EuroSun2026

MULTI-FUNCTIONAL BIFACIAL BUILDING INTEGRATED PHOTOVOLTAIC SHADING FOR ZERO ENERGY SOLAR HOUSE

Summary

This study presents the development and optimization of a multi-functional bifacial building-integrated photovoltaic shading system (MB-BIPVS) for nearly zero-energy solar apartments. The system was designed to combine solar electricity generation, solar shading, façade integration, and structural functionality within an ecological building concept. Simulation results showed that the shading effect of MB-BIPVS alone can reduce building cooling load by approximately 34%. In addition, the bifacial photovoltaic configuration generated 12% more electricity than mono-facial BIPV and 46% more than wall-attached BIPV. The optimized design adopted a 23.5° tilt angle, a 1,000 mm module length, a 12,000 mm width, and a triangular truss support structure. Life-cycle modelling further indicated that circular end-of-life strategies could reduce the total carbon footprint by more than 50%.

Keywords: Bifacial BIPV, Solar shading, Cooling load reduction, ecological design, nearly zero-energy apartment, life-cycle assessment

Field of application for the findings: Building-integrated photovoltaics, solar façades, residential nearly zero-energy buildings, climate-responsive architecture

Addressed audience: Solar energy researchers, façade engineers, BIPV designers, architects, energy modellers, life-cycle assessment specialists

1. Introduction

Nearly zero-energy residential buildings require envelope systems that can perform multiple functions simultaneously. In addition to producing renewable electricity, façade and shading systems must reduce thermal loads, improve indoor comfort, and contribute to architectural integration. Conventional BIPV applications often emphasize electricity production only, whereas climate-responsive housing demands a broader multifunctional approach.

To address this need, the present study investigates a multi-functional bifacial building-integrated photovoltaic shading system (MB-BIPVS) developed for nearly zero-energy solar apartments. The proposed concept combines solar shading, bifacial power generation, façade integration, and structural functionality within a single building element. In doing so, it supports both thermal load reduction and on-site renewable energy harvesting.

The MB-BIPVS concept is embedded within an ecological design framework in which building envelope performance, passive strategies, and active renewable systems are optimized together. This integrated approach is particularly suitable for residential applications, where limited building surface area requires each architectural element to provide more than one performance benefit.

2. Methodology

The MB-BIPVS was optimized through simulation, PV module performance verification, and structural stability assessment. The main design variables included the inclination angle, module geometry, structural support configuration, and façade integration strategy. The objective was to identify a configuration that maximized both shading performance and solar electricity generation while ensuring structural reliability.

The final design adopted a triangular truss structure beneath the photovoltaic modules in order to minimize structural shading and maintain stability. The optimized geometric configuration included a tilt angle of 23.5°, a module length of 1,000 mm, and a total system width of 12,000 mm.

In addition to energy and structural optimization, the environmental implications of the system were assessed using life-cycle inventory modelling. A key methodological feature was the treatment of MB-BIPVS not only as an energy-producing system but also as a structural façade replacement. This approach makes it possible to account for avoided emissions from substituted conventional façade materials. Circular economy scenarios for end-of-life recycling were also considered in order to assess their influence on whole-life carbon performance.

Table 1 shows the key design and performance indicators of the MB-BIPVS concept

Tab. 1: Key design and performance indicators of the MB-BIPVS concept

Parameter	Value	Description
Cooling load reduction by shading	~34%	Reduction in building cooling load due to MB-BIPVS shading
Power gain over mono-facial BIPV	12%	Relative electricity gain of bifacial configuration
Power gain over wall-attached BIPV	46%	Relative electricity gain compared with wall-attached BIPV
Optimized tilt angle	23.5°	Final geometry for shading and generation
Module length	1,000 mm	Optimized module dimension
System width	12,000 mm	Demonstration-scale configuration

3.Results and discussions

The simulation results showed that the shading effect of MB-BIPVS alone can reduce the building cooling load by approximately 34%. This finding is important because it demonstrates that the system contributes to energy savings even before accounting for photovoltaic electricity generation. In other words, the MB-BIPVS acts simultaneously as a solar control device and as a renewable electricity generator.

From the electricity generation perspective, the bifacial configuration clearly outperformed the reference systems. Compared with mono-facial BIPV, the developed system generated 12% more electricity, while compared with wall-attached BIPV the gain reached 46%. These results confirm the value of bifacial operation in façade-related solar systems, especially when the geometry is optimized to exploit reflected and indirect irradiance.

The optimized geometric and structural design also played a major role in the system's final performance. The triangular truss support enabled a stable and architecturally compatible installation while limiting adverse shading by the substructure. The simulated power denity of the final prototype achieved a maximum output of 667.2 kWh/m² per unit module area for one year under Seoul weather condition.

The achieved module output confirms that the design target was successfully met without sacrificing building integration quality, with the system adaptability for habitants, with the maximum use of solar radiation sources and with multi-purpose function of the system in order to maximize the system sustainablity.

From an environmental perspective, the results suggest that the system can significantly improve whole-life carbon performance. Since the MB-BIPVS replaces conventional façade materials while generating electricity, the environmental burden of substituted components can be deducted from the overall life-cycle balance.

Furthermore, the application of circular economy principles indicated that end-of-life recycling strategies could theoretically reduce the total carbon footprint approximately by more than 50%.

These findings show that MB-BIPVS should not be understood as a conventional attached PV system, but rather as a multifunctional ecological façade technology. Its thermal, electrical, structural, and environmental benefits make it highly relevant for future residential nearly zero-energy buildings, particularly where façade surfaces must contribute actively to performance targets.

Figure 1 illustrates the perspective view of the test building and optimized MB-BIPVS configuration showing the bifacial photovoltaic shading geometry and triangular truss support structure for façade integrated application.

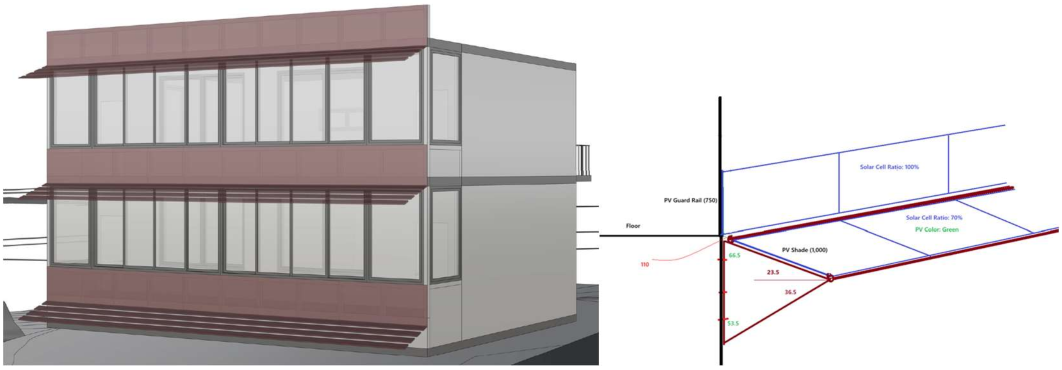

Fig. 1: Perspective view of the test building (Left) and optimized MB-BIPVS configuration (Right)

By maintaining a spacing of 110 at an angle of inclination of 23.5 degrees—the same as the PV shade—we aimed to reduce wind load and improve PV efficiency through convective cooling. Another reason for spacing it 110 at the same angle is to maximize the reflections that will occur on both the PV shade and the PV guard rail surfaces, as well as to allow more light to pass downwards, thereby considering various other positive effects in terms of natural energy and power generation

4. Conclusions

This study demonstrated that MB-BIPVS is a promising multifunctional technology for ecological nearly zero-energy solar house. The optimized system reduced building cooling load by approximately 34%, generated 12% more electricity than mono-facial BIPV and 46% more than wall-attached BIPV, and achieved a power output of 667.2 kWh/m² for one year.

The results confirm that MB-BIPVS can simultaneously provide shading, solar electricity generation, façade functionality, and carbon mitigation benefits. Through the integration of life-cycle thinking and circular economy principles, the system offers a broader environmental value than conventional BIPV approaches. Future work will focus on pilot-scale implementation, real-operation validation, and long-term monitoring under diverse climatic conditions.

5.Acknowledgments

This research was financially supported by the Ministry of Trade, Industry and Energy (MOTIE) and the Korea Institute for Advancement of Technology (KIAT) under Project No. P0026322 through the International Cooperative R&D program EUREKA.

6. Reference

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