



# Literature Review on Unitized Installation Technology for Building-Integrated Photovoltaic (BIPV) Curtain Walls

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## Abstract

Building-Integrated Photovoltaic (BIPV) curtain wall systems combine renewable energy generation with building envelope functionality, representing a key advancement in sustainable architecture. This review systematically examines 20 peer-reviewed studies from the past five years, focusing on unitized BIPV curtain wall installation technology. The analysis covers performance under varied climatic conditions, structural and seismic safety, thermal and energy optimization, lifecycle cost assessment, long-term durability, and smart building management system (BMS) integration. Key advancements identified include climate-adaptive design, multi-objective optimization algorithms, and novel mounting solutions. However, significant gaps persist: the lack of unified international standards, high capital and maintenance costs, insufficient long-term field performance data, and technical challenges in BMS integration. This synthesis provides researchers and practitioners with a consolidated understanding of current knowledge and identifies future research directions to improve the efficiency, reliability, and scalability of unitized BIPV curtain wall systems.

**Keywords:** BIPV Curtain Wall; Unitized Installation; Performance Evaluation; Structural Safety; Smart Integration; Literature Review

## Introduction

The global pursuit of carbon neutrality has driven the integration of renewable energy technologies into the built environment (Balaras et al., 2021; Huang & Wen, 2021). Building-Integrated Photovoltaics (BIPV), which convert building envelopes into energy-generating surfaces, have attracted significant research and industry interest (Kim & Kim, 2022). Among BIPV configurations, unitized curtain wall systems offer distinct advantages—including off-site prefabrication, faster installation, stringent quality control, and seamless architectural integration (Cai et al., 2022; Hasan et al., 2023). However, widespread adoption remains constrained by climate-dependent performance variability (Akbari et al., 2024), structural integrity under extreme loads (Chen et al., 2025; Li & Wang, 2023), high capital and operational costs (Feng et al., 2024), and integration complexity with existing building systems (Guo et al., 2025). A comprehensive review of the current research landscape is therefore essential to address these challenges and advance the technological and economic viability of unitized BIPV curtain wall systems.

## Review Question

This review addresses the following central question: What are the key technological advancements, prevailing challenges, and unresolved research gaps in unitized BIPV curtain wall installation technology, as reported in peer-reviewed literature from the past five years?

## Objective(s) of the Article

This study was guided by three principal objectives: (1) to conduct a systematic synthesis and critical analysis of contemporary research findings concerning the performance characteristics, structural safety, economic feasibility, and smart system integration of unitized BIPV curtain walls; (2) to delineate the predominant technical and economic barriers that impeded the widespread adoption of unitized BIPV systems; and (3) to identify salient research gaps within the existing body of literature and propose viable directions for future scholarly inquiry aimed at advancing the field.

## Research Methodology

### Literature Review Approach

A systematic literature review methodology was adopted to ensure rigorous and reproducible knowledge synthesis. Searches were conducted across Scopus, Web of Science, and ScienceDirect using predefined keywords—"BIPV," "unitized curtain wall," "installation technology," "performance evaluation," "structural safety," "smart integration," and "lifecycle cost"—combined with Boolean operators to optimize retrieval of relevant publications.

Article Selection Criteria Article selection was governed by four criteria. First, relevance: articles must address unitized BIPV curtain

wall installation technology or closely related domains such as system design, performance characterization, and structural analysis. Second, timeliness: only peer-reviewed articles published between January 2021 and December 2025 were included. Third, impact: preference was given to publications in high-impact journals in renewable energy, building engineering, and sustainable construction. Fourth, language: only English-language articles were eligible. Applying these criteria yielded a final corpus of 20 articles spanning the full scope of unitized BIPV curtain wall research.

## Results

**1. Performance Evaluation and Optimization** Research in this domain highlights the need for climate-adaptive BIPV design. Akbari et al. (2024) demonstrated significant performance variability across climatic zones, underscoring the necessity of location-specific optimization. Ali & Ibrahim (2023) developed an NSGA-II-based multi-objective framework balancing thermal comfort with energy generation. Kim and Kim (2022) advanced thermal and electrical optimization strategies for unitized BIPV configurations, while Majumdar & Saini (2022) provided parametric analysis of daylighting and energy capture trade-offs. Qi et al. (2023) found that ventilated configurations substantially improved both thermal regulation and electrical efficiency. Huang and Wen (2021) established baseline performance data for unitized BIPV façades under varying environmental loads.

**2. Structural Safety and Installation Technology** Structural integrity is fundamental to BIPV deployment. Chen et al. (2025) found that current seismic designs perform adequately but require reinforced connection interfaces and standardized guidelines. Li & Wang (2023) confirmed satisfactory wind load resistance in most regions but identified gaps in standards for extreme events such as typhoons. Cai et al. (2022) and Müller & Haas (2024) showed that modular prefabrication improves installation speed and adaptability despite higher upfront costs. Hasan et al. (2023) reviewed mounting innovations enhancing installation efficiency and safety. Das and Raj (2023) addressed maintenance accessibility challenges in high-rise applications, and Jiang and Liu (2024) proposed a design-for-maintainability framework emphasizing lifecycle serviceability.

**3. Economic and Environmental Impact** Economic viability remains critical to BIPV scalability. Feng et al. (2024) reported favorable long-term returns through lifecycle cost analysis, though extended payback periods remain a barrier. Zhang et al. (2024) examined durability challenges under coastal conditions, where salt corrosion increases maintenance costs. González and Bernardo (2022) provided empirical data on module degradation and long-term reliability. Balaras et al. (2021) demonstrated BIPV's contribution to reducing heating and cooling loads, while noting that effects on indoor air quality require further investigation.

**4. Intelligent Technology Integration** BIPV integration with smart building management systems is a rapidly growing research area. Guo et al. (2025) and Lu et al. (2025) explored real-time monitoring and predictive maintenance through building automation platforms, though such integration demands specialized interdisciplinary expertise that presents adoption barriers. Song & Cao (2025) proposed a unified structural and energy modeling framework, advancing holistic design methodologies for intelligent BIPV façades.

## Discussion and Conclusions

As summarized in Table 1, the review of 20 peer-reviewed studies reveals both significant progress and persistent gaps across four thematic domains of unitized BIPV curtain wall technology.

In performance evaluation, while climate-adaptive design and multi-objective optimization have advanced energy and thermal performance (Akbari et al., 2024; Ali & Ibrahim, 2023; Qi et al., 2023), long-term empirical data under extreme conditions, standardized evaluation metrics, and indirect environmental impacts such as indoor air quality remain underexplored.

Regarding structural safety, current designs demonstrate adequate seismic and wind load resistance (Chen et al., 2025; Li & Wang, 2023), and modular prefabrication improves installation efficiency (Cai et al., 2022; Müller & Haas, 2024). However, BIPV-specific seismic guidelines, high modular component costs, and high-rise maintenance accessibility (Das & Raj, 2023) require further attention. For economic impact, LCCA confirms favorable long-term returns despite extended payback periods (Feng et al., 2024), yet uncertainty in energy pricing forecasts and the absence of standardized LCCA protocols for BIPV projects limit reliable economic assessment. Coastal durability challenges further elevate costs (Zhang et al., 2024).

In smart integration, BMS-enabled monitoring and predictive maintenance represent promising advances (Guo et al., 2025; Lu et al., 2025; Song & Cao, 2025), but high sensor deployment costs, interdisciplinary expertise requirements, and the lack of BIPV-BMS interoperability standards impede widespread adoption.

In conclusion, unitized BIPV curtain wall technology has progressed substantially in performance optimization, structural analysis, and smart integration. Nevertheless, the four challenges identified in Table 1—lack of harmonized standards, high costs, insufficient field data, and integration complexity—must be systematically addressed through coordinated academic, industrial, and policy efforts to realize the full potential of this technology in sustainable building design.

**Figure 1** Summary of Key Findings and Research Gaps in Unitized BIPV Curtain Wall Studies

Theme	Key Findings	Research Gaps
<b>Performance Evaluation</b>	Performance varies significantly across climatic zones (Akbari et al., 2024). Multi-objective optimization improves thermal comfort and energy output (Ali & Ibrahim, 2023). Ventilating configurations enhance thermal and electrical performance (Qi et al., 2023).	Limited long-term empirical data under extreme climates. Insufficient attention to indirect impacts such as indoor air quality. No standardized performance evaluation metrics.
<b>Structural Safety</b>	Seismic performance is adequate but connection interfaces need reinforcement (Chen et al., 2025). Wind load resilience is satisfactory in most regions (Li & Wang, 2023). Modular prefabrication improves installation efficiency (Cai et al., 2022; Müller & Haas, 2024).	No internationally accepted BIPV-specific seismic design guidelines. High initial costs of modular components hinder adoption. Limited research on high-rise maintenance accessibility (Das & Raj, 2023).
<b>Economic Impact</b>	LCCA shows favorable long-term returns despite extended payback periods (Feng et al., 2024). Coastal conditions increase durability concerns and maintenance costs (Zhang et al., 2024).	Significant uncertainty in future energy pricing and policy incentive forecasting. No standardized LCCA protocols for BIPV projects.
<b>Smart Integration</b>	BMS integration enables intelligent energy management and real-time monitoring (Guo et al., 2025; Lu et al., 2025). Integrated structural-energy modeling is an emerging research direction (Song & Cao, 2025).	High complexity and cost of sensor deployment limit adoption. Interdisciplinary expertise requirements create practitioner barriers. No interoperability standards for BIPV-BMS interfaces.

## Future Work

Future research should prioritize: (1) harmonized international BIPV standards (Chen et al., 2025; Li & Wang, 2023); (2) cost-effective, durable materials and mounting solutions (Cai et al., 2022; Hasan et al., 2023; Müller & Haas, 2024); (3) longitudinal real-world performance monitoring (González & Bernardo, 2022; Huang & Wen, 2021; Zhang et al., 2024); and (4) streamlined BIPV-BMS integration protocols (Guo et al., 2025; Lu et al., 2025). Resolving these gaps is essential for unitized BIPV to achieve its potential in sustainable building design.

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