The Impact of Geographic Location and Wall Materials on Energy Consumption in Dormitory Buildings: An Empirical Study Based on BIM

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Abstract. The construction sector in China faces significant energy challenges, and university dormitories have especially large amounts of energy use. This study utilizes Building Information Modeling (BIM) with Revit software to investigate how wall materials and geographic latitude influence energy use in dorm buildings. Simulation model of the Building 6 on the Xipu Campus of Southwest Jiaotong University was established for comparison of traditional 200mm solid wall with three composite insulated walls at three different cities: Chengdu (30.76°N), Shanghai (31.23°N) and Tangshan (39.63°N). Key results show that higher latitude (Tangshan vs. Chengdu) can decrease the lighting energy use by about 12% (123.26 MJ/m² compared with 140.02 MJ/m²) due to longer daylight hours and reduced cloud cover in summer, but increases the total energy use, mainly because of larger heating demand. Optimized wall material can save energy consumption a lot; CW102-50-100P composite wall saved 11.6% (1,994.22 GJ versus 2,254.98 GJ) total site energy use from conventional wall. The analysis also found substantial energy losses for extraction and transmission, with conversion factors of 3.167 for electricity and 3.613 for district heating. These findings highlight the potential for latitude-responsive design approaches (in particular, to maximise use of natural light at higher latitudes), paired with improved wall insulation and use of more efficient energy sources. These measures would cut down on energy consumption considerably in student dormitories.

Keywords: building energy consumption, BIM simulation, geographic latitude, wall insulation

1. Introduction

Energy usage is a major problem for China's construction industry. Although significant progress has been made in the last ten years, there is still persistent challenges remain. Under the carbon peaking targets outlined in China's Action Plan for Carbon Dioxide Peaking Before 2030, national efforts must prioritize reducing overall energy consumption and fostering an energy-conserving society [1]. Globally, energy demand in the residential and commercial sectors continues to rise steadily, accounting for 20-40% of total final energy consumption and exceeding that of both industry and transportation [2]. Buildings account for over 30% of worldwide primary energy use [3]. This challenge is particularly acute in high-density settings such as university dormitories, where per capita energy consumption among students is approximately four times the national average [4,5].

Comparing solar spectral incident radiation from the three spatial positions with latitude variations confirms that it has tight correlation with latitude and significantly influences photovoltaic output potential through solar angle [6]. Models that were also used to predict this relationship confirmed that these effects have practical implications for the theoretical potential of electricity generation of electricity generation. Meanwhile, data gathered in construction-material research are palpably informing what influence composition of the vertical envelope surfaces has: historical examination of transition from building materials based on clay to aerified concretion blocks in recent empirical studies confirm dramatic fluctuations in internal energy dynamics due to different thermal performance needs [7]. These effects are supported by retrofit case studies. Examples of documented retrofit measures have provided proof of the achievable energy savings: Palermo University saved more than 60% on electricity and nearly 1/3 of the thermal input, and a university dormitory complex in Tehran attained 30% savings in total [8,9]. These cases illustrate how envelope improvements and material selection can greatly impact building energy performance. From these examples, it can be inferred the consequence that topographical optimisation (whether involved with maximised heliocentric collection or preferred material deployment) is decisive in restricting unnecessary energetic flows. Such premises guide the investigative focus of the present analysis towards specific wall assembly approaches and mix-and-match combinations of solar capture for tangible system efficacy.

Specific study is Building 6 of the Southwest Jiaotong University in Tianyouzhai. The studies of the different wall materials and locations (geographic latitudes) aim at estimating the impacts of heating, cooling and annual total energy use. Its aim is to use statistical methods to figure out how different materials of walls and geographic ranges affect the annual energy consumption of a building in residential buildings. The simulation results give different strategies to use different wall materials in different areas respectively. Ultimately, these findings provide insights into strategies for reducing the carbon emissions along a building's lifecycle, enabling contributors towards carbon neutrality.

2. Research methodology

Revit software was used in this study to calculate and estimate building energy consumption. The building model created in BIM includes geometric information, the material property set and structural element of the building. At the same time, annual energy consuming relevant operational modes are incorporated into this full matrix description to present a comprehensive performance analysis during the whole year cycle. The process consists of the three parts: establishing the model; feeding the data according to the preprocessing of climate parameters; simulation setup referring to the calculation engine software. Furthermore, this technical foundation helps quantify the energy efficiency for this dormitory building.

2.1. Building model establishment

A three-dimensional building model was initially created in Revit based on the two-dimensional drawings. Modelling process also requires detailed input of geometry data, information about material properties (for example, walls, roofs and windows thermal properties), site location, and local weather information. Parameters describing materials extend from thermal conductivity coefficients and surface emissivity indexes to electric transmissive values, and specific heat capacity constants.

2.2. Data input and processing

Geographical position accuracy during data input is important because Revit has the system capability to automatically collect and assign climatological data extracted from geographically nearby meteorological repositories, based solely on the inputted geocoordinates. This climatic dataset includes parameters such as dry-bulb temperature, wet-bulb temperature, and mean daily temperature; these serve as key boundary conditions for seasonal energy simulations. To facilitate accurate load estimates, functional areas (e.g., bedrooms, corridors) were defined concurrently with assigned occupant densities and equipment schedules [10,11].

2.3. Configuration and calculation of energy simulation parameters

Parameters related to energy simulation are configured within the Revit environment, primarily including building usage type, operation schedule, and heating, ventilation, and air conditioning (HVAC) system selection. This case study utilizes a central variable air volume (VAV) system with chillers and hot water boilers serving as the cold and heat sources. After construction, the model is exported in the Green Building XML standard format and imported into professional energy analysis software for detailed energy consumption simulation based on the DOE-2 energy calculation engine.

2.3.1. Technical characteristics of the DOE-2 engine

DOE-2 engine is a standard energy consumption simulation tool of buildings, which is used to help design energy efficiency models for different types of building system, such as air conditioning, heating and ventilation systems. View of a tool that provides results in multiple energy types, including electricity, natural gas, and district heating. By incorporating building design, material thermophysical properties and operating strategy parameters, the tool provides strong technical basis for obtaining accurate energy consumption predictions and evaluation on a building's energy efficiency.

2.3.2. Calculation method of energy conversion factors

To include losses incurred by operating, converting and transmitting different kinds of energy sources, energy conversion factors were used to compute energy consumption. The electricity conversion factor (2.7 kWh_p/kWh_e), it is taken from the Sichuan Province standard DB51/T 5058-2020, which very well reveals the spatial structure of the grid of Sichuan Province dominated by hydropower. This standard value originates from data on the 2020 power generation structure of Sichuan Province, i.e., the proportion of non-fossil energy sources was 92.8% of total power generation [12]. This parameter system reflects the primary energy used when producing final energy.

These standardised steps can cause the Revit platform to obtain accurate base information for building energy consumption, and provide robust support for the scientific planning and optimisation of future energy-saving retrofit measures.

2.4. Modeling parameters of the research case

According to the physical model of the residence, a simplified model of dormitory was produced in Revit. Meanwhile, single-duct variable air volume terminal unit was used as supply air appliances of equipment selection, coupled with a central variable air volume air conditioning system. Heating and cooling sources use water-cooled chillers (energy efficiency = 5.96) and air-source heat pumps (thermal efficiency = 84.5%) [13]. Considering the warm climate characteristics of Chengdu, the exterior walls are constructed with lightweight materials and thin insulation layers, while the interior walls use a lightweight material system without insulation. The case design compared four wall configurations: three composite walls (CW102-50-100P, CW102-85-100P, and CW102-85-215P) and a conventional 200mm solid wall as baseline. Three latitudes encompassing low to high latitude parts of China—Chengdu (30.76°N, 103.98°E), Shanghai (31.23°N, 121.47°E), and Tangshan (39.63°N, 118.17°E)—were used to mimic the geographical coordinates.

The dormitory building contains 144 bedrooms, adopting an open balcony design with some living service facilities arranged in outdoor spaces. The overall building layout complies with the design codes for subtropical climate regions. Specific parameter configurations are presented in Table 1, and the 3D model of the dormitory building, as shown in Figure 1, accurately represents the architectural features and spatial layout of Building Six at Tianyouzhai.

Table 1. Key modeling parameters for the dormitory building

Parameter Category	Specific Parameter	Value / Description
Basic Project Information	Building Type	Dormitory Building
	Number of Floors	6 Floors
	Total Floor Area	3042.27 m²
	Net Conditioned Area	2678.10 m²
Equipment System Configuration	Air Handling Equipment	Single-Duct Variable Air Volume Terminal
	Air Conditioning System	Central Variable Air Volume System
	Cold/Heat Sources	Chillers (COP=5.96), Hot Water Boilers (η=84.5%)
Envelope Parameters	Exterior Wall Construction	Lightweight Materials + Thin Insulation Layer (Climate-Adaptive Design)
	Interior Wall Construction	Lightweight Materials without Insulation
Environmental Parameters	Geographical Coordinates	(30.76°N, 103.98°E); (31.23°N, 121.47°E); (39.63°N, 118.17°E)
	Fresh Air Rate Standard	8.00 L/(s·person)

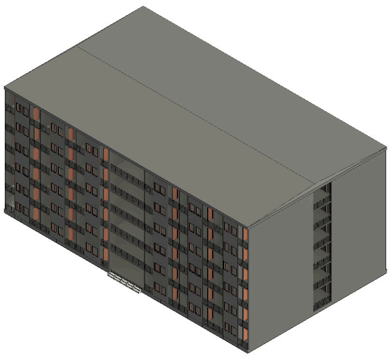

Figure 1. 3D Model of dormitory building (front view). (Picture credit: original)

3. Case study

3.1. Overall energy consumption analysis

After conducting an energy consumption analysis of Building 6 at Tianyouzhai using Revit, it was found that the building's total primary energy consumption amounted to 4,873.72 GJ, with terminal energy consumption at 2,254.98 GJ, resulting in an energy utilization rate of 46.27%. This data indicates significant losses occur during the extraction, processing, and transmission of energy. As shown in the energy conversion coefficients listed in Table 2, electricity (3.167) and district heating (3.613) exhibit the highest losses during conversion, while natural gas (1.084) demonstrates a clear low-carbon advantage. Therefore, to achieve progress in reducing emissions, a viable approach is to decrease reliance on electricity and district heating while simultaneously optimizing the latter's system.

Table 2. Site-to-source energy conversion factors

Type	Site-to-Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	1.200
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil No. 1	1.050
Fuel Oil No. 2	1.050
Propane	1.050
Other Fuel 1	1.000
Other Fuel 2	1.000

3.2. Factors influencing building energy consumption

3.2.1. Influence of geographic location on building energy consumption

The mathematical expression for the solar altitude angle at solar noon for a specific location is

$$\sin h = \sin\varphi\sin\delta + \cos\varphi\cos\delta \quad (1)$$

Where φ is the observer's latitude on Earth and δ is the solar declination angle [14]. Therefore, it is evident that the higher the latitude, the smaller the solar altitude angle at noon. Although increasing latitude decreases the solar altitude angle at noon and reduces solar radiation per unit area, high-latitude regions experience longer daylight hours in summer and reduced cloud cover, leading to lower actual lighting energy consumption [15-17].

An analysis of energy consumption in Building 6 of Tianyouzhai using Revit showed the Electricity Intensity (MJ/m^2), with results listed in Table 3. Chengdu and Shanghai have similar latitudes, while Tangshan's higher latitude results in lower lighting energy consumption.

Table 3. Lighting energy consumption at different latitudes

City	Lighting Electricity Intensity (MJ/m^2)
Chengdu(30.76°N, 103.98°E)	140.02
Shanghai(31.23°N, 121.47°E)	140.02
Tangshan(39.63°N, 118.17°E)	123.26

3.2.2. Effect of exterior wall construction on building energy use

To examine how building energy use is affected by exterior wall construction, this study employs three wall construction examples (naming convention: outer layer thickness - insulation layer thickness - inner layer thickness / mm):

CW102-50-100P: Masonry (standard brick) 102 mm + Insulation 50 mm + Concrete block 100 mm

CW102-85-100P: Masonry (standard brick) 102 mm + Insulation 85 mm + Concrete blocks 100 mm

CW102-85-215P: Masonry (standard brick) 102 mm + Insulation 85 mm + Concrete blocks 215 mm

The results are shown in Table 4. Compared to conventional 200 mm walls, insulated walls significantly reduce energy consumption.

Table 4. Effect of exterior wall construction on building energy use

	CW102-50-100P	CW102-85-100P	CW102-85-215P	Conventional 200mm (Baseline)
Total Site Energy (GJ)	1994.22	2017.75	2225.87	2254.98
Total Source Energy(GJ)	4388.00	4430.81	4803.53	4873.72

The BIM simulation reveals that the most significant factors influencing the student dormitory energy consumption are location and lighting. Lighting energy consumption of Tangshan (39.63°N) is 12% less than Chengdu (30.76°N), and 123.26 MJ/m² (only 140.02 MJ/m²). The study also found the influence of wall materials on insulation: with CW102-50-100P walls, on-site energy is reduced by 11.6% (2254.98 GJ) compared with traditional 200mm walls (1994.22 GJ). Such results suggest that it is possible to optimize the site location and the building wall material to effectively reduce the building energy consumption.

3.3. Development recommendations for green dormitories

The Ministry of Housing and Urban-Rural Development (MOHURD) could take the lead in developing a "Latitude-Adaptive Building Code," mandating the use of the CW102-50-100P benchmark wall assembly for areas north of 35°N to enhance the energy efficiency and environmental performance of wall systems. At the same time, southern provinces might explore the co-optimisation of reflective coatings with active shading. Provincial heating plans should promote low-carbon heat supply sources such as geothermal and biomass energy; for campuses, carbon assessment indexes should consider the dependence on electricity. Reduce emissions at source by reducing the use of high-conversion-rate energy. Putting such regulations into place would substantially reduce national energy consumption. Multidimensional fiscal incentives (such as taking tax rebates for approved renewable energy projects and preferential interest rates for green bonds issued by large campus projects) should also be adopted at the same time to guarantee compliance. Introduce a trading mechanism so projects that meet their annual target carbon reductions can enter the national carbon market, to make fiscal incentives commensurate with targets.

4. Conclusions and outlook

4.1. Conclusions

From the BIM simulation results, high latitude cities (e.g. Tangshan, 39.63°N) can save 12% lighting energy consumption compared with subtropical cities (e.g. Chengdu, 30.76°N) due to more hours of summer daytime and low clouds. Moreover, the CW102-50-100P wall structure decreases the on-site energy consumption by 11.6% from that of traditional 200mm walls, verifying the effect of the designed insulation layer. From the energy structure optimization function analyses, one can also see that greatly decrease the dependency on very volatile energy sources can considerably reduce primary energy loss.

These findings call for a three-pronged intervention approach to residential energy conservation: curb the demand with climate-appropriate design, boost efficiency with improvements to thermal envelopes and lock in carbon savings by upgrading the energy infrastructure. Its advantage lies in overcoming efficiency bottlenecks by multi-level measures. The study not only provides scientific basis of diversified energy-saving measures for campus buildings, but also provides an important model for advancing low-carbon building transformation.

4.2. Outlook

While this study has proposed region-specific retrofit strategies, it did not account for the interconnected response between geographic location and material properties—a critical gap that warrants further investigation. For future research, it will be important to integrate architectural design, geographic parameters, wall structure types and other factors in a single analysis. With this approach, it is also possible to formulate complex energy consumption prediction models that can simulate the complex interplay among these parameters. By taking into account synergies between the climate-dependent design choices and the thermal properties of materials, this more sophisticated model will considerably increase the accuracy of predictions of energy efficiency for university buildings in diverse climatic zones, strengthening the support for sustainable carbon reduction measures.

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