as intended. Benchmarking compares model outputs with published figures to judge whether they are plausible. Neither shows that the model reproduces the behaviour of a particular real building.

5.2 Verification

Table 9. Verification checks

Check	Method	Result
Geometry and WWR	Window and wall areas and azimuths read from the EnergyPlus surface report of all 60 cases	Largest WWR error 0.0 percentage points; window azimuth correct (0°, 90°, 180°, 270°) in 60 of 60 cases
Opaque wall U-factor	Hand calculation from layer thickness and conductivity, compared with EnergyPlus	3.138 W/m²·K by hand and 3.138 W/m²·K in EnergyPlus (without films); the value with films (2.135) implies a film resistance of 0.150 m²·K/W
Window U-factor	Value reported by EnergyPlus compared with input	2.703, 1.901 and 2.302 W/m²·K reported, against inputs of 2.70, 1.90 and 2.30
STPV generator	Incident radiation × glazed area × active fraction × efficiency × inverter efficiency, compared with EnergyPlus for 36 cases	Largest difference 6.7e-14% (rounding). This confirms the inputs are applied as intended; it does not test the fixed-efficiency assumption
Incident solar radiation	Independent transposition of the same weather file to each vertical orientation with pvlib (Perez sky model)	Within 0.31% for all four orientations (Table 10)
Run integrity	EnergyPlus error files of all runs	60 of 60 runs completed with 0 severe errors; the only warnings concern blank schedule-type limits and the absence of a glare calculation point (glare is not assessed)

Table 10. Annual solar radiation on the glazed façade: EnergyPlus and an independent calculation (kWh/m²·yr)

Façade	EnergyPlus	Independent (pvlib)	Difference (%)
North	522	523	-0.17
East	941	942	-0.07
South	1,141	1,144	-0.31
West	949	950	-0.10

The independent calculation confirms that the weather data, solar geometry, orientation convention and sky model in EnergyPlus give the expected solar input to the façade, which is the quantity that drives both heat gain and STPV generation. It uses the same weather file, so it does not test the weather data themselves (Holmgren et al., 2018; Perez et al., 1990).

5.3 Benchmarking against published energy-use figures

Table 11 compares the model with the clear-glazing baseline (mean of the 12 WWR–orientation combinations) with published energy-use figures for offices. The model total of 71.0 kWh/m²·yr lies between the 58 kWh/m²·yr reported for Mobil House, a LEED Platinum-certified office in Dhaka (NZEB South Asia, n.d.), and the roughly 83 kWh/m²·yr implied by that project's statement that it uses 30% less energy than conventional offices in the region (our arithmetic, 58 / 0.7). It is well below the mean of 160 kWh/m²·yr found in a benchmark of 33 office buildings in Indonesia (Purba et al., 2025), which is expected because the model represents a single floor without lifts, pumps, server rooms or common areas.

Table 11. Model energy use (clear glazing, mean of 12 cases) against published figures (kWh/m²·yr)

Item	This model	Published figure
Cooling electricity (including ventilation air)	40.1	20 for air conditioning plus 3.5 for fans (SREDA guideline for government offices)
Lighting	5.5	8.5 (SREDA guideline)
Office equipment	25.5	10.2 (SREDA guideline)
Total	71.0	45 (SREDA guideline); 58 (Mobil House, Dhaka); about 83 (implied conventional offices); 160 (mean of 33 Indonesian offices)

The totals are plausible, but the components differ from the SREDA guideline values: modelled cooling is about 1.7 times the guideline and equipment about 2.5 times, while lighting is lower. Cooling is higher because the ideal loads system conditions all ventilation air (about 131 L/s) including its latent load, and equipment is higher because 10 W/m² was assumed during occupied hours. Lighting is lower because of daylight dimming. The SREDA values are guideline figures for government offices, not measurements. The consequence is that absolute energy and cost values in this paper are indicative. Equipment use is identical in all cases and does not affect comparisons, and the sensitivity of the conclusions to cooling efficiency is tested in Section 4. If real lighting power density is higher than assumed, the lighting penalty of low-VLT STPV would be larger than reported.

5.4 STPV generation

No manufacturer datasheet or measured outdoor yield for an STPV module was available, so the generation model could not be benchmarked against product data. The model's specific yield, which does not depend on the assumed efficiency, is 1,084 kWh/kWp·yr for the south façade, 902 for the west, 894 for the east and 496 for the north (incident radiation × inverter efficiency, with no cell temperature or low-light effects). These values should be compared with datasheet or measured yields when they are obtained. The absolute generation per m² of glass (Table 6) depends directly on the assumed efficiencies of 4–6%.

5.5 Status of the model

The model is verified: geometry, material properties, the generator calculation and the solar input to the façade behave as specified. It is benchmarked at the level of total energy use per m², which is plausible, but not at component level or for STPV output. It is not validated. Validation would require at least one year of metered cooling and lighting electricity from a Dhaka office floor with occupancy and set-point records, calibrated to accepted criteria such as those of ASHRAE Guideline 14, and outdoor measurements of an STPV sample. Until then, the results should be used to compare options, not to predict the consumption of a specific building.

6. Economic analysis

6.1 Method and inputs

The economic comparison treats Low-E double glazing as the conventional option and STPV as the alternative, so only the cost premium of STPV over Low-E is compared with the annual saving. A comparison with clear glazing is given as a secondary check. The annual saving ΔE is the reduction in net electricity use (Section 2.5): the change in cooling, heating and lighting electricity plus the STPV generation. The simple payback period is the cost premium divided by the first-year saving in taka. The net present value (NPV) discounts the saving in each year of the analysis life, with tariff escalation and STPV degradation:

$$NPV = -\Delta C \cdot A + \Sigma_{t=1..N} [\Delta E_{non\text{-}PV} + E_{PV}(1-d)^{t-1}] \cdot \tau(1+e)^{t-1} / (1+r)^t \qquad (2)$$

where ΔC is the installed cost premium per m² of glazing, A is the glazed area, and $\Delta E_non\text{-}PV$ is the annual reduction in non-PV electricity use (cooling, heating and lighting) relative to the Low-E reference, defined as:

$\Delta E_non\text{-}PV = E_non\text{-}PV,Low\text{-}E - E_non\text{-}PV,STPV$

A positive value therefore indicates that STPV uses less non-PV electricity than Low-E glazing, whereas a negative value indicates higher electricity use. E_PV is the first-year STPV electricity generation, d is the annual degradation rate, τ is the first-year electricity tariff, e is the annual tariff escalation rate, r is the discount rate, and N is the analysis period in years. The break-even premium is the value of ΔC for which NPV equals zero.

The tariff is taken from the BERC revision of June 2026, which set the commercial and office flat rate at Tk 15.36/kWh, with Tk 13.82 off-peak and Tk 18.43 at peak (bdnews24, 2026; The Business Standard, 2026). Three tariff scenarios are used: low (Tk 13.82, no escalation), base (Tk 15.36, 3% per year) and high (Tk 18.43, 6% per year). The escalation rates are assumptions; retail tariffs were raised by 8.5% in February 2024 (The Financial Express, 2026) and by an average of 16.7% in June 2026 (The Business Standard, 2026). No quotations for STPV or Low-E glazing in Bangladesh were available, so the installed costs below are assumptions and are the main uncertainty. The STPV range is informed by an industry estimate of €400–800/m² for semi-transparent PV modules made in 2012 (EPIA, cited by optics.org, 2012), and current prices may differ; the assumed cost includes the inverter and wiring. Quotations from suppliers should replace these values.

Table 12. Economic inputs

Input	Value	Basis
Electricity tariff, year 1	Tk 13.82 / 15.36 / 18.43 per kWh (low / base / high)	BERC June 2026 off-peak, flat and peak commercial rates
Tariff escalation	0% / 3% / 6% per year	Assumed
Low-E DGU installed cost	Tk 9,000/m² (about USD 73)	Assumed
Clear DGU installed cost	Tk 6,500/m² (about USD 53)	Assumed
STPV DGU installed cost	Tk 24,600 / 36,900 / 61,500 per m² (USD 200 / 300 / 500); premium over Low-E Tk 15,600 / 27,900 / 52,500 per m²	Assumed; includes inverter and wiring
Exchange rate	Tk 123 per USD	Bangladesh Bank reference rate of about Tk 122.9 (Financial Express, Aug 2026)
Analysis life, discount rate	25 years; 10% nominal	Assumed
STPV degradation	0.5% per year	Assumed
Not included	Demand charges, taxes, incentives, inverter replacement, maintenance differences, non-energy benefits	–

6.2 Results

Table 13 gives the economics of the lowest-energy STPV variant in each of the 12 WWR–orientation combinations, compared with Low-E glazing, at mid-range STPV cost and the base tariff. The first-year saving is positive in 6 of the 12 combinations (all at WWR of 40% or more) and negative in the other 6, where STPV increases electricity use; the east façade at WWR 40% is almost break-even (-32 kWh/yr). The largest saving is 1,943 kWh/yr (Tk 29,842) for the south façade at WWR 60% with VLT 20%, but its cost premium of Tk 1,004 thousand gives a simple payback of 33.7 years and an NPV of −Tk 0.68 million. No combination has a payback within the 25-year life at mid-range cost.

Table 13. Economics of the best STPV variant against Low-E glazing (mid-range STPV cost, base tariff)

WWR (%)	Façade	STPV	Year-1 saving (kWh)	Year-1 saving (Tk)	Premium (Tk thousand)	Simple payback (years)	NPV (Tk million)
20	North	VLT 40%	-1,311	-20,134	335	no saving	-0.57
20	East	VLT 40%	-912	-14,011	335	no saving	-0.50
20	South	VLT 40%	-474	-7,284	335	no saving	-0.42
20	West	VLT 40%	-751	-11,540	335	no saving	-0.47
40	North	VLT 40%	-584	-8,972	670	no saving	-0.78
40	East	VLT 40%	-32	-497	670	no saving	-0.68
40	South	VLT 30%	599	9,206	670	72.7	-0.57
40	West	VLT 40%	272	4,180	670	160.2	-0.63
60	North	VLT 40%	208	3,191	1,004	314.8	-0.97
60	East	VLT 30%	917	14,082	1,004	71.3	-0.85
60	South	VLT 20%	1,943	29,842	1,004	33.7	-0.68
60	West	VLT 30%	1,343	20,626	1,004	48.7	-0.78

Negative savings mean STPV uses more electricity than Low-E glazing.

Table 14 varies cost and tariff for the best case. Only the low cost scenario gives a payback within the 25-year life (20.9, 18.8 and 15.7 years for the low, base and high tariff), and even there the NPV at a 10% discount rate is negative; the nearest to break-even is the low cost, high tariff scenario at −Tk 0.05 million. Across all nine cost and tariff scenarios, the best STPV variant in none of the 12 combinations has a positive NPV against Low-E glazing, and none has a payback of 10 years or less. Against clear glazing the best case has a payback of 18.2 years at mid-range cost, but the NPV is still negative (−Tk 0.42 million).

Table 14. Best case (south façade, WWR 60%, VLT 20%) against Low-E glazing: simple payback in years (NPV in Tk million)

STPV cost scenario	Low tariff	Base tariff	High tariff
Low (Tk 24,600/m²)	20.9 (-0.33)	18.8 (-0.23)	15.7 (-0.05)
Mid (Tk 36,900/m²)	37.4 (-0.77)	33.7 (-0.68)	28.1 (-0.49)
High (Tk 61,500/m²)	70.4 (-1.66)	63.3 (-1.56)	52.8 (-1.38)

Because the cost inputs are uncertain, the break-even premium (Table 15, Figure 6) is the more robust result. For the best case it is Tk 6,504 to Tk 14,221 per m² over Low-E glazing, depending on tariff, so STPV would need an installed cost of about Tk 15,504 to Tk 23,221 per m² (USD 126 to 189), or 1.7 to 2.6 times the assumed cost of Low-E glazing. This is below even the low cost scenario of Tk 24,600/m². The break-even premium is lower for the other combinations, and for WWR 20% it is negative because STPV saves no energy.

Table 15. Break-even cost premium of the best STPV variant over Low-E glazing (NPV = 0, Tk per m² of glazing)

WWR (%)	Façade	STPV	Low tariff	Base tariff	High tariff
20	North	VLT 40%	none	none	none
20	East	VLT 40%	none	none	none
20	South	VLT 40%	none	none	none
20	West	VLT 40%	none	none	none
40	North	VLT 40%	none	none	none

WWR (%)	Façade	STPV	Low tariff	Base tariff	High tariff
40	East	VLT 40%	none	none	none
40	South	VLT 30%	2,911	4,056	6,287
40	West	VLT 40%	1,275	1,765	2,715
60	North	VLT 40%	643	888	1,363
60	East	VLT 30%	3,012	4,207	6,540
60	South	VLT 20%	6,504	9,116	14,221
60	West	VLT 30%	4,495	6,300	9,828

"None" means STPV uses more electricity than Low-E glazing, so no premium is justified. The assumed premiums are Tk 15,600, 27,900 and 52,500 per m².

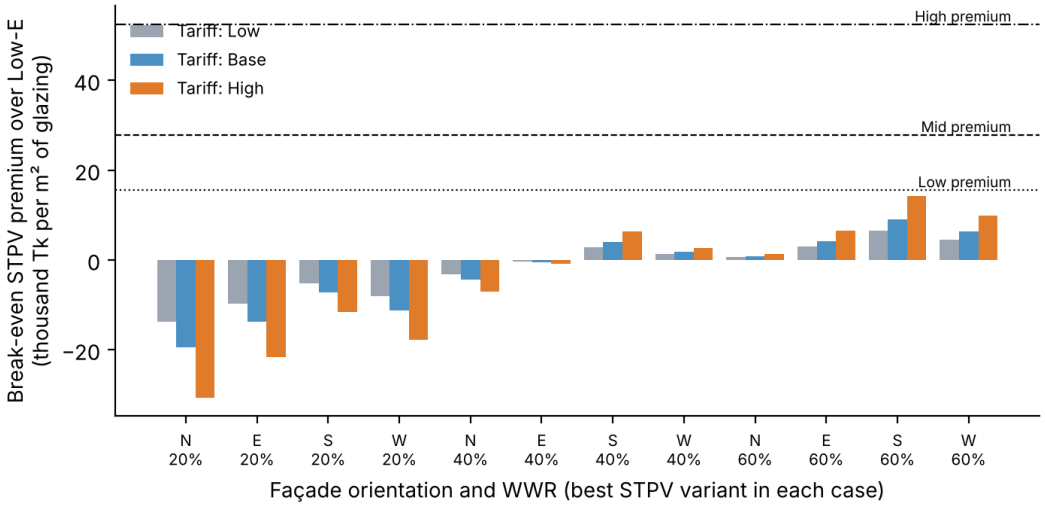

Figure 6. Break-even premium of the best STPV variant over Low-E glazing for the three tariff scenarios. Horizontal lines are the assumed premiums for the low, mid and high STPV cost scenarios.

The net metric in Section 3 credits all STPV output at the retail tariff. In the hourly results, the share of STPV output consumed in the same hour averages 96% across the STPV cases and is lowest (83%) for the east façade at WWR 60% and VLT 20%; in the best case it is 86%. If surplus output were not credited, the best-case break-even premium would fall from Tk 9,116 to Tk 7,681 per m² (16% lower) at the base tariff. Whether surplus is credited depends on the utility's net-metering arrangement, which should be confirmed.

6.3 Sensitivity and uncertainty of the economic results

The conclusions of Section 6.2 depend on assumed costs and tariffs, so they were tested in two ways, both applied to the results of the 60 simulations without new EnergyPlus runs. The first-year saving of each combination was split into STPV generation (Table 6 multiplied by the glazed area) and the change in cooling, heating and lighting electricity (the remainder of the saving in Table 13). With this split, Equation (2) reproduces the NPVs of Tables 13 and 14 to within Tk 0.01 million, the break-even premiums of Table 15 to within 0.2%, and the paybacks of Table 14 to within 0.1 years; the largest payback difference in Table 13 is 0.4 years, for a case with a payback of about 315 years.

One-at-a-time sensitivity. Table 16 and Figure 7 vary one input at a time for the best case (south façade, WWR 60%, VLT 20%), with all other inputs at their mid-range values (NPV −Tk 0.68 million). The installed cost of STPV dominates: over the assumed range of Tk 24,600 to 61,500 per m² the NPV varies from −Tk 0.23 to −Tk 1.56 million. STPV output (×0.5 to ×1.5), discount rate and

tariff escalation are next in importance. No single input brings the NPV to zero within the ranges tested. In Table 16 the tariff and its escalation are varied separately, whereas in Table 14 they were varied together.

Table 16. One-at-a-time sensitivity of the best-case NPV of STPV against Low-E glazing (south façade, WWR 60%, VLT 20%)

Input varied	Range (favourable → unfavourable)	NPV, favourable (Tk million)	NPV, unfavourable (Tk million)	Swing (Tk million)
STPV installed cost	Tk 24,600 → 61,500 per m²	−0.23	−1.56	1.33
STPV output	×1.5 → ×0.5	−0.50	−0.85	0.36
Discount rate	6% → 14%	−0.52	−0.76	0.24
Tariff escalation	6% → 0% per year	−0.58	−0.74	0.17
Low-E installed cost	Tk 10,800 → 7,200 per m²	−0.61	−0.74	0.13
Tariff, year 1	Tk 18.43 → 13.82 per kWh	−0.61	−0.71	0.10
Analysis life	30 → 20 years	−0.66	−0.70	0.05
STPV degradation	0.2% → 1.0% per year	−0.67	−0.69	0.02

Other inputs at mid-range values: STPV Tk 36,900/m², Low-E Tk 9,000/m², tariff Tk 15.36/kWh with 3% escalation, discount rate 10%, degradation 0.5%, life 25 years.

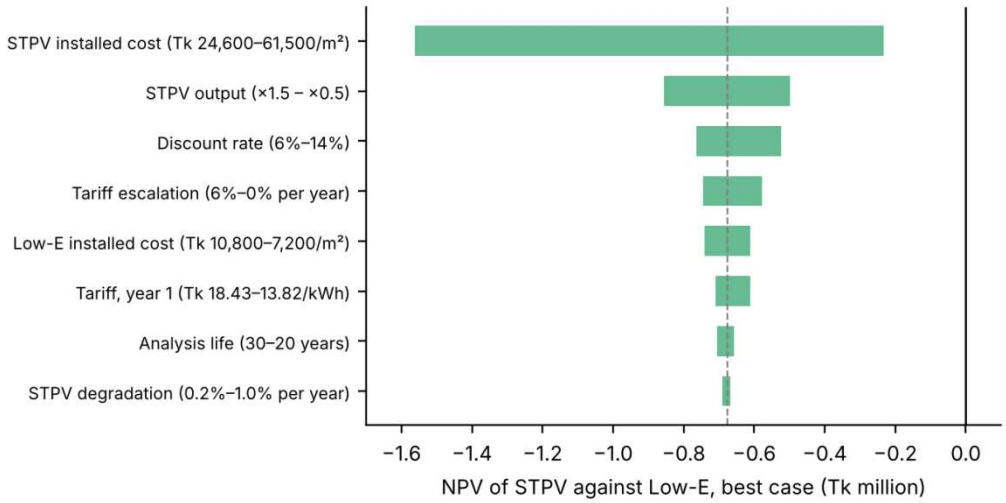

Figure 7. One-at-a-time sensitivity of the NPV of STPV against Low-E glazing for the best case. Bars span the ranges in Table 16; the dashed line is the mid-range, base-tariff NPV (−Tk 0.68 million).

Monte Carlo analysis. All inputs were then varied together in 20,000 random draws, using triangular distributions (minimum, most likely, maximum) for STPV installed cost (Tk 24,600, 36,900, 61,500 per m²), first-year tariff (Tk 13.82, 15.36, 18.43), tariff escalation (0%, 3%, 6%), discount rate (6%, 10%, 14%), degradation (0.2%, 0.5%, 1.0%) and STPV output multiplier (×0.5, ×1.0, ×1.5), and a uniform distribution for Low-E installed cost (Tk 7,200 to 10,800 per m²). The distributions encode the assumed ranges of this study, not measured variability; the inputs were sampled independently, although tariffs and escalation are in reality related, and the probabilities below are conditional on these assumptions and are not forecasts.

For the best case the median NPV was −Tk 0.78 million (5th to 95th percentile −1.33 to −0.35), lower than the mid-range value of −Tk 0.68 million because the cost distribution is skewed towards high values (mean Tk 40,900 per m² against a most likely value of Tk 36,900). The NPV was positive in 4 of 20,000 draws (0.02%), and in none of the draws for the other five combinations (Table 17, Figure

8a). The rank correlation of the NPV with the inputs was −0.93 for STPV cost, +0.25 for STPV output, −0.16 for discount rate, +0.11 for escalation, +0.11 for Low-E cost, +0.05 for tariff and −0.01 for degradation, confirming that STPV cost is the controlling uncertainty.

To show how much cheaper STPV would have to be, the STPV cost distribution was scaled down (Figure 8b, Table 17). At 75% of the assumed cost the probability of a positive NPV in the best case is about 2%, at 50% (mean Tk 20,500 per m²) it is about 36%, and at 40% about 70%; for the other combinations it remains below 15% at 50% of the cost. This is consistent with the break-even premium of Section 6.2, and it shows that only a large reduction in installed cost would change the economic conclusion.

Table 17. Monte Carlo results for the six combinations in which STPV uses less electricity than Low-E glazing (20,000 draws)

Combination	STPV	Median NPV (Tk million)	5th–95th percentile (Tk million)	P(NPV>0) at assumed cost (%)	P(NPV>0) at 75% of cost (%)	P(NPV>0) at 50% of cost (%)
South 60%	VLT 20%	−0.78	−1.33 to −0.35	0.02	2.0	35.8
West 60%	VLT 30%	−0.89	−1.42 to −0.47	0.0	0.1	13.8
East 60%	VLT 30%	−0.97	−1.50 to −0.56	0.0	0.0	4.0
South 40%	VLT 30%	−0.65	−1.00 to −0.37	0.0	0.0	4.2
West 40%	VLT 40%	−0.71	−1.06 to −0.44	0.0	0.0	0.2
North 60%	VLT 40%	−1.09	−1.62 to −0.69	0.0	0.0	0.0

NPV of the best STPV variant against Low-E glazing. The last two columns scale the STPV installed cost distribution to 75% and 50% of its assumed value. Probabilities are conditional on the assumed distributions.

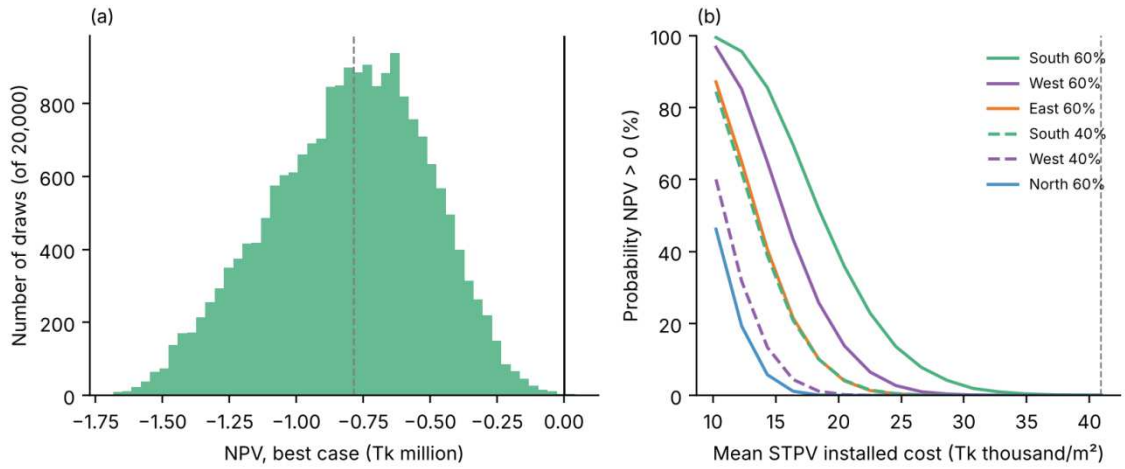

Figure 8. Monte Carlo uncertainty analysis. (a) Distribution of the best-case NPV (20,000 draws); dashed line: median, solid line: NPV = 0. (b) Probability of a positive NPV for six combinations as the mean STPV installed cost is reduced; the dashed vertical line marks the assumed mean of Tk 40,900 per m².

6.4 Discussion of the economic results

On energy savings alone, and with the assumed costs, STPV glazing is not economically justified against Low-E glazing in any of the 12 combinations. The best case, a south-facing glazed façade with large WWR and VLT 20%, comes closest, and would reach break-even if the installed cost fell to roughly 1.7 to 2.6 times that of Low-E glazing, or if tariffs rose faster than assumed. Benefits that were not valued could change the balance: reduced glare, lower carbon emissions, reduced dependence on backup generation during supply interruptions, avoided demand charges and the architectural value of an integrated façade. These need separate assessment. The conclusions of this

section are conditional on the assumed costs and should be recomputed with supplier quotations, which is possible through the supplementary workbook.

7. Discussion

7.1 Why the result depends on WWR and orientation

Three effects interact. First, in the model STPV and Low-E glazing give almost the same cooling electricity (Table 3: 11,006 kWh/yr for Low-E glazing against 11,034 to 11,146 kWh/yr for STPV), so STPV saves little cooling compared with a solar-control glass; its advantage over Low-E glazing comes from generation. Second, a lower VLT raises lighting electricity (Table 3), and in the 15 m deep plan this penalty is large when the glazed area is small. Third, generation grows with glazed area and with incident radiation (Table 6), which favours large south-facing glazing. The break-even multipliers in Table 8 summarise the outcome: at WWR 60% on the south and west façades STPV with VLT 30% needs almost no generation to match Low-E glazing, whereas at WWR 20% it needs about 2 to 7 times the assumed output.

7.2 Comparison with previous studies

Table 18 relates the findings to the studies reviewed in Section 1.2. The comparison is qualitative: absolute energy values are not compared because the buildings, climates, glazing properties and metrics differ, and the abstracts and bibliographic records available for this review do not allow a like-for-like numerical comparison. The findings are consistent with the reported dependence of the optimum transmittance on orientation (Miyazaki et al., 2005) and with the observation that the benefit varies between climates (Xu et al., 2014). The choice of comparator also matters, which Olivieri et al. (2014) addressed by comparing STPV with a solar-control glass: here STPV looks more favourable against clear glass than against Low-E glass, as Tables 4 and 5 show.

Table 18. Comparison with previous studies (qualitative)

Study	Setting and approach	Finding as reported	Relation to this study
Miyazaki et al. (2005)	Standard office floor, Japan; EnergyPlus simulation of heating and cooling loads, daylighting and electricity production	Optimum solar-cell transmittance presented for different orientations; WWR also studied	Same approach. Here too the best VLT depends on orientation (Table 5); Low-E glazing is added as a comparator
Li et al. (2009)	Generic reference office, Hong Kong; measurements on a semi-transparent PV panel plus case studies with daylight-linked lighting control and cost analysis	Integrated system produced electricity and reduced lighting and cooling requirements	Relative to Low-E glazing with the same dimming control, low-VLT STPV raises lighting electricity (Table 3); the net benefit comes from generation and appears only at larger glazed areas
Didoné and Wagner (2013)	Office buildings in Brazilian climates; simulation of semi-transparent PV windows	Energy-saving potential reported for (sub)tropical conditions	Similar warm climate; the results here are specific to the Dhaka weather file and the stated assumptions
Xu et al. (2014)	Office façades, central China; optimal PV cell coverage ratio	Optimum determined for the local climate; benefit noted to vary between climates	Supports a Dhaka-specific assessment rather than transfer of results from other climates
Uddin et al. (2023)	Office building, Bangladesh climate; three configurations of semi-transparent CdTe window systems	Windows can conserve energy and provide daylight; Bangladesh lacks BIPV policies and guidelines	Closest earlier study. This paper focuses on the WWR–orientation–VLT trade-off against Low-E glazing, with verification status, economics and uncertainty analysis

Findings are summarised from the abstracts and bibliographic records of the cited papers; see the note at the end of the reference list.

7.3 Implications for design in Dhaka

The results suggest an order of decisions. First, glazed area: at WWR 20% Low-E or clear glazing was best on every façade, and STPV needed about 2 to 7 times the assumed output to compete (Table 8). Second, orientation: STPV reduced net electricity below Low-E glazing only on south-, west- and east-facing façades with WWR of 40% to 60%, and on the north façade at WWR 60%, with the best VLT falling from 40% to 20% as solar exposure increased (Table 5). Third, cost: even in the best case STPV had a negative NPV unless its installed cost fell to about Tk 15,500–23,200 per m² (Section 6.2), and the uncertainty analysis shows that only a large cost reduction would change this (Table 17). STPV therefore looks most promising as a premium option for large south- or west-facing façades where non-energy benefits (Section 6.4) justify part of the cost, and is a poor choice for small windows.

7.4 Robustness and remaining uncertainty

The pattern across WWR and orientation is robust to the assumed STPV efficiency: the order in which combinations become favourable as output increases follows solar exposure and WWR (Table 8), and between 4 and 7 of the 12 combinations favour STPV over a threefold range of output (Table 7). The negative economic result is also robust within the stated assumptions: no single input brought the best-case NPV to zero (Table 16), and only 4 of 20,000 random combinations did (Table 17). The main uncertainties that remain are those this study could not vary: the optical and thermal properties of the glass, the lighting power density, and the absence of validation against measured data (Section 5.5). These should be addressed first when product data or measurements become available.

8. Limitations

- The glazing properties, STPV efficiencies and installed costs are assumed values, not measurements or quotations for a specific product, and the conclusions depend on them (Sections 4 and 6).
- The STPV generation model has fixed efficiency and no cell temperature effect, and it is decoupled from the heat balance; the thermal effect of the cells is represented only through the SHGC value.
- A single zone with one glazed façade and adiabatic floor and ceiling represents a typical intermediate floor of a larger building; roof, multi-façade glazing, neighbouring building shade and urban heat island effects are not modelled.
- The ideal loads air system with a constant COP does not represent real part-load behaviour or dehumidification equipment, and the model is not calibrated against measured data, so absolute energy values are indicative.
- The model is verified and benchmarked but not validated against measured data (Section 5), and the economic analysis excludes demand charges, incentives, inverter replacement and non-energy benefits (Section 6).
- The weather file is an older typical year for a single station.
- The sensitivity analysis rescales STPV output and economic inputs; glazing properties, lighting power density and building depth were not varied (Section 4.3), and the Monte Carlo distributions are assumed ranges, not measured uncertainties (Section 6.3).

9. Conclusions

For a single-floor office in Dhaka, STPV glazing reduces net annual electricity use only when the glazed area is large enough and the façade receives enough sunlight. Under the assumptions used here: (i) STPV was best in 6 of 12 WWR–orientation combinations, all at WWR of 40% or more; (ii) the lowest net electricity was 63.3 kWh/m²·yr for a south-facing façade at WWR 60% with VLT 20%, 17.1% below clear glazing and 9.3% below Low-E glazing; (iii) at WWR 20% Low-E or clear glazing was better than STPV on every orientation because the lighting penalty exceeded the generation; (iv) the best VLT decreases as solar exposure increases, from 40% on the north façade to 20% on the south; (v) the model was verified, including an independent solar-radiation calculation within 0.31%, but not validated against measurements; (vi) with the assumed costs, STPV was not economically justified against Low-E glazing in any combination: the best case would need an installed cost of about Tk 15,500 to 23,200 per m² (1.7 to 2.6 times Low-E glazing) to break even; and (vii) over the sensitivity ranges tested, STPV beat Low-E glazing in 4 to 7 of the 12 combinations for output multipliers of ×0.5 to ×1.5, and the economic result was dominated by installed cost: in a Monte Carlo analysis of 20,000 draws the best-case NPV was positive in 0.02% of draws, and only a reduction of the STPV installed cost to about half of the assumed mean raised this to about 36%.

The practical recommendation is to consider STPV for south-, west- and east-facing façades with large glazed areas, to prefer Low-E glazing for small windows and for most north-facing façades, and to verify the result with measured product data and supplier prices. On energy savings alone STPV is not yet cost-justified under the assumptions used here. Further work should replace the assumed properties and costs with measured data and quotations, validate the model against metered data from a Dhaka office, include cell temperature effects, shading and daylight glare, and extend the sensitivity analysis to glazing properties (U-factor, SHGC, VT), lighting power density and building depth, which need new simulation runs.

References

ASHRAE. ANSI/ASHRAE Standard 62.1: Ventilation and Acceptable Indoor Air Quality, Table 6-1 (minimum ventilation rates in the breathing zone, office space). American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta.

bdnews24 (2026). Bangladesh hikes retail electricity price by 17%. 3 June 2026. https://bdnews24.com/economy/9efadd3c57ad

Chae, Y.T., Kim, J., Park, H., Shin, B. (2014). Building energy performance evaluation of building integrated photovoltaic (BIPV) window with semi-transparent solar cells. Applied Energy, 129, 217–227.

Crawley, D.B., Lawrie, L.K., Winkelmann, F.C., Buhl, W.F., Huang, Y.J., Pedersen, C.O., Strand, R.K., Liesen, R.J., Fisher, D.E., Witte, M.J., Glazer, J. (2001). EnergyPlus: creating a new-generation building energy simulation program. Energy and Buildings, 33(4), 319–331.

Didoné, E.L., Wagner, A. (2013). Semi-transparent PV windows: a study for office buildings in Brazil. Energy and Buildings, 67, 136–142. https://doi.org/10.1016/j.enbuild.2013.08.002

EPIA estimate cited in: optics.org (2012). BIPV glass: price range for semi-transparent PV modules, 30 April 2012. https://optics.org/indepth/3/3/6

Holmgren, W.F., Hansen, C.W., Mikofski, M.A. (2018). pvlib python: a python package for modeling solar energy systems. Journal of Open Source Software, 3(29), 884.

ISO 8995-1:2002. Lighting of work places – Part 1: Indoor. International Organization for Standardization, Geneva.

Li, D.H.W., Lam, T.N.T., Chan, W.W.H., Mak, A.H.L. (2009). Energy and cost analysis of semi-transparent photovoltaic in office buildings. Applied Energy, 86(5), 722–729. https://doi.org/10.1016/j.apenergy.2008.08.009

Liu, D., Sun, Y., Wilson, R., Wu, Y. (2020). Comprehensive evaluation of window-integrated semi-transparent PV for building daylight performance. Renewable Energy, 145, 1399–1411. https://doi.org/10.1016/j.renene.2019.04.167

Lu, L., Law, K.M. (2013). Overall energy performance of semi-transparent single-glazed photovoltaic (PV) window for a typical office in Hong Kong. Renewable Energy, 49, 250–254.

Miyazaki, T., Akisawa, A., Kashiwagi, T. (2005). Energy savings of office buildings by the use of semi-transparent solar cells for windows. Renewable Energy, 30(3), 281–304. https://doi.org/10.1016/j.renene.2004.05.010

NZEB South Asia (n.d.). Mobil House, Dhaka, Bangladesh (case study). https://nzeb.in/case-studies/south-asia-case-studies/south-asia-list/mobil-house/

Olivieri, L., Caamaño-Martín, E., Moralejo-Vázquez, F.J., Martín-Chivelet, N., Olivieri, F., Neila-Gonzalez, F.J. (2014). Energy saving potential of semi-transparent photovoltaic elements for building integration. Energy, 76, 572–583.

Perez, R., Ineichen, P., Seals, R., Michalsky, J., Stewart, R. (1990). Modeling daylight availability and irradiance components from direct and global irradiance. Solar Energy, 44(5), 271–289.

Purba, E.R., Ahda, Y., Chaeruni, W., et al. (2025). Benchmarking energy use intensity of 33 office buildings in Indonesia. Evergreen, 12(4), 2000–2012. https://doi.org/10.5109/7402632

Refat, K.H., Sajjad, R.N. (2020). Prospect of achieving net-zero energy building with semi-transparent photovoltaics: a device to system level perspective. Applied Energy, 279.

Solar and Wind Energy Resource Assessment (SWERA), United Nations Environment Programme and National Renewable Energy Laboratory. Dhaka/Tejgaon typical-year weather file BGD_Dhaka.419230_SWERA.epw.

SREDA (2025). Energy management guidelines for government office buildings: energy consumption standards (kWh/m²/year). Sustainable and Renewable Energy Development Authority, Government of Bangladesh.

The Business Standard (2026). Power tariff hiked 16.7% as govt moves to cut subsidy burden. 3 June 2026. https://www.tbsnews.net/node/1453181

The Financial Express (2026). Electricity prices hiked across the board. June 2026. https://thefinancialexpress.com.bd/bangla/economy/electricity-prices-hiked-across-the-board

The Financial Express (2026). Exchange rate down as dollar demand ebbs. August 2026. https://thefinancialexpress.com.bd/economy/exchange-rate-down-as-dollar-demand-ebbs

Uddin, M.M., Ji, J., Wang, C., Zhang, C. (2023). Building energy conservation potentials of semi-transparent CdTe integrated photovoltaic window systems in Bangladesh context. Renewable Energy, 207, 512–530. https://doi.org/10.1016/j.renene.2023.03.049

U.S. Department of Energy. EnergyPlus Engineering Reference and Input Output Reference, Version 24.2.0.

Xu, S., Liao, W., Huang, J., Kang, J. (2014). Optimal PV cell coverage ratio for semi-transparent photovoltaics on office building façades in central China. Energy and Buildings, 77, 130–138. https://doi.org/10.1016/j.enbuild.2014.03.052

Zhang, W., Lu, L. (2019). Overall energy assessment of semi-transparent photovoltaic insulated glass units for building integration under different climate conditions. Renewable Energy, 134, 818–827.

Supplementary materials

The following supplementary files accompany the paper as separate files.

- S1 – EnergyPlus models (epJSON) for all 60 cases.
- S2 – Python scripts that generate, run, verify and post-process the simulations, and the annual, monthly and economic result tables.

- S3 – Excel workbook that recalculates net electricity, payback, NPV and break-even premium when cooling COP, STPV output, tariff, escalation, discount rate or glazing costs are changed on its Assumptions sheet.
- S4 – Sensitivity and uncertainty analysis (Sections 4.2 and 6.3): Python scripts (data.py, econ.py, analysis.py, check_reproduction.py), the output tables (break-even multipliers, one-at-a-time economic sensitivity, Monte Carlo draws and summaries) and Figures 5, 7 and 8.

The S4 calculations post-process the results of the 60 simulations (Tables 4, 6 and 13) and need no EnergyPlus runs; check_reproduction.py compares them with Tables 7, 13, 14 and 15.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- STPVDhakaSupplementaryFiles.zip