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Analysis of Key Factors of Energy Consumption in University Teaching Buildings

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Abstract. In response to the goals of improving energy efficiency and achieving dual carbon, this study focuses on high-energy-consuming university teaching buildings, aiming to identify the key factors affecting their energy consumption and to provide a reference for related energy conservation work. The study selected four building cases with the same basic parameters and set up the control and experimental groups using the control variable method. The effects of geographical location, building type, and enclosure structure were discussed, respectively. The annual energy consumption was simulated and analyzed by professional software. The results show that the three factors have a significant impact on the energy consumption of the teaching building, and the role of the envelope is the most prominent, followed by the geographical location, which has a relatively small impact on the building type; At the same time, heating and refrigeration related energy consumption accounts for the highest proportion of the total energy consumption, which is the core link of energy consumption regulation by various factors. This study clarifies the roles of various factors in the energy consumption of teaching buildings, provides clear guidance for targeted implementation of energy-saving measures in the design, transformation, and operational management of university teaching buildings, and helps reduce energy consumption in these buildings.

Keywords: Green building, energy consumption analysis, public building.

1. Introduction

Against the backdrop of the double carbon goal promotion and urban energy optimization, building energy efficiency has become the key to green development, and public buildings are an important part of urban energy consumption [1]. As the core unit of the city, colleges and universities' building energy consumption accounts for 83.2% of the total energy consumption of colleges and universities, and the teaching building has become the main source of energy consumption of colleges and universities due to its high frequency of use and dense personnel [2].

The energy consumption of the university teaching building has distinctive characteristics. First, it is highly time-based, and energy consumption is highly bound to the teaching schedule. During recess and lunch break, the equipment is running at full load, and energy consumption rises sharply, while after-school and holiday hours fall sharply [3]. Second, the space density is high, and the density of classroom staff is much higher than that of ordinary buildings. Intensive heat dissipation

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and energy consumption demand push up local energy consumption; Third, it is highly volatile. Curriculum adjustment and temporary activities will lead to short-term changes in energy consumption. At present, most teaching buildings have problems of high energy consumption and insufficient efficiency, such as poor insulation of old buildings and unsatisfactory air conditioning operation, which not only increases the operating cost of colleges and universities, but also runs counter to the low-carbon goal, and has great energy-saving potential.In academic research, scholars have explored the energy use of public buildings. Geographical location, enclosure structure, and function all affect energy consumption. In the North, heating accounts for most of a building's energy use, while in the South, cooling does. High-quality enclosure structures can reduce cold and heat loss [4]. Research shows that renovating the shell, lighting, air conditioning, and electrical systems can reduce annual building energy use by up to 55.44% [5]. Cities, though covering little land, consume 60% to 80% of energy. In buildings, this share reaches 36% [6]. Air conditioning is the largest energy user [7]. Differences in heat and cooling needs also stem from building orientation [8]. Recent research is becoming multi-dimensional, producing new ideas and achievements in educational architecture. Integrating photovoltaic technology with teaching buildings can achieve energy self-sufficiency. Data show photovoltaic power generation can offset 11.4% of teaching building consumption and reduce the campus's overall building power use by 1.8% [9]. For campus resource allocation, artificial intelligence (AI) systems can collect three core types of real-time data: energy use of teaching buildings, space usage, and equipment operation , using a global smart internet of things (IoT) network [10]. However, previous studies often focus on single factors, lack comparative analysis, and do not fully consider teaching building energy characteristics. As a result, energy-saving suggestions lack specificity.

Based on this, this study takes the university teaching building as the object, selects four cases with the same basic parameters, and uses the control variable method to set up the control and experimental groups. Through the Revit 2025 professional software, it analyzes the impact of geographical location, building type, and enclosure structure on energy consumption, defines the rules of each factor, provides support for the energy-saving design, transformation, and operation management of the teaching building, and helps colleges and universities to achieve energy consumption reduction and double carbon goals.

2. Research subjects

2.1. Core building parameters

The four cases selected in this study are based on the development of a unified building model. The building adopts a symmetrical layout design, with a plan size of 16.4m × 50.0m, a standard floor height of 4m, a total of 5 floors, a total building area of 3280 m^2, and a total building volume of 13120 m^3. There is no underground space in the building. All areas are equipped with a central air conditioning system. Each case adopts the same building scale, number of floors, and plane layout.

2.2. Internal spatial characteristics

The interior of the building covers 40 independent functional spaces, with a single space area ranging from 31.02 m^2 to 66.0 m^2. Among them, the core functions of teaching building related cases (including basic cases, experimental group 1 and experimental group 3) are positioned as classrooms and discussion rooms, and the density of designers is 3.88M ^{2}/person; As the case of the sports center in experimental group 2, the main function orientation is fitness and activities, and its

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personnel density is adjusted to 9.48m ²/person. For the power density of lighting and equipment, the research team carried out adaptation optimization according to the functional requirements of each space, so as to ensure the unity of non-research variables.

2.3. Case grouping and variable design

In this study, a single-variable control method was used to set up one basic control group and three experimental groups, ensuring the credibility of the research conclusion. See Table 1 for detailed grouping.

Table 1. Case core parameter configuration table

Case Type	Core Variable	Geographical Location	Building Function	Envelope
Basic Case (For Comparison)	None	Reference Area	Academic Building	Lightweight walls
Experimental Group 1	Geographical Location	Comparative Regions	Building Function	Lightweight walls
Experimental Group 2	Building Function	Reference Area	Sports Center	Lightweight walls
Experimental Group 3	Envelope	Reference Area	Building Function	Heavy-duty Insulated Thermal Barrier Wall

3. Research methods and results

3.1. Research methods

This study uses the method of case comparative analysis to take Revit 2025 software as the core technology tool. The tool can rely on the three-dimensional building model, integrate multiple types of data such as climate parameters, envelope thermal performance and energy consumption equipment parameters, complete the dynamic simulation of energy consumption for 8760 hours throughout the year, and generate key indicators such as total site energy consumption, sub item energy consumption such as heating/cooling/lighting/equipment and unit area energy consumption.The study sets the energy consumption data of the basic case as the reference standard, and with the help of the energy consumption comparison between the experimental group and the basic case, makes a quantitative analysis on the influence effects of the three variables of geographical location, building type and enclosure structure, and then clarifies the internal laws of various factors on building energy consumption, and finally realizes the core research goal of "identifying the key influencing factors and quantifying the specific impact degree".

3.2. Research findings

3.2.1. Basic case energy consumption analysis results

The basic case is the teaching building (light wall) in the benchmark area. Its energy consumption data provides a benchmark for subsequent comparative analysis. The specific indicators are shown in Table 2 below.

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Table 2. Base case energy consumption and proportion table

Energy consumption indicators	numerical value	Percentage of total site energy consumption
Total site energy consumption (GJ)	3987.41	100%
Energy consumption per unit area (MJ/m²)	1226.13	-
Heating Energy Consumption (GJ)	1268.01	31.80%
Cooling Energy Consumption (GJ)	1552.02	38.92%
Lighting Energy Consumption (GJ)	518.83	13.01%
Equipment Energy Consumption (GJ)	648.54	16.26%

According to the data, the energy consumption of Heating, Ventilation, and Air Conditioning (HVAC) (heating+cooling) in the basic case accounts for 70.72% of the total site energy consumption, which is the core component of the energy consumption of the teaching building. The proportion of cooling energy consumption is slightly higher than that of heating energy consumption, reflecting the climate energy consumption characteristics of the benchmark area.

3.2.2. Experimental Group 1 (geographical location variable) comparative analysis

Experimental Group 1 only altered the geographic location, with all other parameters consistent with the baseline case. The energy consumption comparison results are shown in Table 3 below.

Table 3. Geographical location variable energy consumption comparison table

Energy consumption indicators	Basic Case	Experimental Group 1	Change in quantity (GJ)	Rate of Change
Total site energy consumption (GJ)	3987.41	4517.29	+529.88	+13.29%
Energy consumption per unit area (MJ/m²)	1226.13	1389.07	+162.94	+13.29%
Heating Energy Consumption (GJ)	1268.01	134.53	-1133.48	-89.39%
Cooling Energy Consumption (GJ)	1552.02	3215.38	+1663.36	+107.17%
Lighting + Equipment Energy Consumption (GJ)	1167.37	1167.37	0	0%

The impact of geographical location change on energy consumption is mainly reflected in the sudden drop of heating energy consumption and the doubling of cooling energy consumption. Compared with the regional heating demand, the heating energy consumption decreased by 1133.48 GJ, but the sharp increase in cooling load (an increase of more than 100%) increased the total site energy consumption by 13.29%, which proved that the climate difference directly determines the structure and total amount of building energy consumption through the dominant HVAC load.

3.2.3. Experimental Group 2 (building type variable) comparative analysis

Experimental group 2 changed the building function from the teaching building to the sports center, and the other parameters were consistent with the basic case. The energy consumption comparison results are as follows, as shown in Table 4.

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Table 4. Building type variable energy consumption comparison table

Energy consumption indicators	Basic Case	Experimental Group 2	Change in quantity (GJ)	Rate of Change
Total site energy consumption (GJ)	3987.41	3576.00	-411.41	-10.32%
Energy consumption per unit area (MJ/m²)	1226.13	1099.62	-126.51	-10.32%
Heating Energy Consumption (GJ)	1268.01	943.05	-324.96	-25.63%
Cooling Energy Consumption (GJ)	1552.02	1473.85	-78.17	-5.04%
Lighting Energy Consumption (GJ)	518.83	482.96	-35.87	-6.91%
Equipment Energy Consumption (GJ)	648.54	676.14	+27.60	+4.26%

The core impact pathway of building type change is that reduced occupancy density leads to decreased heat dissipation load. The sports center's occupancy density (9.48 m²/person) is lower than that of the teaching building (3.88 m²/person), resulting in a 25.63% reduction in heating energy consumption. Simultaneously, optimized lighting power density reduces lighting energy consumption by 6.91%. Although the addition of special equipment in the sports center led to a slight increase in equipment energy consumption, the overall site energy consumption of the building decreased by 10.32%, which fully demonstrated the significant control value of functional adaptation for building energy consumption.

3.2.4. Experimental Group 3 (envelope variable) comparative analysis

In experimental group 3, the building envelope was replaced by a heavy-duty thermal insulation wall from a lightweight enclosure wall. The other parameters in this group were completely consistent with the basic case. See Table 5 for the relevant energy consumption comparison data.

Among the various energy-saving measures, the energy-saving effect produced by the optimization of the enclosure structure is the most prominent. With the help of the reduction of the heat transfer coefficient, the heavy insulation wall can effectively reduce the outward loss of indoor heat in winter and the invasion of outdoor heat into the room in summer, thus reducing the heating energy consumption by 49.32%, cooling energy consumption by 20.28%, and ultimately reducing the total site energy consumption by 23.58%. It is worth noting that the optimization measures have no impact on the energy consumption of lighting and equipment. This result fully proves that energy saving through optimizing the thermal performance of buildings is the core role of heavy insulation walls.

Table 5. Envelope variable energy consumption comparison table

Energy consumption indicators	Basic Case	Experimental Group 3	Change in quantity (GJ)	Rate of Change
Total site energy consumption (GJ)	3987.41	3047.14	-940.27	-23.58%
Energy consumption per unit area (MJ/m²)	1226.13	937.00	-289.13	-23.58%
Heating Energy Consumption (GJ)	1268.01	642.57	-625.44	-49.32%
Cooling Energy Consumption (GJ)	1552.02	1237.19	-314.83	-20.28%
Lighting + Equipment Energy Consumption (GJ)	1167.37	1167.37	0	0%

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4. Conclusion

Based on the comparative analysis conclusion of four groups of cases, this study identified the core elements that affect the energy consumption of university teaching buildings, which are the envelope performance, geographical location, and building type from high to low. As the key barrier layer of heat exchange inside and outside the building, the performance of the envelope directly affects the operating load of the HVAC system. The measured data of this study show that the total energy consumption of buildings can be reduced by 23.58% by using heavy insulation walls, and the heating energy consumption can be reduced by nearly 50%. This result fully shows that the performance optimization of the building envelope is the primary breakthrough point of building energy efficiency transformation, especially suitable for areas with strong heating demand. Geographical location affects the energy consumption composition of buildings through the decisive role of climate conditions. Comparing the energy consumption difference between the area and the reference area is essentially the reverse transformation effect of the building's "cooling heating" load. This factor directly determines the core direction of building energy efficiency design: the northern region should focus on improving the insulation performance of the enclosure structure and optimizing the heating system, while the southern region should take improving the efficiency of the refrigeration system as the core task. Building types mainly rely on indirect factors such as personnel density and equipment configuration to affect building energy consumption. Taking the sports center and the teaching building as an example, the energy-saving effect of the sports center is more prominent. This difference is mainly due to the reduction of the heat dissipation of its personnel and the optimization and upgrading of the lighting system. However, the impact of building type on energy consumption is significantly weaker than that of envelope performance and geographical location. Therefore, in the actual design work, it is necessary to scientifically match energy consumption parameters in combination with building functional requirements.

In addition, the four groups of cases show that the energy consumption of HVAC accounts for more than 70% of the total energy consumption, indicating that the system is the core link of energy consumption control. All key factors exert their influence on energy regulation by acting upon HVAC loads.

The building envelope was confirmed as the most critical factor influencing energy consumption in this university's teaching buildings. Compared to lightweight walls, buildings with heavy insulated walls achieved a 23.58% reduction in total energy consumption, demonstrating the most significant energy-saving potential among all influencing factors. Geographic location decisively shapes the energy consumption structure of teaching buildings. Regional climate variations cause heating and cooling energy demands to exhibit inverse trends, directly influencing overall building energy consumption levels. The effect mechanism of building types on the energy consumption of teaching buildings is mainly reflected in the indirect realization by affecting the load generated by personnel activities and equipment operation. The practice shows that after the scientific and reasonable optimization design of the building function layout, the energy-saving benefit of about 10% can be achieved. Among the various energy consumption components of the teaching building, the HVAC system plays a leading role, accounting for more than 70% of the total building energy consumption. At the same time, the system is also the core carrier of the key influencing factors of various energy consumption mentioned above.

The current research on the energy consumption of teaching buildings is insufficient. The research object is limited to a single building model, and does not cover scenes such as the reconstruction of old teaching buildings of different sizes. Conclusion: the universality is limited; key influencing factors such as window wall ratio and operation management are not included; It

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relies more on simulation calculation, lacks actual measurement calibration, and fails to meet the demand for carbon emission reduction. Future research can expand cases to teaching buildings of different types and ages to complement the influencing factor system. The "simulation+measurement" optimization model is adopted to deepen the correlation analysis between energy consumption and carbon emissions and develop collaborative energy-saving schemes. Prepare design guidelines and carry out pilot projects to promote the implementation of achievements.

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