Creativity and Innovation
2025, VOL. 9, NO. 3, 134-137
DOI: 10.47297/wspciWSP2516-252728.20250903

# Research on Optimization of Building Facade Design in the Context of Climate Change: A Case Study of Jinan, Shandong

Xuankai Yue, Xiaoxue Su*, Min Gao, Ying Zhong, Xinyuan Zhang

Shandong Vocational and Technical University of Engineering, Jinan, Shangdong, 250200

**ABSTRACT**
This study takes Jinan, Shandong as the research object to explore optimization strategies for building facade design in the context of climate change. By analyzing the climatic characteristics and trends in the Jinan region, the challenges faced by existing building facade designs are assessed. The research proposes adaptive design principles and discusses optimization strategies from three aspects: material selection, structural design, and application of green technologies. The results indicate that adopting climate-adaptive design strategies can significantly improve the performance of building facades, providing theoretical basis and practical guidance for facade design in Jinan and similar climatic regions.

**KEYWORDS**
climate change; building facade; design optimization; Jinan Shandong; adaptive design; green building

## 1 Introduction

With the intensification of global climate change, the construction industry is facing unprecedented challenges that demand adaptive and resilient design approaches. As the critical interface between buildings and their surrounding environment, the building façade plays a pivotal role in regulating thermal performance, natural ventilation, daylighting, and overall energy efficiency. Therefore, the optimization of façade design is of paramount importance in enhancing not only the energy performance of buildings but also the comfort and health of occupants.

This study focuses on the city of Jinan, located in Shandong Province, China, to investigate climate-responsive strategies for building façade optimization under the pressures of a changing climate. Jinan is situated in a warm temperate, semi-humid continental monsoon climate zone, characterized by hot, humid summers and cold, dry winters. In recent years, the city has experienced increasingly volatile climate conditions, including rising average temperatures, extended heatwaves, and an increased frequency of extreme weather events such as heavy rainfall, strong winds, and abrupt temperature fluctuations. These environmental stressors pose new challenges for the thermal insulation, airtightness, solar control, and material durability of building envelopes.

In light of these climatic shifts, it is crucial to develop façade design strategies that are both climate-adaptive and energy-efficient. Such strategies may include dynamic shading systems, advanced glazing technologies, thermal insulation enhancements, and the use of climate-responsive materials. Moreover, integrating passive design principles—such as optimizing building orientation, window-to-wall ratio, and natural ventilation paths—can significantly reduce reliance on mechanical heating and cooling systems. This research aims to provide a comprehensive analysis of these strategies within the specific climatic context of Jinan, offering design guidelines and performance benchmarks that support sustainable building development in similar climate zones[2].

This research aims to analyze the climatic characteristics and trends in the Jinan region, assess the challenges faced by existing building facade designs, and propose corresponding optimization strategies. Through literature review, case analysis, and simulation calculations, the study explores principles and methods for climate-adaptive facade design, providing references for building facade design in Jinan and similar climatic regions.

## 2 Climatic Characteristics and Trends in Jinan

Jinan is located in the central region of Shandong Province and lies within a warm temperate, semi-humid continental monsoon climate zone. This climatic classification is traditionally characterized by four distinct seasons, with hot, humid summers and cold, dry winters. However, in recent years, under the growing influence of global climate change, the region's climatic characteristics have undergone notable and complex transformations.

One of the most significant changes has been the steady rise in the annual average temperature. Long-term meteorological data indicate a clear warming trend, with a marked increase in the frequency, duration, and intensity of extreme high-temperature events, particularly during the summer months. These prolonged heatwaves not only elevate cooling demands for buildings but also exacerbate urban heat island effects, placing additional stress on urban infrastructure and occupant comfort.

In addition to temperature-related changes, the distribution of annual precipitation in Jinan has become increasingly erratic. While the total annual rainfall has not significantly declined, its temporal and spatial distribution has shifted considerably. There has been a rise in extreme precipitation events, such as sudden torrential downpours and short-duration, high-intensity storms, often resulting in localized flooding and increased moisture loads on building envelopes. These conditions pose heightened risks for façade water infiltration, material degradation, and mold growth, underscoring the need for enhanced waterproofing and drainage strategies in façade design.

Furthermore, wind patterns in Jinan have also shown discernible changes. Although the average wind speed has decreased over recent decades, there has been an increase in the number of days with strong or gusty winds. This shift presents a unique challenge for building façades, which must be engineered to withstand intermittent high wind loads and pressure differentials, even if the overall wind climate appears to be less intense. Façade elements such as windows, cladding systems, and shading devices must be designed with increased resilience and structural stability to prevent damage during wind events.

These evolving climatic conditions highlight the growing complexity and urgency of designing adaptive and resilient building façades in Jinan. A comprehensive understanding of these regional climate trends is essential for developing effective, climate-responsive façade strategies that can mitigate the adverse impacts of climate change while promoting energy efficiency, occupant comfort, and long-term building durability[3].

These climate changes pose new challenges for building facade design. Firstly, rising temperatures and increased extreme high-temperature weather require better thermal insulation performance of facades. Secondly, changes in precipitation patterns demand stronger waterproofing and drainage capabilities. Additionally, changes in wind speed and increased extreme weather events require higher structural safety and durability of facades. Therefore, traditional building facade design methods can no longer meet current needs, necessitating optimization and innovation[4].

Fig1 Vertical Forest Tower (Boeri Studio, Milan)

(Origin：https://zhuanlan.zhihu.com/p/26699186）

## 3 Optimization Strategies for Building Facade Design

In response to the climatic characteristics and trends in Jinan, this study proposes the following optimization strategies for building facade design:

Firstly, establish adaptive design principles. These include the principle of integrity, which considers building functions, environmental conditions, and climatic factors comprehensively; the principle of dynamism, ensuring designs can adapt to potential future climate changes; and the principle of regionality, making full use of local climatic characteristics and resources.

Secondly, optimize material selection and structural design. It is recommended to use high-performance insulation materials, such as vacuum insulation panels and aerogels, to improve the thermal insulation performance of facades. Additionally, adopting double or triple-glazed curtain walls and ventilated facades can enhance the thermal performance and ventilation effects. Furthermore, consider using smart materials like phase change materials and thermochromic materials, enabling facades to automatically adjust performance based on environmental changes[5].

Finally, integrate green technologies and renewable energy. Incorporate vertical greening and building-integrated photovoltaics (BIPV) into facade design. Vertical greening not only improves the microclimate around buildings but also reduces surface temperatures and mitigates the urban heat island effect. BIPV technology integrates solar photovoltaic components into building facades, serving as both building envelopes and power generators, enhancing building energy self-sufficiency. Additionally, consider integrating small wind turbines into facade designs to fully utilize wind energy resources[4].

## 4 Case Analysis

Taking a high-rise office building in Jinan as a case study, this research applies the aforementioned optimization strategies to upgrade the building's façade system in response to regional climatic challenges. The original façade design employed single-glazed curtain walls, which exhibited poor thermal insulation and solar control capabilities. As a result, the building experienced excessive indoor heat gain during the summer months, leading to elevated cooling demands and significantly increased air conditioning energy consumption. The lack of dynamic shading and thermal buffering also contributed to occupant discomfort and inconsistent indoor environmental quality.

In the optimized design, a series of advanced façade technologies and climate-responsive strategies are implemented to address these deficiencies:

Double Low-Emissivity (Low-E) Glazed Curtain Walls: The single-glazed system is replaced with a double-glazed configuration incorporating Low-E coatings on the inner surfaces. This dramatically improves the façade's thermal insulation and reduces solar heat gain while maintaining high levels of visible light transmittance. The cavity between the glass panes enhances insulation and contributes to a more stable indoor thermal environment.

Integrated Adjustable Shading Systems: Between the two layers of glazing, adjustable blinds or louvers are installed, allowing users or automated systems to modulate daylight and solar radiation based on real-time environmental conditions. This dynamic shading strategy helps to minimize glare, control indoor temperatures, and reduce dependence on artificial lighting and cooling systems.

Photovoltaic (PV) Glass on the Outer Façade: The external glazing incorporates photovoltaic glass panels, transforming the building envelope into an active energy-generating surface. These panels serve a dual purpose: they provide effective solar shading while converting solar radiation into electricity, thereby contributing to the building's renewable energy supply. This integration of energy-harvesting technology supports the goals of nearly zero-energy buildings and carbon neutrality.

Vertical Greening Systems on the South Façade: To further enhance thermal performance and environmental quality, a vertical green wall system is installed on the south-facing façade. This system utilizes climbing plants and modular planters to create a living barrier that shades the building surface, reduces façade temperatures through evapotranspiration, and improves urban microclimates. Additionally, the green façade contributes to aesthetic enhancement, biodiversity promotion, and noise reduction.

The combined effect of these optimizations results in a significant improvement in the building's overall energy efficiency, indoor thermal comfort, and environmental sustainability. Preliminary simulation results and performance assessments indicate a substantial reduction in cooling loads during summer, a decrease in peak energy demand, and enhanced occupant satisfaction. This case study illustrates the practical benefits and feasibility of implementing climate-adaptive façade systems in high-rise office buildings within regions experiencing intensified climatic variability, such as Jinan[3].

Simulation results indicate that the optimized façade design yields substantial improvements in the building's energy performance and environmental impact. Specifically, the integration of double Low-E glazing with adjustable internal shading systems leads to a 30% reduction in summer air conditioning energy consumption, significantly lowering peak cooling loads and improving thermal comfort during periods of extreme heat. In winter, enhanced thermal insulation provided by the double-glazed system contributes to a 15% reduction in heating energy consumption, reducing energy demand and associated operational costs.

The incorporation of photovoltaic (PV) glass on the outer façade further enhances the building's sustainability by generating renewable electricity onsite. Simulation data show that the PV system is capable of meeting approximately 20% of the building's annual electricity demand, effectively offsetting grid dependency and contributing to carbon emission reductions. This energy contribution plays a vital role in supporting green building certification goals, such as LEED or China's Three Star Rating System.

Moreover, the vertical greening system installed on the south-facing façade has demonstrated additional environmental benefits. Through the processes of shading and evapotranspiration, the green façade effectively reduces the external surface temperature of the building by 5–8°C during peak summer periods, thereby contributing to the mitigation of the urban heat island (UHI) effect. This not only improves the microclimate around the building but also enhances the thermal performance of the façade itself, further reducing cooling loads.

Taken together, these simulation findings underscore the significant application potential of climate-adaptive façade design strategies in the context of Jinan's evolving climatic conditions. By effectively combining passive design measures, advanced materials, and renewable energy technologies, the optimized façade system demonstrates how integrated solutions can address both energy efficiency and environmental sustainability. This case study provides a valuable reference for future high-performance building projects in regions experiencing similar climatic shifts and highlights the critical role of façade design in achieving resilient and low-carbon urban development[2].

## 5 Conclusion

This study takes Jinan, Shandong as an example to explore optimization strategies for building facade design in the context of climate change. The results indicate that adopting climate-adaptive design principles, optimizing material selection and structural design, and integrating green technologies and renewable energy can significantly improve facade performance, reduce building energy consumption, and enhance indoor environmental quality. Specific conclusions are as follows:

The climate change trends in Jinan require building facade designs to pay more attention to insulation, waterproofing, and structural safety.

Adaptive design principles should form the foundation of building facade design, including integrity, dynamism, and regionality principles.

The use of high-performance materials, smart materials, and advanced structural forms can significantly enhance facade performance.

The integration of green technologies such as vertical greening and BIPV can improve the environmental benefits and energy self-sufficiency of buildings.

The optimized facade design demonstrates significant application effects in Jinan, providing references for architectural design in similar climatic regions.

Future research could further explore adaptive design strategies for different climatic zones and synergistic optimization methods for facade design and overall building performance, offering more comprehensive solutions to address climate change challenges.

## Funding

2024 Annual College Students Science and Technology Innovation Project (Number: 153)

## References

[1] Aloshan M ,Aldali K .Empirical study of facade retrofits for optimizing energy efficiency and cooling in school buildings in Saudi Arabia[J]. Energy Reports,2024,124105-4128.

[2] Yu H ,Zhang H .A new method for predicting wind-driven rain catch ratios on building facades in urban residential areas using machine learning models[J].Building and Environment,2025,270112467-112467.

[3] Tashiro S ,Harada Y .Psychological and physiological thermal effects of biophilic built environment using virtual reality: A pilot study for certified green building[J].Building and Environment,2025,270112534-112534.

[4] Zilong Z ,Yu-Feng L ,Andrew S , et al.Improving LEED-certified building loads on borehole heat exchangers by coupling subsurface variables [J].Applied Thermal Engineering,2023,224

[5] Hu C ,Zhang G ,Meng X , et al.Influence of color reflectance on the thermal performance of building facades: A factor model-based detective analysis[J].Case Studies in Thermal Engineering,2025,67105793-105793.