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Original Paper

Research on Carbon Emission Calculation of University Teaching Buildings under the Dual-Carbon Goals—Taking a University Teaching Building in Chengdu as an Example

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Abstract

In the context of an increasingly severe global ecological crisis, promoting green and low-carbon transformation has become a major issue that all humanity is facing together. The Chinese government has clearly set the strategic goals of carbon peak and carbon neutrality, demonstrating the responsibility and commitment of a major country. The construction industry, as an important sector in terms of energy consumption and greenhouse gas emissions, its low-carbonization process directly affects the realization of the country's emission reduction targets. This study focuses on a teaching building of a university in Chengdu region. Through a systematic examination of its architectural features, thermal performance of the enclosure structure, energy system configuration and operational energy consumption characteristics, a scientific and comprehensive carbon emission assessment system is constructed, and based on this, multi-dimensional carbon footprint analysis is carried out. This research not only provides data support and technical routes for the subsequent implementation of energy-saving renovations and low-carbon upgrades of the case building, but also creates a replicable model for the sustainable development practices of similar public buildings.

Keywords

Dual Carbon Target, Efficient Teaching Building, Carbon Emission Calculation

1. Introduction

According to the authoritative climate research report of the United Nations, the current global average temperature has shown a significant upward trend compared to the baseline before the Industrial Revolution, and this temperature increase has approached the critical point of the climate safety threshold. The international climate science community has generally warned that if no immediate global emission reduction actions are taken, humanity will face irreversible ecological crises. As a responsible developing country, China has taken the lead in proposing a strategic carbon emission reduction commitment, namely achieving a historical turning point of carbon emissions decreasing from increase within the next decade, and reaching a dynamic balance between carbon emissions and carbon absorption around the middle of this century. These series of climate governance measures demonstrate China's leadership and responsibility in the global environmental governance system. The severity of current climate change has exceeded the scope of a mere environmental issue and is gradually evolving into a systemic challenge related to the sustainable development of human civilization.

The construction industry, as an important pillar industry of the national economy, has faced the issue of energy consumption, which has become a key bottleneck restricting the sustainable development of the economy and society. Under the dual pressures of global climate warming and energy crisis, the energy utilization efficiency of the construction industry directly affects the realization process of the national carbon peak and carbon neutrality strategic goals. Currently, the energy demand during the operation of buildings remains high, not only increasing the burden on the national energy supply system, but also causing continuous impacts on the quality of the ecological environment. Through technological innovation and design optimization to enhance the energy efficiency of buildings, it has profound strategic significance for building a green and low-carbon urban development model and ensuring a healthy and comfortable living environment for residents. This transformation is not only an inevitable choice in response to resource constraints, but also the necessary path to promote high-quality urbanization construction.

In the contemporary social system, higher education institutions, as the core carriers of knowledge dissemination and talent cultivation, have seen the energy consumption management of their campus buildings become a crucial part of the sustainable development strategy. These academic complexes not only feature diverse architectural forms but also exhibit distinct energy consumption characteristics due to their special public nature, which gives them unique potential for renovation in terms of energy conservation and environmental protection. Especially in the current era when ecological civilization construction and the concept of low-carbon development have gained widespread recognition, higher education institutions are treating building energy conservation as an important topic in campus planning and management. As the typical representative of functional spaces on campus, the energy consumption patterns of teaching buildings are relatively clear and distinguishable, but they face special energy management challenges due to the continuous high-density activities of teachers and students, complex space usage requirements, and the need for meticulous operation and maintenance. This characteristic precisely provides a feasible basis for implementing precise energy-saving upgrades.

2. The Necessity of Energy Conservation and Emission Reduction in University Buildings

In the context of the continuous deepening of the development of education and the process of urban-rural integration, China's higher education institutions are showing a development trend of prioritizing both scale expansion and quality improvement. From the perspective of building energy consumption, as typical large-scale public building complexes, university campuses, due to their special functional requirements and continuous operation characteristics, have become the third largest energy-consuming entity after commercial complexes and administrative office buildings. The total energy consumption of educational buildings throughout the year, including continuous heating and cooling, operation of experimental equipment, and supporting services for teachers and students' lives, has occupied a significant proportion of the total social building energy consumption. This energy consumption model not only has a significant contradiction with the green development strategy implemented in our country, but also directly affects the realization process of the dual-carbon goals. Therefore, building an energy-saving campus infrastructure system and optimizing the energy consumption structure of buildings have become key issues for the sustainable development of higher education in the current field.

In the current macro context of global climate governance, higher education institutions, as important carriers of social sustainable development, have elevated their responsibility for carbon reduction to a strategic level. At the national level, the "Implementation Plan for the Construction of a National Green and Low-Carbon Development System for Education" and other guiding documents have established a system framework. Local education authorities have also formulated practical technical norms and construction standards, forming a complete policy loop from top-level design to implementation paths. The international academic community has also demonstrated a high level of action consciousness. Starting from the 2019 North American Summit, more than 7,000 universities worldwide, including top global institutions, represented by their representatives, concluded a milestone commitment for carbon reduction, clearly setting the goal of systematically decarbonizing campus operations by achieving net zero emissions by the middle of this century. This governance pattern of multi-party collaboration among government, industry, academia, and research has not only reflected the urgency of responding to the climate crisis but also demonstrated the exemplary leading role of higher education institutions in ecological civilization construction.

3. Research Subjects and Methods

3.1 The Research Subject

This article selects a representative teaching building in a certain university in Chengdu as the key analysis case. It systematically examines the physical characteristic parameters of the building, the energy consumption records of the past three years, the configuration of major energy-consuming equipment, and the potential space for energy-saving optimization. Through rigorous carbon footprint calculation and multi-dimensional energy consumption data analysis, it deeply explores the technical paths and implementation strategies for energy-saving renovations of campus buildings. The research results can provide a practical theoretical basis and technical support for the energy management departments of educational institutions when formulating energy efficiency improvement plans for campus buildings.

The selected building strictly complies with the relevant energy-saving design norms of the country and local areas. In the planning and design stage, it fully considers the dual factors of energy efficiency and environmental protection. It not only fully meets the current public building energy-saving standard system but also fully embodies the green building concept of sustainable development. Through comprehensive optimization of the building's envelope structure, mechanical and electrical systems, and renewable energy utilization, this project achieved the goal of reducing energy consumption and environmental impact, and at the same time reserved technical space for the improvement of future building energy-saving standards, demonstrating the contemporary architecture's profound understanding and practice of ecological civilization.

This building significantly surpasses the current national standards in terms of building energy conservation, achieving a technical breakthrough of 20% improvement in the thermal performance of the envelope structure compared to the normative requirements. In the specific construction plan, the exterior wall system adopts an innovative composite construction design: 200mm lightweight aggregate concrete blocks as the main structure, covered with 70mm high-performance glass fiber insulation board, and the measured overall heat transfer coefficient of the wall is controlled at an excellent level of 0.48W/(m²·K); the roof engineering selects an 80mm water repellent expanded perlite insulation mortar system, with a heat transfer coefficient of 0.43W/(m²·K) that is particularly outstanding. The window system is equipped with a break-bond aluminum alloy Low-E double-glazed glass combination, which not only achieves a low heat transfer coefficient of 2.30W/(m²·K), but also effectively controls solar radiation heat gain through a 0.44 comprehensive shading coefficient. It is particularly worth noting that this project innovatively adopts a ground source heat pump heating and cooling combined supply system, which realizes the dual functions of efficient cooling in summer and stable heating in winter through the heat storage characteristics of the underground soil. This system selection not only conforms to the passive energy-saving design concept but also significantly improves the overall energy efficiency of the building.

This article focuses on the direct energy consumption carbon emission calculation within the boundary of the teaching building of this building. The calculation period is from 2020 to 2024, covering five consecutive natural years. The specific research scope includes four major energy-consuming systems during the operation of the building: end power equipment (including teaching equipment, office equipment, etc., socket electricity consumption); indoor and outdoor lighting system electricity consumption; central air conditioning and split air conditioning equipment electricity consumption and air source heat pump hot water supply system electricity consumption. Through the establishment of a complete energy consumption monitoring system, the carbon footprint characteristics of the teaching building operation stage were quantified, providing data support for subsequent energy efficiency optimization and carbon neutrality path planning.

3.2 The Research Methods

3.2.1 Common Methods for Carbon Emission Accounting

1. Measurement Method

The method of obtaining carbon emission data through actual measurement has become one of the important approaches in the current carbon accounting field. This method uses professional measuring instruments to conduct on-site direct measurements of specific emission sources, enabling the acquisition of the most authentic carbon footprint data. Under the premise of scientific sampling and standardized operation, the measured data has high accuracy and reliability. However, this method still faces significant challenges in practical application: it requires a large amount of time and technical resources, the measurement procedure is complex and cumbersome, and the representativeness of the samples and data quality control are relatively difficult. Due to these implementation obstacles, the cases using the measurement method in China are relatively limited, mainly concentrated in specific fields such as online monitoring of flue gas emissions from power plants and the calculation of carbon fluxes in agricultural and forestry ecosystems that require high-precision data. Compared with other carbon accounting methods, the measurement method has advantages in data accuracy, but its promotion and application still need to overcome high technical barriers and economic costs.

2. Emission Factor Method

As one of the core carbon measurement methodologies recommended by the Intergovernmental Panel on Climate Change (IPCC), the emission factor method constructs a scientific and rigorous carbon emission quantification system by combining standardized unit product greenhouse gas emission equivalents (i.e., emission factors) with the activity level data of specific carbon sources. The core advantage of this method lies in its establishment of a transparent calculation logic of "activity data ×emission factor = carbon emission quantity", where the activity data covers the scale of material usage and the terminal consumption of various energy sources, while the emission factor can be obtained through two standardized approaches: one is by referring to the dynamic updated carbon emission factor databases published by authoritative institutions such as the International Energy Agency (IEA) and the United States Environmental Protection Agency (EPA), and the other is through specialized calculations based on energy audits data for specific production processes. Due to its combination of theoretical rigor and operational convenience, this method has been incorporated into international standards such as ISO14064 and has become one of the most widely used carbon accounting tools globally. Its calculation accuracy is highly dependent on the timeliness and regional representativeness of the emission factor database. It is worth noting that with the development of life cycle assessment

(LCA) technology, current emission factors have extended from traditional energy combustion emissions to comprehensive carbon footprint parameters covering the entire process from raw material extraction to transportation.

3. Material Balance Method

The material balance method, as an important method for carbon emission accounting, is based on the law of conservation of mass in physics and quantifies carbon emissions by systematically analyzing the mass balance relationship between input raw materials and output substances in the production process. This technology can be used for the assessment of carbon footprints of the entire process chain and can also conduct detailed analysis for specific processes. Its significant advantage lies in the ability to precisely identify the contribution differences of different emission sources. However, it should be noted that to achieve this level of precision, a complete data collection system needs to be established, and various production activity data need to be classified and continuously monitored in multiple dimensions. This high-standard implementation requirement inevitably leads to a significant increase in human and management costs in practical applications, and the relationship between data accuracy and economy needs to be weighed in actual application.

3.2.2 The Research Methods of This Article

Due to the particularity of carbon emission accounting for teaching buildings, after systematic analysis and scientific verification, this study finally determined to adopt the emission coefficient method as the core calculation method. This method has significant advantages over the measurement method: Firstly, its theoretical basis has been verified through extensive academic research and practical application, and it has a high degree of reliability; Secondly, the data collection channels are mature and stable, which can effectively reduce research costs and time investment; Thirdly, the operation process is highly standardized, making it easy for the research team to quickly master and apply. It is worth noting that although the measurement method has higher theoretical accuracy, its requirements for professional technical teams, expensive equipment, and complex sampling processes often create obstacles to its practical application in teaching buildings. The emission coefficient method, by establishing a systematic parameter system, can not only ensure the scientific nature of the calculation results but also balance the practicality and economy of the research, making it the mainstream choice in the field of carbon emission research for educational buildings.

The carbon footprint assessment of this teaching building is conducted through the systematic calculation using the internationally recognized emission factor calculation method. Its core calculation model is based on the rigorous formula system of "activity data × emission coefficient". Specifically, this method first precisely defines the key emission sources within the operational boundaries of the organization, such as energy consumption and material usage, by collecting basic activity data such as electricity consumption and gas usage, and then multiplying it by the corresponding emission factors approved by authoritative institutions. Among them, the emission factor represents the equivalent amount of carbon dioxide produced per unit of activity data. To improve the calculation accuracy, this model also incorporates the regional grid emission factor adjustment coefficient and adopts differentiated calculation parameters for different energy types to ensure that the final carbon emission total data is scientific and comparable.

$$Q = \frac{\sum e_i \times C_i}{A} \tag{1}$$

In the formula: Q represents the unit greenhouse gas CO2 emission volume, in kg CO2 per square meter; e_i represents the activity level of the i^{th} type of carbon source; C_i represents the greenhouse gas CO2 emission factor corresponding to the i^{th} type of carbon source; A represents the building area in square meters.

Based on a rigorous carbon footprint measurement methodology, this study systematically calculated the greenhouse gas emissions of the target institution using authoritative data sources. During the implementation process, first, detailed energy consumption statistics provided by the school's logistics management department were collected and organized as the basic activity level data. Then, in combination with the specific conditions such as the climate characteristics, building types, and energy structure of the campus location, emission parameters that were in line with the actual situation were obtained through on-site investigations. In terms of the determination of carbon emission factors, strict reference was made to the "IPCC National Greenhouse Gas Inventory Guidelines" and relevant technical specifications issued by the Ministry of Ecology and Environment of China. Finally, a series of professional parameters including the power emission factor of 0.5703 kg CO_2/kWh were selected to ensure the scientificity and comparability of the calculation results. This measurement method not only conforms to the internationally accepted greenhouse gas accounting standards but also fully takes into account the particularity of local application scenarios.

3.3 The Energy-using Equipment for Buildings

The HVAC system of this teaching building adopts an efficient and energy-saving ground source heat pump technology solution. Two large-capacity screw-type chillers are configured as the core cooling equipment, with each unit having a cooling capacity of 1,658 kW. The system design fully considers energy efficiency optimization and operational flexibility. The ground source heat pump main room is located on the first floor of the building, and the underground buried pipe heat exchanger is used to achieve dual functions of cooling in summer and heating in winter. This design not only meets the annual temperature control requirements of the building, but also significantly reduces the system operation energy consumption by adopting renewable energy technology, reflecting the advanced design concept of modern buildings in terms of energy conservation and environmental protection. The unit configuration adopts a dual-unit parallel mode, which is convenient for flexible adjustment of operation strategies according to load changes, ensuring the cooling and heating capacity under extreme climate conditions and achieving efficient operation under partial load conditions.

According to the standards and norms of the HVAC industry, the operating parameters of this building's HVAC system strictly follow the seasonal temperature regulation requirements: in the cooling mode, the chilled water system maintains a standard temperature difference of 7℃ supply water/12℃ return water; in the heating mode, an energy-saving low-temperature heating configuration of 45℃ supply water/40℃ return water is adopted. It should be particularly noted that the operation mode of this system continued the traditional heating method in 2020, and the technical upgrade was completed from 2021 to 2024, fully activating the low-temperature heating system that complies with the requirements of the "Design Code for Heating, Ventilation and Air Conditioning of Civil Buildings" (GB50736-2012). The adjustment of these operating parameters has increased the system's energy efficiency ratio by approximately 15% and reduced pipeline heat loss by about 20%.

4. The Carbon Emission Calculation for the Teaching Building Construction

4.1 The Classification of Building Carbon Emission Sources

Based on on-site investigation and data analysis, it was found that the energy usage of this teaching building during the period from 2020 to 2024 exhibited a feature of a single power supply. The electricity consumption composition mainly consisted of five major sections: the power supply system for teaching areas, the building lighting system, seasonal air conditioning equipment (cooling in summer and heating in winter), and the vertical transportation elevator system and other infrastructure electricity consumption. Through system monitoring data, the specific energy consumption values of each electricity-consuming unit in the past five years have been completely recorded in Table 1, which provides detailed basic data support for subsequent energy efficiency optimization.

Table 1. Summary of Energy Consumption of Teaching Buildings from 2020 to 2024

Var	Year				
	2020	2021	2022	2023	2024
Building Area	10 357	10 357	10 357	10 357	10 357
Non-Heating Electricity Consumption(m2)	764 321	553 210	452 316	984 329	876 854
Heating Electricity Consumption (kWh)	225 336	212 758	218 312	521 319	507 237
Electricity Consumption for Non-Heating Purposes per Unit Area (kWh/m2)	44.82	43.89	40.21	74.34	64.78
Heating Electricity Consumption per Unit Area (kWh/m2)	19.34	18.21	16.54	20.62	18.67

This building employs an advanced electric refrigeration ground source heat pump system to achieve year-round climate control. With the same integrated equipment, it can meet the dual demands of cooling in summer and heating in winter. The energy efficiency operation analysis of the system needs to distinguish the seasonal electricity load: during the non-heating season, the electricity consumption mainly comes from the cooling unit, circulating pump, ventilation equipment, and conventional building electrical equipment; while during the heating season, it is necessary to specifically calculate the special heating energy consumption of the ground source heat pump system under low-temperature conditions, and its heat exchange efficiency is closely related to the thermal properties of the soil.

4.2 The Carbon Emission Accounting Results over the Past Five Years

The carbon emission data of teaching buildings from 2020 to 2024 are shown in Figure 1.

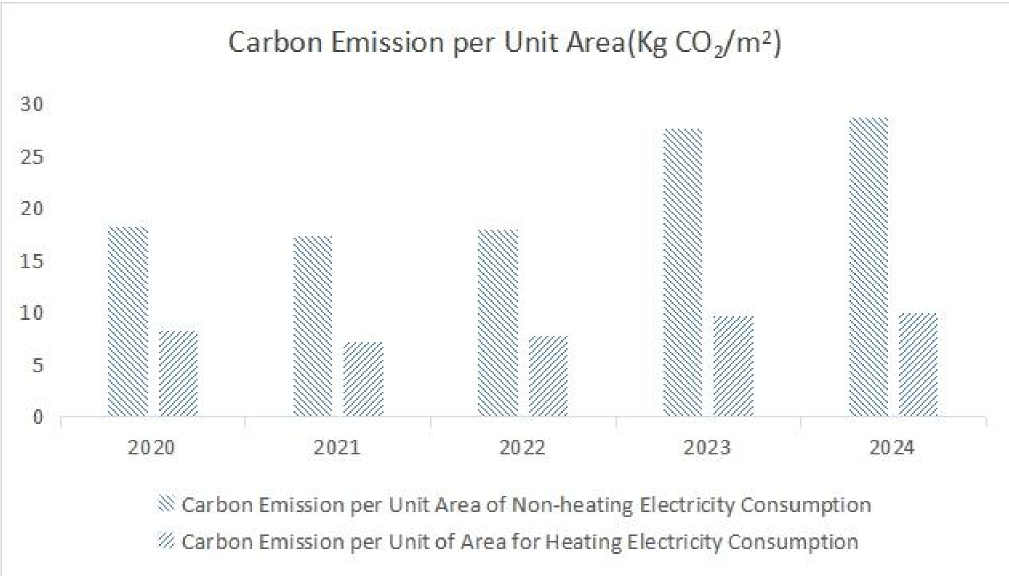

Figure 1. 2020-2024 Carbon Emissions of Teaching Buildings

A systematic analysis of the building carbon emission data from 2020 to 2024 shows that the total carbon emission of buildings reached its peak in 2023, followed by 2024. In 2021, due to the impact of the epidemic prevention and control policies, the number of students and teachers in schools decreased sharply, resulting in the lowest carbon emission level in five years. The energy consumption structure of buildings presents a significant characteristic: the average carbon emission per unit area of non-heating systems (including central air conditioning cooling, ventilation equipment, water supply and drainage systems, office equipment and lighting, etc.) is three times that of heating systems over the five-year period. During 2023-2024, the heating energy consumption remained relatively stable, while the proportion of non-heating system energy consumption continued to rise, which fully indicates that there is significant potential for energy savings in aspects such as improving the energy efficiency of mechanical and electrical equipment, renovating intelligent lighting systems, and optimizing energy usage behaviors.

According to the monthly monitoring report of the carbon emission data of teaching buildings in 2024, the carbon emission level shows a significant seasonal fluctuation pattern. Specifically, the peak of winter heating demand in December reaches the annual carbon emission peak, followed by January the next year; in August, due to the school summer vacation, the overall energy consumption drops to the lowest point of the year; in April, which is in the climate transition period, the carbon emission level also remains at a relatively low level. Before and after concentrated vacation periods such as winter and summer holidays, the carbon emission level often shows a steep upward or downward curve, and this fluctuation pattern is strongly correlated with the mobility of energy consumption population and changes in temperature regulation requirements of buildings.

The energy consumption and carbon emission characteristics of teaching buildings exhibit significant seasonal features, which are closely related to the building usage patterns and climatic conditions. During the summer operation period, the ground source heat pump system demonstrates excellent energy efficiency performance: between June and July, the COP value of this system remains at a relatively high level, and combined with the intermittent operation strategy, the carbon footprint of the cooling process remains at a relatively low level. Conversely, during the winter operation period from November to February, the system's energy efficiency drops significantly, the outdoor low-temperature environment leads to a reduction in the temperature difference of the heat pump, the COP value significantly decreases, and the continuous heating demand further increases the building's carbon emission intensity. Data analysis shows that the carbon emissions during the heating period in December can reach twice that of the cooling period in July, highlighting the potential for energy efficiency improvement in the winter heating system. It is recommended to optimize operation strategies (such as implementing low-temperature operation modes during winter vacations) and integrate renewable energy technologies such as solar energy to effectively reduce the carbon intensity of winter heating. This finding provides an important reference basis for the full life cycle carbon neutrality path of educational buildings.

5. The Suggestions for CO_2 Emission Reduction of University Buildings

5.1 The Seasonal Energy Regulation

The energy consumption characteristics of buildings have a significant correlation with climatic conditions, and the fluctuation range is often influenced by both the usage period and external environmental changes. From a temporal perspective, during the school break periods and before and after holidays, due to the drastic changes in personnel mobility, energy consumption shows a distinct peak-valley pattern; while the differences in temperature and humidity adjustment requirements caused by seasonal changes directly lead to the periodic changes in the operating load of the air conditioning system. The carbon footprint of teaching buildings in cold seasons is significantly higher than that in summer conditions. This phenomenon mainly results from the decline in the energy efficiency coefficient (COP) of the ground-source heat pump system in low-temperature environments, which leads to an increase in energy consumption. To address this characteristic, it is recommended to improve it through refined temperature control strategies: while ensuring basic comfort, moderately lower the heating setpoint, and switch to the maintenance low-temperature operation mode during the unoccupied period. This can effectively alleviate the heat load pressure and achieve systematic optimization of carbon emissions during the heating stage.

5.2 To Strengthen the Management of Energy-consuming Equipment

In the current energy management system of the campus, there is a significant energy redundancy issue in the lighting and electronic equipment of the teaching areas. This is mainly manifested as continuous operation of full-area lighting during non-teaching hours and full-load power supply in scenarios with low usage rates. This energy allocation model neither conforms to the current trend of intelligent management of educational facilities nor aligns with the concept of sustainable development. It is recommended to adopt a hierarchical control strategy, dynamically adjust the lighting range based on actual usage needs, and simultaneously establish a supervision mechanism combining property inspections and self-governance by teachers and students. Through conducting ecological campus-themed educational activities, enhance users' awareness of energy conservation, thereby systematically reducing the carbon footprint of building lighting and achieving a balance between the operational efficiency of teaching spaces and environmental responsibility.

5.3 To Establish the Energy Regulatory System

To effectively enhance the energy management efficiency of the campus, it is necessary for the school to establish a systematic energy supervision system. By establishing sound institutional norms and detailed implementation rules, regular monitoring of various energy usage behaviors can be carried out. Consider building an intelligent energy IoT network to integrate scattered energy-using equipment, monitoring terminals, and control systems, and construct a comprehensive management center that integrates equipment operation and maintenance, energy scheduling, and data analysis. This platform should have basic functions such as remote control of air conditioning systems and time-based, location-based, and grade-based control of lighting facilities. At the same time, it should integrate fault warning and diagnosis modules to achieve intelligent operation and maintenance of the energy system. During the specific implementation process, it is necessary to base on the local climate characteristics and the energy usage patterns of the campus, conduct a comprehensive assessment of the existing energy facilities, and scientifically plan the application scenarios of renewable energy. Through the dual drive of technological innovation and management optimization, the campus energy conservation and emission reduction work can be effectively promoted and achieve practical results.

6. The Conclusion

This article focuses on the teaching buildings of a university in Chengdu. Through in-depth examination of its energy consumption data, it systematically calculates the greenhouse gas emissions generated by the building during operation. The usage patterns and seasonal variations of the building all have an impact on energy consumption. The carbon emissions are high in winter because the efficiency of the ground source heat pump is low. Therefore, the heating method needs to be adjusted. Closing some classrooms and enhancing energy conservation awareness can reduce lighting and equipment energy consumption. It is suggested that the school introduce relevant regulations and establish a campus energy Internet of Things platform to achieve more effective energy management. It is emphasized that in combination with the region and the school's own characteristics, actively utilize renewable energy to achieve energy conservation and emission reduction. An in-depth analysis of the energy usage patterns of educational buildings and the formulation of reasonable energy-saving renovation strategies are carried out. This academic discussion based on empirical data not only reveals the typical characteristics of energy usage in educational buildings, but also provides a valuable analytical model for the energy conservation and emission reduction research of similar public buildings. The demonstration effect at the methodological level is worthy of attention and reference by researchers in the field of building energy conservation.

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References

Aiming, Y., Zhen, Z., Xuliang, J. et al. (2022). Carbon emission analysis of two crystalline silicon components throughout the life cycle. *IOP Conference Series: Earth and Environmental Science*, *983*(1). https://doi.org/10.1088/1755-1315/983/1/012111

Feng, J. W. (2024). *Research on Carbon Emission Calculation of Building Envelope Structures under the Dual-Carbon Goals*. Anhui University of Architecture.

Jiang, K. W. (2024). *Research on Carbon Emission Calculation and Low-Carbon Development Strategies of Universities*. East China University of Science and Technology.

Opel, O., Strodel, N., Werner, K. et al. (2017). Climate-neutral and sustainable campus Leuphana University of Lueneburg. *Energy*, 1412628-2639. https://doi.org/10.1016/j.energy.2017.08.039

Opher, T., Duhamel, M., Posen, D. I. et al. (2021). Life cycle GHG assessment of a building restoration: Case study of a heritage industrial building in Toronto, Canada. *Journal of Cleaner Production*, *279*. https://doi.org/10.1016/j.jclepro.2020.123819

Wei, Y. H. (2024). *Research on Carbon Emission Calculation and Emission Reduction Optimization of Prefabricated Buildings Based on LCA*. Xihua University.

Zhang, E. Y. (2024). *Research on Carbon Emissions during the Operation Phase of University Teaching Buildings*. Hebei Institute of Architectural Engineering.

Zhang, M. X., Cui, Y. F., & Wang, X. J. (2025). Carbon Emission Calculation and Prediction of University Electricity Consumption Based on SARIMA Model. *Science and Industry*, *25*(21), 106-112.

Zhang, Q., Zhu, J. M., & Wang, Y. (2025). Calculation of Carbon Emissions of University Teaching Buildings and Research on Carbon Reduction Strategies in Hanzhong Area. *Building Energy Conservation (in Chinese and English)*, *53*(09), 138-147.

Zhang, X., Liu, K., & Zhang, Z. (2020). Life cycle carbon emissions of two residential buildings in China: Comparison and uncertainty analysis of different assessment methods. *Journal of Cleaner Production*, *266*. https://doi.org/10.1016/j.jclepro.2020.122037

Zhao, X. Y., Li, B. Q., & Chen, W. J. (2024). Carbon Emission Calculation and Analysis of a Typical University Teaching Building in North China. *Energy Saving*, *43*(08), 10-12.