INFLUENCE OF DESIGN PARAMETERS ON OFFICE BUILDING ENERGY AND BIFACIAL PHOTOVOLTAIC POWER GENERATION BASED ON SENSITIVITY ANALYSIS

Summary

Buildings account for approximately 40% of total societal carbon emissions, and while bifacial photovoltaic (bPV) systems represent a promising carbon reduction technology, research on the application of bPV systems with buildings remains limited. This study develops an EnergyPlus based coupled model for elevated bPV installed on the roof of an office building and employs two performance indicators, building energy and bPV power generation. By combining sensitivity analysis with parametric simulation, the study evaluates the relative effects of five design parameters, including bPV tilt angle, panel spacing, installation height, roof albedo, and the convective heat transfer coefficients at the roof exterior surface as well as the front and rear surfaces of the bPV panel. The results provide guidance for optimizing applied system design in terms of both building energy and power generation.

Keywords: bifacial photovoltaic, sensitivity analysis, parametric simulation, performance indicators, design parameters

Field of application for the findings: Building energy efficiency, solar energy systems

Addressed audience: Building energy engineers, solar energy researchers, architects, and building designers

1. Introduction

Collectively accounting for approximately 40% of global greenhouse gas emissions, the mitigation of building-related carbon outputs represents not merely a necessary endeavor, but an urgent necessity (González-Torres et al., 2025). Thus, several policies are being implemented to address this challenge. Nevertheless, this objective can be accomplished not merely through reducing energy use but also through incorporating renewable energy systems for power generation in office buildings.

Among emerging renewable energy technologies, bifacial photovoltaic (bPV) panels have attracted increasing attention due to their ability to generate electricity from both front and rear surfaces. Bifacial solar cells can absorb incident and reflected radiation from both the front and rear surfaces, thereby achieving higher energy yields compared to conventional monofacial modules (Zhong et al., 2023).

The adoption of applied bPV with roof systems in office buildings remains limited due to insufficient understanding. While existing research has extensively investigated critical design parameters such as module mounting height (Johnson and Manikandan, 2023), roof albedo (Gu et al., 2021), tilt angle (Patel et al., 2019), and installation configuration (Li et al., 2022), limited attention has been given to the convective heat transfer coefficients (CHTC) at the roof exterior surface as well as the front and rear surfaces of the bPV panel. Furthermore, the extent to which these design parameters affect the performance metrics of the applied system is unclear.

This study addresses this gap by develops an EnergyPlus based coupled model for elevated bPV installed on the roof of an office building that links bPV energy simulation with building energy simulation, and subsequently applying global sensitivity analysis (SA) to identify the most influential design parameters.

2. Methodology

2.1. Modeling of roof-mounted elevated bifacial photovoltaic systems

This study develops a simulation model in EnergyPlus 24.2 to assess the energy performance of a building applied with roof-mounted elevated bPV systems (see Fig. 1). The building model was adapted from Zhuang et al. (Zhuang et al., 2021), incorporating internal heat gains from occupancy, lighting, and equipment, along with envelope thermal properties (GB 50189-2015) and HVAC system configurations, to serve as a reference for subsequent comparisons. Building upon this baseline, a bPV system was then introduced. Since EnergyPlus does not natively support bPV modules, an equivalent modeling approach was adopted, in which the bifacial system was decomposed into two single-sided photovoltaic generators. Finally, the bPV system was applied with the building model by mounting the panels above the roof as exterior shading surfaces. This configuration also allowed the thermal effect of bPV shading on roof heat gain to be simultaneously evaluated.

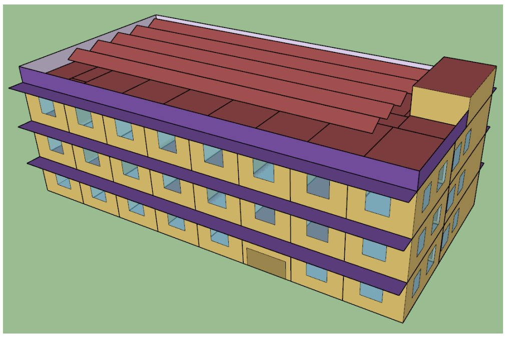

Fig. 1: A coupled model of roof-mounted elevated bifacial photovoltaic systems installed on buildings

2.2. Sensitivity analysis methods

SA can be categorized into screening methods, local sensitivity methods, and global sensitivity methods (Andrea Saltelli et al., 2000). Local SA varies one parameter at a time while keeping others fixed, whereas global SA allows all parameters to vary simultaneously (Mara and Tarantola, 2008). In this study, a global SA approach was adopted to quantify the influence of each design parameter on the two performance indicators, bPV power generation and building energy, while accounting for the interactions among parameters.

Monte Carlo analysis (Breesch and Janssens, 2010) combined with Latin Hypercube Sampling (LHS) was employed to generate the input parameter samples, as LHS ensures full coverage of the range of each parameter and has been widely validated in building performance analysis (Tian, 2013). The Standardized Regression Coefficient (SRC) was used as the sensitivity index, where the sign of the SRC indicates the direction of influence and the absolute value reflects the degree of importance of each parameter on the output.

2.3. Design parameters

Five design parameters were selected as inputs for the global SA, as summarized in Tab. 1. The PV tilt angle was set to 30°, covering a range from horizontal (0°) to a high-tilt configuration (60°). Panel spacing was 1.418 m, with the range spanning from densely packed (0.5 m) to widely spaced (5.0 m) arrangements to capture the trade-off between ground use and inter-row shading. The installation height above the roof was set to 1.021 m, ranging from near-flush mounting (0.1 m) to elevated configurations (1.5 m). Exterior roof albedo was assigned a value of 0.8, with the lower bound of 0.2 corresponding to gray roof surfaces. The CHTC (i.e., at the roof exterior surface as well as the front and rear surfaces of the bPV panel) were both set with uniform distribution from 5 to 25 W/m²·K.

Tab. 1: Design parameters, units, and variation ranges for sensitivity analysis

Parameter	Unit	Range
PV tilt angle	°	0 - 60
Panel spacing	m	1.0 - 2.0
Installation height above roof	m	0.1 - 1.5
Exterior roof albedo	-	0.2 - 0.8

CHTC	W/m²·K	5 - 25

3. Results and discussion

The global SA results reveal that the five design parameters exhibit varying degrees of influence on the two performance metrics, namely bPV power generation and building energy. Each parameter demonstrates a distinct contribution to the output variance, indicating that their effects on bPV generation performance and building energy are not uniform.

4. Conclusion

This study presents an EnergyPlus simulation model for the assessment of an applied roof-mounted elevated bPV and office building system. By applying global SA, the relative importance of five design parameters, namely PV tilt angle, panel spacing, installation height, roof albedo, and CHTC (i.e., at the roof exterior surface as well as the front and rear surfaces of the bPV panel), on both bPV power generation and building energy performance was systematically evaluated. The results demonstrate that different parameters exert varying levels of influence on the two performance metrics. The findings provide a useful reference for the applied design and optimization of elevated bPV systems in office building applications.

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