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ISSN 2959-6157

Impact of Geographical Location and Building Type on Public Building Energy Consumption: A BIM-Based Simulation Study of a Teaching Building in Kunming

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Abstract:
Against the backdrop of the high proportion of global building energy consumption and total carbon emissions, promoting building energy efficiency is a key measure to achieve the "dual carbon" goals. This study takes a teaching building in Kunming as the research object, constructs a Building Information Model (BIM) based on Revit, and simulates and analyzes the impact of different geographical locations (Kunming, Xi'an, Beijing, Harbin) and building types (teaching buildings, cinemas, police stations) on energy consumption. The results show that climate conditions are the fundamental factor affecting building energy consumption, Kunming has the lowest annual energy consumption due to its mild climate, while Harbin, a frigid region, has significantly higher heating energy consumption. Building functions and operation modes also have a significant impact on energy consumption, teaching buildings consume less energy than continuously operated buildings due to their intermittent use. Energy-saving strategies suitable for Kunming are further proposed, such as natural ventilation, intelligent lighting, and the utilization of renewable energy, providing a theoretical basis and practical reference for the energy-saving design of public buildings in mild climate zones.

Keywords: energy simulation; climate adaptation; building information model.

1. Introduction

In the grand context of global efforts to address climate change and promote sustainable development, green buildings have evolved from a cutting-edge concept to a core force driving profound transformations in the construction industry. With the urgency of the Paris Agreement goals and the advancement of "carbon neutrality" commitments from over 70 countries worldwide, the green and low-carbon transformation of the construction industry, a major contributor to energy consumption and carbon emissions, has become an inevitable choice for the future. This transformation not only responds to the rigid constraints of external policies but also proactively addresses resource and environmental pressures, energy security concerns, and people's inherent demand for healthy and livable environments. Against this backdrop, green buildings, leveraging their advantages in energy conservation and emission reduction throughout the full life cycle, have moved from demonstration pilots to large-scale promotion and officially entered a fast track of high-quality development. Today, the connotation of green buildings has expanded from single energy conservation and environmental protection to a comprehensive system covering multiple values such as resource conservation, health and comfort, and intelligence and efficiency. Promoting the popularization and development of green buildings is a systematic project integrating policy guidance, technological innovation, market-driven forces, and public participation, which holds irreplaceable strategic significance for building a beautiful China and a sustainable future.

In the context of energy crises and dual carbon goals, building energy conservation becomes particularly important. Studies have shown that the application of intelligent lighting systems can significantly reduce building lighting energy consumption [1]. Secondly, the rational design of window position and size can effectively introduce fresh air and expel stale air, achieving an energy-saving ventilation effect [2]. At the same time, photovoltaic roofs can be used on rooftops or facades, effectively replacing traditional building exterior materials, avoiding environmental pollution issues, and thus achieving good energy-saving and emission-reduction effects [3]. Under the combined effect of multiple measures, the carbon emissions of public buildings, urban residential buildings, and rural residential buildings account for approximately 4:4:2, with the carbon emissions growth rate of public buildings slowing down in 2022 [4]. In the future, as technology continues to advance and policies continue to improve, green buildings will play an increasingly important role in achieving carbon neutrality goals, driving the construction industry towards more green, low-carbon, and sustainable development [5]. Therefore, in-depth research on the influencing factors of building energy consumption and the proposal of targeted optimization measures are of great significance.

This study takes a teaching building of Yunnan Agricultural University as an example, conducts energy consumption analysis using Revit software, quantitatively analyzes the impact of different geographical locations and building types on energy consumption, and further proposes optimization strategies suitable for Kunming.

2. Research Methods and Models

2.1 Case Building Information

This building is located in Kunming (25.13°N, 102.75°E). Kunming is situated in the southwest of China, serving as an important gateway opening up to Southeast Asia and South Asia, and a hub of the "Belt and Road Initiative". The city center has an altitude of approximately 1,891 meters, making it a typical plateau city. The case building is a two-story teaching building facing north, with a height of about 8 meters. Its exterior walls are of brick structure, interior walls are made of gypsum boards, floors are concrete, and the roof is covered with asphalt shingles. The heating, ventilation, and air conditioning (HVAC) system adopts a central Variable Air Volume (VAV) system. A 3D view of the building model is shown in Figure 1.

ISSN 2959-6157

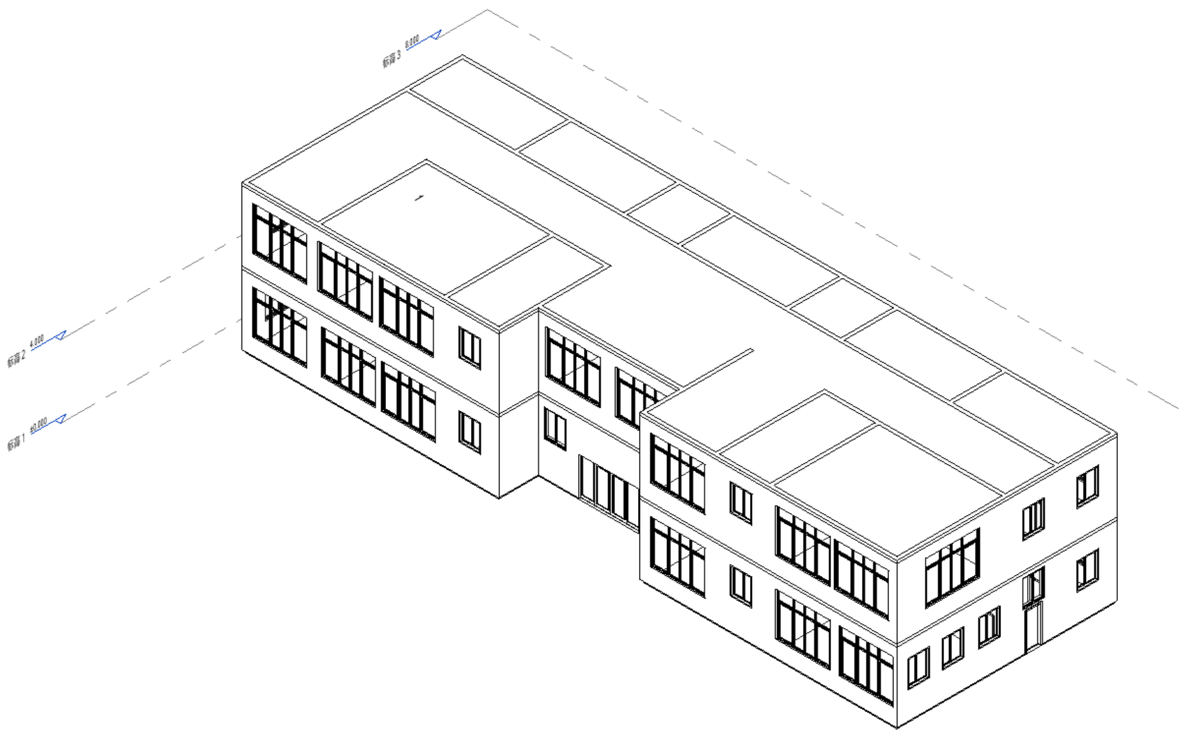

Fig. 1 3D View of the Building Model

2.2 Climate Condition Analysis

Kunming belongs to a northern subtropical climate, but due to its plateau geographical environment, it exhibits temperate climate characteristics of “characterized by warm winters and cool summers”, and is renowned both at home and abroad as the “Spring City”. Owing to its unique plateau subtropical climate, the temperature in summer is much lower than that in southern regions, and the temperature in winter is much higher than that in northern regions. As a result, the demand for air conditioning and heating is extremely low, which can effectively reduce building energy consumption.

2.3 Simulation Tools and Parameter Settings

This study uses Autodesk Revit software to establish a Building Information Model (BIM) and conduct energy simulation analysis. As a core BIM tool, Revit supports parametric design and multi-disciplinary collaboration, is suitable for the whole-life cycle management of buildings, and helps improve project efficiency and quality. The case model is constructed based on an actual teaching building of Yunnan Agricultural University. Its HVAC system includes a single-duct VAV system, central VAV system, hot water heating, and cooling water units. In combination with Kunming’s climate characteristics, the envelope structure is designed as follows: the exterior and interior walls adopt lightweight structures, and the roof uses a light-colored insulated roof. The indoor personnel mainly include students, teachers, and cleaning staff. The electrical equipment is dominated by multimedia devices and chandeliers, with peak usage hours from 8:00 to 21:25. Specific parameter settings are shown in Table 1 and Table 2.

Table 1. Parameter Settings of the Model Building

Project Parameter Item	Setting Value for Teaching Building
Building Equipment	VAV - Single Duct
HVAC System	Central VAV, HW Heating, Cooling Unit with 5.96 COP, Boiler Efficiency of 84.5%
Fresh Air Volume	Fresh Air Volume per Person: 8.00 L/s

Table 2. Thermal Properties of Materials for the Building Model

Interior Wall	Lightweight Structure - No Insulation Layer
Floor Slab	Heavyweight Structure - No Insulation Layer
Roof	Typical Insulation Layer - Light-Colored Roof
Floor	Lightweight Structure - No Insulation Layer
Exterior Wall	Lightweight Structure - Typical Insulation Layer for Mild Climate
Glass	Double-Layer Clear - No Coating
Shading	Basic Shading

2.4 Comparative Scheme Design

To analyze the impact of geographical location on energy consumption, this study selects four cities, namely Kunming, Xi'an, Beijing, and Harbin, forcomparison.These four cities represent different climate zones in China: Kunming belongs to the mild zone, Xi'an and Beijing belong to the cold zone, and Harbin belongs to the frigid zone. They have significant climate gradient differences, which facilitate a comprehensive revelation of the impact of geographical location on building energy consumption.

Meanwhile, to explore the impact of building types, this study further compares the energy consumption differences among teaching buildings, cinemas, and police stations. Cinemas have a large number of people and high equipment energy consumption, and police stations feature continuous operation. These characteristics form a distinct contrast with the usage mode of teaching buildings, which helps identify the impact of building functions and operation modes on energy consumption.

3. Research Results and Discussion

3.1 Impact of Geographical Location

3.1.1 Total Energy Consumption Comparison

Building energy consumption assessment usually involves two core concepts: site energy and source energy. Site energy refers to the energy consumption directly measured within the building boundary (such as electricity meter and gas meter readings), which is related to operating costs and self-energy efficiency. Source energy traces back to the energy production end, including all losses during power generation and transmission and distribution processes, and can better reflect the real environmental costs of buildings. This study selects four geographical locations, namely Kunming, Xi'an, Beijing, and Harbin, for energy consumption comparison to analyze the impact of geographical location on energy consumption. The results of the comparative analysis of total energy consumption in different regions are shown in Table 3.

From the data comparison in Table 3, it can be clearly seen that building energy consumption performance is closely related to local climate conditions. Among the four cities, Kunming has the lowest energy consumption, Xi'an and Beijing are relatively close, and Harbin is significantly higher than the other cities.

Due to its low-latitude plateau geographical location and "Spring City" climate characteristics, Kunming has small temperature fluctuations throughout the year, no need for strong heating in winter, and no need for large-scale cooling in summer. Therefore, its unit total building site energy consumption (660.46 GJ) and unit total building source energy consumption (1196.99 GJ) are much lower than those of other cities, approximately half of Harbin's. Xi'an and Beijing both belong to the temperate monsoon climate and have similar energy consumption levels. However, because Xi'an is located deep in the inland basin and has more significant continental characteristics, it is hotter in summer and colder in winter, resulting in its unit total building source energy consumption (1786.64 MJ/m²) being slightly higher than that of Beijing (1520.09 MJ/m²), which is slightly moderated by the ocean. As the city with the highest latitude and the most severe cold in winter, Harbin has a huge demand for heating and a significantly long heating duration. In addition, there is greater energy loss during transmission, leading to its unit total building source energy consumption (3300.49 MJ/m²) being far higher than that of other regions, reaching 2.8 times that of Kunming. This result highlights the fundamental impact of climate conditions on building energy consumption, and the urgency of building energy conservation and heating system efficiency improvement in cold regions is particularly prominent.

ISSN 2959-6157

Table 3. Building Energy Consumption in Different Regions

Region	Energy Type	Total Energy Consumption [GJ]	Unit Total Building Energy Consumption [MJ/m²]
Kunming	Site Energy	503.16	660.46
	Source Energy	993.09	1196.99
Xi'an	Site Energy	610.59	735.95
	Source Energy	1482.30	1786.64
Beijing	Site Energy	568.08	684.72
	Source Energy	1261.16	1520.09
Harbin	Site Energy	883.22	1064.56
	Source Energy	2738.28	3300.49

3.1.2 Heating and Cooling Energy Analysis

The analysis of heating and cooling energy consumption is shown in Table 4. The heating and cooling energy consumption of the four cities shows an obvious correlation with regional climate. In terms of heating energy consumption, affected by its high latitude and long cold winter, Harbin has extremely high energy consumption (578.11 GJ), far exceeding that of other cities. Xi'an (199.57 GJ) has higher heating energy consumption than Beijing (130.65 GJ), which has a similar climate but a more significant heat island effect or better thermal insulation conditions, due to its high humidity and less sunlight in winter, resulting in a cold and damp feeling. Benefiting from the "Spring City" climate, Kunming has an extremely low demand for heating (52.64 GJ). Cooling energy consumption reflects the impact of different climate types. Kunming (295.5 GJ) has the highest total cooling energy consumption due to its long annual cooling period and strong solar radiation. Beijing (282.41 GJ) has high energy consumption driven by both cooling and dehumidification due to its hot and humid summer. Xi'an (256 GJ) has a dry and hot climate, and natural ventilation can be carried out at night, resulting in relatively low cooling energy consumption. Harbin (150.1 GJ) has a cool and short summer, leading to the smallest demand for cooling. On the whole, climate conditions dominate the structure of building energy consumption. Heating energy conservation in cold regions is the key, and the cumulative effect of long-term low-intensity cooling in mild regions should not be ignored either.

Table 4. Cooling and Heating Conditions of Buildings in Different Regions

Region	Regional Cooling [GJ]	Regional Heating [GJ]
Kunming	295.5	52.64
Xi'an	256	199.57
Beijing	282.41	130.65
Harbin	150.10	578.11

3.2 Impact of Building Type

3.2.1 Total Energy Consumption by Building Type

By comparing the energy consumption of schools, cinemas, and police stations, the impact of building types on energy consumption is analyzed. The analysis of the main sources of energy consumption in this region is shown in Table 5. It can be seen from Table 7 that the teaching building has the lowest energy consumption per unit area because it is only used during the day, has a large flow of people, and has a low demand for air conditioning. The cinema has the highest energy consumption due to its all-day operation and dense population; to maintain a comfortable environment, cooling, heating, and lighting equipment need to operate continuously at high load. As a 24-hour public service facility, the police station has moderate energy consumption. However, due to continuous lighting, equipment operation, and environmental control in some areas, its unit energy consumption is still significantly higher than that of the teaching building.

Table 5. Energy Consumption of Different Building Types

Type	Energy Type	Total Energy Consumption [GJ]	Unit Total Building Energy Consumption [MJ/m²]
Teaching Building	Site Energy	503.16	660.46
	Source Energy	993.09	1196.99
Cinema	Site Energy	983.88	1185.88
	Source Energy	1860.65	2242.67
Police Station	Site Energy	820.55	989.32
	Source Energy	1560.55	1889.95

3.2.2 Heating and Cooling Energy by Building Type

Table 6 presents the analysis results of heating and cooling energy consumption of different building types. The cooling and heating energy consumption of the teaching building is much lower than that of the cinema and the police station. Among them, the cinema has the highest cooling energy consumption (610.52 GJ) due to its dense population, large amount of equipment heat generation, and the need to continuously maintain a low-temperature environment. The police station ranks second (511.25 GJ) due to the continuous air conditioning demand caused by 24-hour operation; the teaching building has the lowest cooling energy consumption (295.5 GJ), which is related to its intermittent use mode.

Table 6. Cooling and Heating Conditions of Different Building Styles

Type	Regional Cooling [GJ]	Regional Heating [GJ]
Teaching Building	295.5	52.64
Cinema	610.52	75.54
Police Station	511.25	90.72

3.3 Discussion of Research Results

This study reveals the significant impact of geographical location and building type on energy consumption through simulation analysis. In terms of geographical location, the building energy consumption characteristics of different climate zones are significantly different. Although the mild zone (Kunming) benefits from favorable climate conditions and has the lowest overall energy consumption, the cumulative effect of its long-term cooling energy consumption remains a point of concern. The cold zones (Xi'an, Beijing) need to take into account both winter heating and summer cooling, with moderate energy consumption levels. The frigid zone (Harbin) has the most prominent energy consumption due to its long heating period and extremely high heating demand. This finding emphasizes the importance of implementing regionally differentiated strategies in building energy conservation work, that is, formulating corresponding energy efficiency standards and technical routes according to different climate characteristics.

In terms of building types, the differences in usage modes and environmental control requirements lead to significant differences in energy consumption. The intermittently used teaching buildings have the lowest energy consumption, while the continuously operated cinemas with dense populations have the highest energy consumption, and the 24-hour operated police stations have moderate energy consumption. This indicates that building functions and usage modes are also key factors affecting energy consumption, suggesting that targeted measures should be taken according to the characteristics of different building types in energy conservation management.

It is worth noting that the difference between source energy and site energy highlights the importance of energy conversion and transmission and distribution efficiency. Especially in frigid regions like Harbin, the source energy reaches more than three times the site energy, indicating that improving energy production efficiency and reducing transmission and distribution losses also have great energy-saving potential.

4. Energy-Saving Optimization Strategies

4.1 Optimization of Passive Energy-Saving Design

Passive design strategies, particularly the application of

ISSN 2959-6157

natural ventilation, are effective techniques for moderating building temperatures. Studies have demonstrated that natural ventilation can reduce operating costs while improving thermal comfort and indoor air quality [6]. Rational natural ventilation is one of the lowest-cost energy-saving measures. During the transition seasons, organizing effective cross-ventilation using outdoor fresh air can directly remove indoor residual heat and moisture, significantly reducing or even completely replacing air conditioning cooling energy consumption, lowering building operating costs, and at the same time improving indoor air quality and enhancing personnel comfort.

An analysis of energy consumption efficiency reveals that classroom energy demands for natural ventilation can be reduced not only in transitional seasons but also in winter. This is achieved by enhancing the ventilation effectiveness ratio for heat distribution when the natural ventilation rate remains constant, and by reducing this ratio when the supply air temperature is stable [7]. Kunming has a cool summer, with an average temperature of only about 19℃ in the hottest month. By opening windows to introduce outdoor air, indoor residual heat can be directly removed, almost completely replacing air conditioning cooling and saving a large amount of electricity. In addition, the local area has small temperature differences throughout the year but large day-night temperature differences; night ventilation can store cold in the building structure, effectively reducing the daytime cooling load. At the same time, Kunming has a suitable humidity, and ventilation is not easy to introduce excessive moisture load, avoiding the stuffy feeling that may occur in high-humidity areas and ensuring the comfort and effectiveness of ventilation cooling. Therefore, natural ventilation is a highly efficient passive energy-saving strategy in Kunming.

4.2 Optimization of Active Systems

The adoption of intelligent lighting systems in colleges and universities mainly stems from their significant economic benefits and management advantages. The primary driving factor is to respond to the national “dual carbon” policy and the demand for building a resource-saving campus. As major energy consumers, colleges and universities have a high proportion of lighting electricity consumption. Through strategies such as turning off lights when people leave and dimming on demand (such as adjusting brightness in combination with natural light), intelligent systems directly reduce electricity consumption and carbon emissions, conforming to the development goal of green campuses. Secondly, Kunming’s sufficient lighting conditions provide advantages for technology application; intelligent systems can maximize the use of natural lighting, automatically dimming or turning off lights in areas near windows, achieving efficient energy conservation. Research findings indicate that utilizing illuminance suitability analysis to determine the trigger threshold for energy-saving lights and intelligent systems can ensure lighting energy savings and visual comfort, eliminate the “energy use rebound effect”, and achieve favorable technical and economic outcomes [8]. Therefore, intelligent lighting is not only a technological upgrade but also an important way for colleges and universities in Kunming to achieve refined energy management and reduce operating costs.

4.3 Utilization of Renewable Energy

4.3.1 Building Applications for Geothermal Pump Technology

The emissions of a ground-source heat pump used in buildings are generally lower than those of other traditional HVAC systems. Considering the high installation cost associated with deep-hole drilling, a shallow-hole ground-source heat pump presents a more viable alternative [9]. The ground-source heat pump applied in Kunming has high energy-saving efficiency, which stems from the perfect combination of its unique geological and climate conditions. Kunming is located on the Yunnan-Guizhou Plateau, where the temperature of shallow underground soil is stable throughout the year (approximately 18-20℃), providing an excellent heat source and heat sink for the ground-source heat pump. This enables the system to have a much higher coefficient of performance (COP) during winter heating than traditional air-source heat pumps and electric heating, and also higher efficiency during summer cooling than ordinary air conditioners, significantly reducing operating energy consumption. Secondly, Kunming’s “spring-like climate throughout the year” results in a relatively balanced cooling and heating load of buildings. The ground-source heat pump exchanges heat with the soil through underground buried pipes, extracting heat in winter and discharging heat in summer. The annual load balance avoids soil heat imbalance, ensuring the long-term efficient and stable operation of the system, thereby realizing the sustainable utilization of geothermal energy. In addition, this system has no local carbon emissions, outstanding environmental benefits, and is highly in line with the requirements of green buildings. Therefore, the ground-source heat pump is an ideal solution for Kunming to balance high-efficiency energy conservation and environmental protection. Studies confirm that ground-source heat pump systems can significantly reduce carbon emissions [10].

4.3.2 Building Application of Solar Energy Technology

Kunming belongs to a low-latitude plateau mountain monsoon climate, with an annual sunshine duration of approximately 2,200 hours and strong solar radiation. It is rich in solar energy resources, providing favorable natural conditions for the application of solar thermal and photovoltaic technologies. The photovoltaic system can be connected to the grid for power generation to supply electricity to building lighting, air conditioning, and other equipment, directly reducing operating costs and carbon emissions. Kunming has no severe cold in winter but still has heating demand; the solar thermal system can effectively supplement the winter heat load and improve indoor thermal comfort. In terms of system integration, new terminal equipment such as radiant ceiling air conditioners can be adopted. The improved radiant ceiling air-conditioning system replaces traditional air conditioning, offering advantages such as a small footprint, absence of wind draught sensation, high heat exchange capacity of the radiant ceiling device, and the ability to meet building load requirements with a small temperature difference between supply and return water [11]. At the same time, photovoltaic roofs or photovoltaic curtain walls can be installed to efficiently utilize solar energy while taking into account the aesthetics of the building, realizing the rational use of resources and energy conservation and emission reduction. The combination of solar energy generation with the natural cooling effects of green roofs presents a promising solution that not only enhances building performance but also mitigates the urban heat island effect [12]. This technical path is highly in line with the national “dual carbon” strategy and the green energy development goals of Yunnan Province. With policy support, its technical and economic benefits are becoming increasingly prominent. Therefore, the utilization of solar energy is an inevitable choice for Kunming to achieve economical, efficient, and sustainable development of building energy conservation.

5. Conclusion and Outlook

5.1 Conclusion

Through building energy consumption simulation, this study systematically analyzes the impact mechanisms of geographical location and building type on energy consumption, and proposes suitable energy-saving optimization strategies for teaching buildings in Kunming. The results show that geographical location is a fundamental factor affecting building energy consumption; relying on its unique mild climate conditions, Kunming has the lowest annual energy consumption, while Harbin has particularly prominent heating energy consumption due to its long frigid period. Meanwhile, building functions and operation modes have a significant impact on energy consumption levels; the intermittent use characteristics of teaching buildings make their energy consumption per unit area lower than that of cinemas and police stations that require continuous operation. The study also finds that the perspective shift from site energy to source energy reveals greater energy-saving potential, especially in northern heating regions, where improving energy production and transmission and distribution efficiency is crucial. Finally, the climate-adaptive energy-saving strategies proposed for teaching buildings in Kunming (such as natural ventilation, intelligent lighting, and the utilization of solar energy and geothermal energy) demonstrate high technical and economic benefits and emission reduction potential, providing an effective approach for promoting the construction of green campuses.

5.2 Outlook

This study reveals the impact of geographical location and building type on energy consumption through quantitative simulation and proposes targeted energy-saving strategies, providing a theoretical basis and practical reference for the energy-saving design of public buildings in Kunming. However, this study still has certain limitations. Firstly, the energy consumption simulation is based on typical assumptions and does not fully consider the differences in human behavior and equipment operation characteristics in actual use. Secondly, the analysis of optimization strategies is mainly based on theoretical calculations, and no verification and benefit evaluation of actual projects have been conducted.

Future research can be further deepened in the following aspects: first, conduct collaborative optimization research on multi-technical coupling to explore the integrated design method of natural ventilation, intelligent control, and renewable energy systems. Second, strengthen the monitoring and collection of actual operation data, and verify the accuracy of simulation results and calibrate the model through empirical research. Third, comprehensively consider economic and environmental benefits to construct an energy-saving technology evaluation system suitable for different climate zones. Through the above research, more scientific and comprehensive technical support can be provided for the large-scale promotion and refined operation of green buildings.

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