Analysis of Building Energy Consumption Based on Geographical Location: Taking a Dormitory Building in a University in Wuhan as an Example

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Abstract: In the context of increasing concerns about global environmental sustainability, the impact of building energy consumption on the environment and resources has attracted attention. In order to cope with global climate change, university dormitories are densely populated places, and their energy consumption is directly related to energy efficiency and environmental sustainability. Taking the impact of dormitory building energy consumption in a university in Wuhan as an example, this article uses Revit software to model and conduct data analysis to explore the impact of different geographical locations on dormitory building energy consumption. By comparing the three cities of Harbin, Hong Kong and Singapore, this paper concludes that building energy consumption in different geographical locations has a significant impact. Climate conditions and geographical environment cause differences in energy consumption in different regions. Based on the actual situation, this article puts forward relevant suggestions, such as using renewable energy, improving energy conversion efficiency, optimizing building design, etc. The research in this article can provide a relevant scientific basis, promote the rational utilization and conservation of energy in university dormitory buildings, and positively contribute to promoting the development of green buildings and achieving the goal of carbon peak carbon neutrality.

1 INTRODUCTION

The "dual carbon" strategy is a significant development strategy proposed by the country to respond to global climate change and promote sustainable development. "Carbon peaking" and "carbon neutrality" are currently environmental protection projects that have received widespread attention worldwide. In the process of development, green buildings take environmental friendliness and pollution reduction as their main goals, and are one of the important means for the country to implement the "double carbon" strategy (Ge, 2024). Energy consumption mainly comes from the construction industry and other fields. In terms of building energy conservation, the country started late, which resulted in high building energy consumption and low utilization rates. According to statistics, in 2022, the total energy consumption in the entire building process will be 2.27 billion tce (ton of standard coal equivalent), accounting for approximately 45.5% of China's total energy consumption (Xu et al., 2021). To reach the carbon dioxide emissions peak before 2030 and achieve the strategic goal of carbon neutrality before 2060, buildings need to reduce energy consumption through green and environmentally friendly processing methods. As an important building type, university dormitories bear the living needs of many students (Yang, 2023). As one of the important buildings that account for the largest proportion of construction area among university buildings and are used by students for the longest time, dormitory buildings have disadvantages such as high energy consumption, poor living environment, high density, and single form. They not only cause a large amount of waste of money and energy in universities but also directly Affect students' quality of life (Wu, 2020). In addition, geographical location will affect the design and construction of buildings, and building energy consumption is particularly affected by geographical location. Therefore, studying the impact of geographical location on building energy consumption will help formulate targeted energy-

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saving and emission reduction measures and provide a more effective path for realizing the "dual carbon" strategy.

Compared with foreign countries, the development of building energy conservation in the country was late and started slowly. For example, there are certain disadvantages in dormitory buildings in Chinese universities, including unreasonable early design, aging equipment, and inadequate energy consumption management. In the energy-saving design of university dormitory buildings based on BIM technology, Wu Shuang discovered that the energy-saving problems of university dormitory buildings in Xi'an are mainly caused by factors such as university planning, building orientation, building lighting, building shape design, and door and window materials. Consumption increased significantly. In addition, Qiu Yanyan's research on energy-saving strategies for existing buildings in some universities in Guangzhou found that existing buildings in universities in Guangzhou mainly have problems such as poor thermal performance of envelope structures, poor shading effects, unreasonable use of air-conditioning equipment, and backward lighting equipment (Qiu, 2021).

College buildings are an important part of school buildings and bear the important responsibility of providing students with learning and living places (Dai, 2024). This paper takes a dormitory building in a university in Wuhan as the research object to explore the impact of the outdoor environment affected by climate change due to different geographical locations on building energy consumption. By using Revit software to model the dormitory building, the data is unified, and the model selects the calculation and analysis of energy consumption data from different geographical locations to explore the specific impact of geographical location on energy consumption, such as climate conditions, light, rain, etc. The degree of influence of factors on dormitory energy consumption. Through in-depth analysis, this article will propose more feasible building energy-saving methods and measures to promote the construction industry's development in a more energy-saving and environmentally friendly direction. This article is of great significance to the energy consumption of a dormitory building in a university in Wuhan but also helps to comprehensively understand the universal impact of geographical location on building energy consumption, providing reference for sustainable development.

2 DATA AND METHODS

2.1 Research Objects

Wuhan City is located in central China, in the eastern part of Hubei Province. As can be seen from Figure 1, the geographical coordinates are between 113° 41’ and 115° 05’ east longitude and between 29° 58’ and 31° 22’ north latitude. It is located in the subtropical monsoon climate zone, with a humid climate, abundant annual rainfall, and moderate temperatures. It has the characteristics of rain and heat in the same season, light and heat in the same season, cold winters and hot summers, and four distinct seasons. The average annual temperature in Wuhan is between 15.8℃ and 17.5℃, and the annual precipitation is between 1150 mm and 1450 mm. The central rainfall is concentrated from June to August every year, accounting for about 40% of the annual rainfall.

Figure 1: Geographical location of Wuhan City (Picture credit: Original)

2.2 Method

Building information modeling (BIM) has five major characteristics: visualization, coordination, simulation, optimization, and graphability. It can also conduct a more accurate and comprehensive energy consumption analysis of buildings (Bao et al., 2024). BIM technology can convert traditional two-dimensional engineering drawings into three-dimensional visual models, and is widely used in many fields such as passive building engineering, building construction engineering, building protection engineering, and municipal drainage construction engineering (Wang, Zhao and Liu, 2023). Revit is a professional building information modeling (BIM) software launched by Autodesk, which is used for modeling and design of architecture, structure, electromechanical and other majors. It includes functions such as parametric modeling, automatic updates, intelligent object libraries, and model collaboration, which can improve modeling efficiency and team collaboration efficiency. Revit software is not only a powerful architectural design tool, but it can also be used to analyze building energy consumption. With the help of Revit's energy consumption analysis function, architects and engineers can evaluate and optimize the energy consumption of buildings during the design stage and can also simulate and calculate the energy consumption of existing buildings to achieve energy conservation and emission reduction goals.

2.3 Modelling Process

The model is based on the actual architectural structure of a dormitory building in a university in Wuhan, as can be seen in Figure 2. Revit software is used to build a simplified model and perform data analysis.

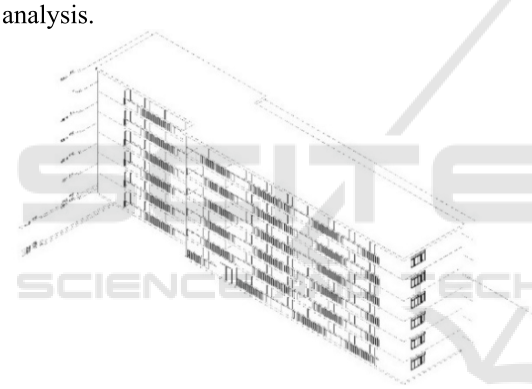

Figure 2: A three-dimensional view of a dormitory building in a university (Picture credit: Original)

Table 1: Basic information of building model.

Parameter	Value
Geographical location	Latitude 30.4843, Longitude 114.4009
Climate	North subtropical monsoon (humid) climate
Building Type	Dormitory
Building orientation	north
Construction area	The total area is 2756.28 square meters
Floor number	Level 6

As shown in the basic information of the building model in Table 1, the building type in this study is a dormitory, with coordinates of 30.4843 north latitude and 114.4009 east longitude. The main climate type is tropical monsoon climate. The building has six floors and a building area of 2756.28 square meters.

Table 2: Parameter settings of the building model.

Parameter	Value
Project	Dormitory
Building Schedule	Default
Building Equipment	VAV-Single Duct
HVAC System	Central VAV, HW Heating, Chilled Water Unit COP: 5.96, Boiler Efficiency: 84.5
Fresh Air Information	Fresh air per person: 8.00 L/s

As shown in the building model parameter settings in Table 2, the building equipment of the dormitory building uses VAV-single air duct, the building air penetration level is medium, the HVAC system uses central VAV, HW heating, chiller unit COP is 5.96, and boiler efficiency is 84.5, the fresh air volume per person is 8 liters/second.

Table 3: Thermal property parameters of building materials.

Element	Construction
Exterior Walls	Lightweight construction - typical mild climate insulation
Interior Walls	Lightweight construction – no insulation
Exterior wall-underground	Heavy construction – classic mild climate insulation
Roof	Typical Insulation - Light Colored Roofing
Floors	Lightweight construction – no insulation
Slabs	Heavy construction – no insulation
Glass Coloring	Double layer clear – uncoated Basic sunshade

As shown in Table 3, the thermal property parameters of building materials, in the material thermal properties, the exterior wall uses a lightweight structure and a typical mild climate insulation layer, the interior wall uses a lightweight structure and no insulation layer, and the roof uses a typical insulation layer and light-colored roofs, while using uninsulated floors and slabs.

3 RESULTS

Energy consumption analysis was conducted through the Revit building model, and the energy monitoring time was 24 hours. As shown in Table 4, the following data was obtained. The total source energy is 6078.63GJ, and the total site energy is 3078.57GJ. The total source energy is nearly twice the total site energy. The energy consumption of the site energy per unit total building area and energy consumption per air-conditioned building area is 1116.93 MJ/m2, and the source energy is 2205.37 MJ/m2. In building energy consumption, source energy usually refers to the energy consumed by the building, that is, the form of energy supplied to the building. Energy consumption during operation mainly comes from the building's ventilation, heating, refrigeration, lighting, and electrical equipment (Gao et al., 2024). If the use of source energy is too high, the energy efficiency of the building is likely low or there is energy waste.

Table 4: Site and source energy of the modeling building.

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total/Net Site Energy	3078.57	1116.93	1116.93
Total/Net Source energy	6078.63	2205.37	2205.37

As shown in Table 5, the cooling energy consumption in Wuhan is much higher than the heating energy consumption. The heating energy consumption is 309.48GJ, and the cooling energy consumption is 1804.23GJ, which is close to six times. This is because Wuhan's geographical location, climatic conditions and other factors result in high refrigeration energy consumption.

Table 5: End use of the modeling building.

	District Cooling [GJ]	District Heating [GJ]
Heating	0.00	309.48
Cooling	1804.23	0.00

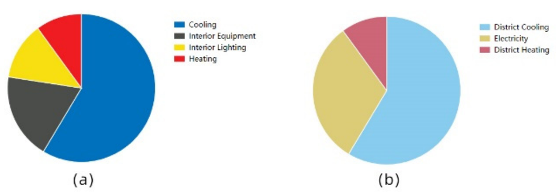

Figure 3: Pie chart of energy consumption and specific uses: (a)Terminal energy consumption diagram; (b) Regional energy usage map (Photo/Picture credit: Original)

As shown in Figure 3, cooling accounts for more than three-fifths of the total energy consumption, internal lighting and equipment account for two-fifths of the total energy consumption, and the remaining one-fifth is used for heating. This also illustrates the significant demand for refrigeration due to climatic conditions. As shown in Figure 3, in the area of heating energy consumption, its proportion is smaller than the electricity energy consumption and much lower than the cooling energy consumption, indicating that the demand for heating is small and the building is less affected by the outdoor temperature.

As shown in Table 6, the conversion coefficient of heating energy consumption is 3.613, accounting for the largest proportion, indicating that in energy consumption, the energy conversion efficiency required for heating is low, and relatively more raw energy needs to be consumed to meet the heating demand. Secondly, the conversion coefficient of electric energy is 3.167. Although it is not as high as the heating energy consumption, it still accounts for a large proportion. This shows that buildings have a large demand for electrical energy consumption, which is used for power supply, lighting, air conditioning, etc., resulting in a high conversion coefficient of electrical energy.

Table 6: Site to Source Energy Conversion Factors.

Energy types	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613

4 DISCUSSION

The climate type of a geographical location greatly impacts building energy consumption. For example, building heating energy consumption in northern regions is relatively large. Due to the cold climate in the north, the building insulation performance of homogeneous buildings is relatively poor, resulting in a large amount of energy being required to maintain indoor temperatures in winter. Therefore, the location of the research project was compared with three cities with different climates: Harbin, Hong Kong and Singapore; the energy consumption of the dormitory building model was analyzed and the differences and effects of geographical location on energy consumption were compared.

Harbin is located in the northeastern region of China and belongs to the southwest of Heilongjiang Province. It is located between 125°42′～130°10′ east longitude and 44°04′～46°40′ north latitude. It has a mid-temperate continental monsoon climate, with long and cold winters, short and cool summers, and four distinct seasons. The annual average temperature is about 5.6℃, and the annual precipitation is about 423 mm.

Hong Kong is located in southern China, across the sea from Macau and adjacent to Shenzhen. It has an oceanic subtropical monsoon climate, abundant rainfall, and four distinct seasons. The annual average temperature is about 23.3°C, which may drop below 10°C in winter and exceed 31°C in summer.

Singapore is located at the southern tip of the Malay Peninsula, adjacent to Malaysia across the Strait of Johor to the north and facing Indonesia across the Singapore Strait to the south. It has a tropical rainforest climate with abundant rainfall, small annual and daily temperature differences, and an average annual temperature between 23-35°C.

As shown in Table 7, the energy consumption of source energy and site energy in the four locations is compared. In Harbin, the site energy is relatively close to Wuhan and Hong Kong, but the source energy is much higher than the three cities, indicating that the total amount of raw materials and fuel consumed in the operation process is relatively higher. Harbin has long and cold winters, so buildings require a lot of energy for heating. Buildings may also use traditional heating methods, such as coal-fired and gas-fired boilers, which have relatively low energy efficiency. Secondly, some college dormitory buildings may have old structures and poor thermal insulation performance, requiring more energy to maintain a comfortable indoor temperature. In Singapore, the site energy is much higher than that of the other three cities. This may be because Singapore has a tropical rainforest climate with high temperature and humidity. Dormitory buildings require a lot of energy to cope with indoor cooling and ventilation needs, so the site energy consumption is relatively high. big. The data shows that the building energy consumption in Harbin is the highest, mainly due to the cold and long winter in Harbin. The temperature is low, the heating demand is large, and the energy utilization rate is low. This also shows that the more direct influencing factor is the huge difference in energy consumption due to different climate types and temperature changes caused by geographical location.

Table 7: Site and Source energy of the buildings in different sites.

Areas	Energy Type	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Wuhan	Total/Net Site Energy	3078.57	1116.93	1116.93
	Total/Net Source Energy	6078.63	2205.37	2205.37
Hong Kong	Total/Net Site Energy	3724.90	1351.42	1351.42
	Total/Net Source Energy	6023.76	2185.47	2185.47
Singapore	Total/Net Site Energy	5205.29	1888.52	1888.52
	Total/Net Source Energy	7532.19	2732.74	2732.74
Harbin	Total/Net Site Energy	3294.24	1195.18	1195.18
	Total/Net Source Energy	9528.84	3457.14	3457.14

As shown in Table 8, the four cities' regional heating and cooling energy consumption is very different. Due to the different geographical locations of the four cities, Singapore is located near the equator and has a tropical rainforest climate with high temperature and humidity. Frequent use of air-conditioning equipment is required inside the dormitory building to cool down to maintain indoor comfort. On the contrary, in winter, the temperature is comfortable, the heating demand is extremely low, and the heating energy consumption is zero. Harbin's geographical location has the highest latitude among the four cities. It has a mid-temperate continental monsoon climate. Winters are long and cold, while summers are short and cool. The building structure has insufficient thermal insulation and poor thermal insulation, and the climate is cold and heating. The high demand has led to high heating energy consumption, which is almost three times that of Wuhan.

Table 8: End use of the buildings in different sites.

Areas	District Cooling [GJ]	District Heating [GJ]
Wuhan	1804.23	309.48
Hongkong	2738.78	21.26
Singapore	4240.43	0.00
Harbin	759.96	1569.43

Regarding the energy consumption of cooling and heating, the city's climate zone and seasonal temperature directly impact energy consumption. In Wuhan, Hong Kong, and Singapore, summers are relatively hot, and cooling demand and energy consumption increase as they get closer to the equator, showing an increasing trend. On the contrary, heating energy consumption shows an increasing trend as the latitude increases.

5 SOLUTIONS

The above research shows that building energy consumption will be affected by changes in geographical location, thus exacerbating carbon emissions. Based on the climate conditions and geographical environment of different geographical locations, we need to take a series of targeted response measures to improve energy efficiency, thereby reducing energy consumption and achieving sustainable development goals. Therefore, formulating and implementing effective countermeasures is the key to solving the impact of geographical location on the energy consumption of university dormitory buildings.

On the one hand, renewable energy can reduce energy consumption. Renewable energy has the characteristics of low energy consumption and cost. In a sense, energy is the foundation for the development of modern social civilization and the key to maintaining social operations, people's production and life, and industrial development and other social activities. However, most of the energy is non-renewable. In order to solve the increasingly severe energy dilemma and better maintain the operation of society, people have discovered renewable energy based on this, mainly including solar energy, wind energy, geothermal energy, hydro energy and other non-renewable energy sources. Fossil renewable energy. The advantages of this energy are strong energy saving effect, high environmental protection and high economic benefits. In this study, the energy-consuming equipment is air conditioning, fresh air, heating, etc. The purpose of these equipment is to maintain the comfortable temperature of the human body as the main goal. Wind energy is a kind of usable energy provided to humans due to the work done by air flow. In the early design of the building, measures such as the layout, proportion, and orientation of windows and walls were optimized to achieve natural ventilation, increase indoor air flow rate, reduce reliance on traditional energy, and reduce carbon emissions.

On the other hand, it can improve energy usage efficiency and reduce energy conversion coefficient. Improving energy efficiency is inseparable from the use of energy-saving equipment and the supervision and management of equipment. Such as air conditioners, fans, washing machines, lighting facilities, etc. The energy consumption generated by the operation of these equipment is high, and more energy-saving technologies need to be adopted to improve energy efficiency and reduce energy conversion coefficients. The factors that affect the cooling load of air conditioners mainly include building layout, thermal performance of the building envelope, and heat dissipation of lighting equipment. Therefore, reducing the cooling load of air conditioners requires improving the building layout, improving the thermal performance of the envelope structure, and reducing the heat dissipation of lighting equipment personnel (Qiu, 2021). The increase in metreing devices is helpful for determining the energy consumption in each building area in a timely manner, discovering weak links in energy use, effectively preventing the unreasonable utilization of energy, and enhancing people's energy-efficiency awareness to some extent (Liu and Ren, 2020). Realize the control of equipment when it is not in use, to reduce unnecessary losses, thereby more effectively improving usage efficiency.

6 CONCLUSIONS

This article selects a dormitory building in a university in Wuhan for analysis, and conducts energy consumption analysis and explores the impact of different climates on the cooling and heating loads of dormitory buildings through three cities in different climate zones. Conduct simulation analysis through Revit software to intuitively obtain detailed results of building energy consumption. This article found that geographically, the building energy consumption of cities closer to the equator is higher than that of areas farther from the equator, and the source energy of areas with lower latitudes is higher than that of areas with higher latitudes. In terms of cooling energy consumption, areas with lower latitudes face greater energy consumption pressure, while heating energy consumption is lower. In terms of heating energy consumption, areas with higher latitudes have greater heating needs and consume more energy. This shows that geographical location significantly impacts the energy consumption of university dormitory buildings. With the continuous development of social economy and the increasingly prominent energy issues, we can respond to the challenges posed by geographical location and different climate types through more refined energy management and intelligent building design. At the same time, increase the research and utilization of renewable energy, actively promote energy-saving and emission reduction technologies, promote the sustainable use of building energy in universities, jointly respond to challenges such as global climate change and energy security, and promote the sustainable development of building energy consumption.

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