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BUILDING ORIENTATION EFFECTS ON HVAC ENERGY PERFORMANCE: EDUCATIONAL BUILDING ANALYSIS IN CHINA'S HOT-SUMMER-COLD-WINTER ZONE

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ABSTRACT

This study investigated the impact of building orientation on HVAC energy consumption in educational buildings within China's hot summer and cold winter (HSCW) climate zone. Through EnergyPlus simulations of a representative teaching building in Chongqing, this research analysed heating, cooling, and total HVAC energy consumption patterns across 24 different orientations. The results demonstrate that building orientation significantly influences energy performance, with the south-facing orientation (180°) achieving optimal energy efficiency at 58.55 kWh/m², while the west-facing orientation (270°) exhibits the highest consumption at 63.01 kWh/m², representing a 7.62% variation. The study reveals that maintaining the building orientation within ±15° of due south can effectively optimise year-round energy performance, particularly in regions with significant seasonal variations. Furthermore, the findings indicate distinct seasonal patterns, with south-facing orientations demonstrating superior winter performance through optimal solar gain while requiring careful solar control strategies during summer. This study provides quantitative evidence to support the development of specific orientation design guidelines for building energy standards, offering practical insights for architects and urban planners in creating energy-efficient educational facilities in HSCW climate zones.

Keywords: Building Orientation, Energyplus, Building Performance Simulation (BPS), Energy Consumption, Energy Use Intensity (EUI)

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1. INTRODUCTION

Building energy consumption has become a critical focus in the global energy landscape because buildings account for a substantial portion of the total energy use worldwide. Estimates suggest that buildings contribute approximately 30-40% of global energy consumption, with public buildings often consuming even higher amounts (Lee & Park, 2023; Zhang et al., 2019). As urbanisation and population growth continue to drive energy demand, improving energy efficiency in the building sector has emerged as an essential strategy for addressing the global energy crisis (Kampelis et al., 2018; Zhang et al., 2019).

In China, the role of the building sector in national energy consumption is particularly pronounced. In 2021, buildings accounted for 36.3% of China's total energy consumption and 38.2% of its energy-related carbon emissions or 4.07 billion tons of CO2 (China Association of Building Energy Efficiency & Chongqing University, 2023). Given these figures, the need for effective strategies to enhance energy efficiency and reduce carbon emissions has never been more urgent. This challenge is particularly pressing in China's hot summer and cold winter (HSCW) regions, where seasonal extremes significantly influence building energy consumption. With approximately 550 million people living in this zone, the HSCW region is responsible for 45% of China's building energy use, highlighting the potential impact of optimising energy efficiency in this area (Tsang et al., 2022).

Building orientation is a crucial yet often underemphasised element among the various factors that influence building energy consumption. The orientation determines the amount and duration of solar radiation that a building receives, significantly affecting indoor temperatures and the demand for heating and cooling. Existing regulations, such as the "Design Standard for Energy Efficiency of Public Buildings" (GB 50189-2015) and the "Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zones" (JGJ 134-2010), acknowledge the importance of orientation but provide only general qualitative guidelines without quantitative specificity (Ministry of Housing and Urban-Rural Development of the People's Republic of China & General Administration of Quality Supervision, 2015; China Architecture & Building Press (CABP), 2010). For instance, GB 50189-2015 mandates that the thermal performance of the building envelope be optimised according to the climate zone to reduce energy loss, but does not explicitly address building orientation. JGJ 134-2010 only recommends prioritising south-facing or near-south-facing orientations to maximise solar gain and reduce both winter heating and summer cooling energy consumption. Consequently, there remains a gap in the literature and practice for a more comprehensive, data-driven approach to optimise building orientation for energy efficiency.

In addition to the orientation, various studies have highlighted the impact of multiple interrelated factors on building energy consumption. Chen et al. (2020) categorised these into three domains: building characteristics (e.g., envelope design, insulation, and window-to-wall ratio), building service systems (e.g., HVAC efficiency and lighting control), and occupant behaviour (e.g., operating schedules and plug loads). These factors interact with the orientation and significantly influence the thermal load and system performance. While the current study focuses specifically on orientation, it builds on this broader understanding of energy-related design variables to frame the investigation.

Previous studies have demonstrated the influence of building orientation on the energy consumption. Uprety et al. (2021) found that south-facing buildings, particularly in the Northern Hemisphere, achieve optimal solar gain, thereby reducing both winter heating and summer cooling loads. Similarly, Tong (2013) emphasised the importance of passive design strategies, including orientation, in leveraging local climatic conditions to improve energy efficiency. Additional research, such as those conducted by Yang et al. (2015) and Liu et al. (2014), further supports the role of orientation in enhancing passive design and achieving sustainability goals. However, the specific impact of building orientation on university buildings in HSCW regions remains unexplored despite the potential for significant energy savings in this context. Recent studies have provided compelling evidence regarding the impact of building orientation on energy consumption and indoor thermal comfort under various climatic conditions. Dai et al. (2023) found that aligning courtyard buildings with their optimal orientation could increase comfort hours in winter and summer by 62.9% and 37.1%, respectively. Ashmawy and Azmy (2018) reported that west-facing buildings in Cairo could consume up to 26% more energy annually than their south-facing counterparts could. Similarly, Pathirana et al. (2019) demonstrated that building orientation significantly affected discomfort hours in tropical residential buildings, based on simulations of 300 orientation combinations. Albatayneh et al. (2018) further showed that rotating a Jordanian building to a north–south orientation could improve thermal performance and reduce heating loads by nearly 35%. These findings reinforce the critical role of building orientation in performance-based design, and justify further research on HSCW educational buildings.

Although existing research has established the importance of building orientation in energy efficiency, opportunities remain for further investigation in specific contexts. Educational buildings are among the primary contributors to public building energy consumption because of their high occupant density, extended daytime use, and increasing construction scale. As of June 2024, China has 3,117 higher education institutions that accommodate millions of students and staff who spend extended periods indoors, thereby necessitating stable indoor environmental quality and energy-intensive operations (Ministry of Education of the People's Republic of China, 2024). These characteristics make educational buildings a representative and impactful typology for orientation-based energy optimisation research. Furthermore, while existing energy efficiency standards provide general orientation guidelines, there is still a lack of detailed data-supported strategies tailored to specific building types in the HSCW climate zone.

While previous studies on orientation-energy relationships have mostly focused on office, residential, or general commercial buildings, this study specifically addresses a population gap by focusing on a typical university teaching building located in China's HSCW region. By systematically analysing the orientation-energy relationship in this underrepresented building type and climatic context, this research contributes to the field in several aspects: (1) it offers quantitative evidence of orientation-related energy consumption patterns in educational buildings in the HSCW climate zone; (2) it explores the correlations between building orientation and both heating and cooling energy demands, providing insights for year-round energy efficiency optimisation; and (3) it generates practical implications that could inform both building design practices and energy efficiency standards. Using EnergyPlus simulation software, this study examines how different orientations affect energy use, aiming to provide a valuable reference for architects, urban planners, and policymakers, particularly in regions with significant seasonal variations.

2. METHODOLOGY

2.1 Building Details and Climatic Conditions

China is home to a rapidly expanding number of primary, secondary, and higher-education institutions. According to the Ministry of Education of the People's Republic of China (2023), by 2023, there were 3,074 higher education institutions in China, with a total enrollment of 47.63 million students, representing a 2.27% increase from the previous year. As these institutions grow and new campuses are being constructed, the overall floor area of academic buildings increases annually. This expansion not only leads to higher energy consumption but also emphasises the importance of optimising building design to improve energy efficiency. Understanding how specific design factors, such as building orientation, influence energy consumption is crucial, particularly in regions with HSCW climates where seasonal energy demands are significant.

This study focused on a teaching building located in China's HSCW region to examine the impact of orientation on energy consumption. The building, constructed in 2005, is a five-story structure with a framed system designed to have a service life of 50 years. It features Class 2 fire resistance and a seismic intensity rating of 6. The building's primary functional areas include classrooms, teacher lounges, and restrooms, all of which serve the daily needs of the students and staff.

The selected university classroom building represents a common and standardised layout that is widely adopted across educational institutions in China's HSCW region. It features typical usage patterns, occupancy schedules, and construction materials. Focusing on a single representative case allows for precise parameter control and in-depth simulation of the orientation effects. This enables a clear interpretation of the results while maintaining methodological rigour. Although broader generalisability could be achieved with multicase comparisons, the chosen approach prioritised simulation accuracy and relevance to similar university buildings in this climate zone.

Key structural elements, such as 240 mm thick exterior walls with tiled facades and interior cement mortar plastering, contribute to insulation and durability. A flat roof includes waterproofing and insulation layers that help maintain the indoor temperature throughout the year. Standard split-type air conditioners control the indoor climate, while occupants manually operate lighting. These building components and systems are the conventional practices in educational buildings across China's HSCW region.

Figures 1 and 2 illustrate the building's front elevation and standard floor plan, respectively, offering further insight into its structure and layout. The visualised simulation results help illustrate the relationship between building orientation and annual energy consumption, serving as a basis for evaluating orientation-related design strategies.

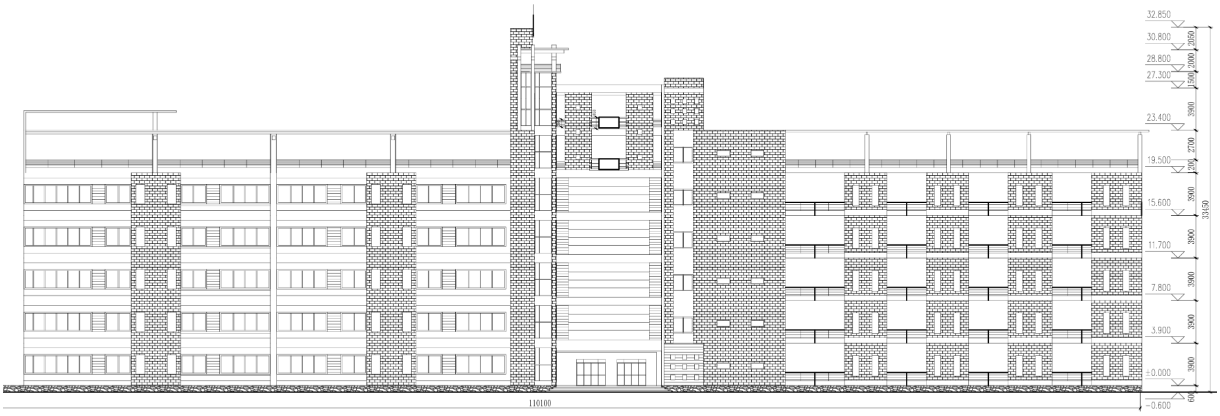

Figure 1: Front Elevation (Scale 1:100)

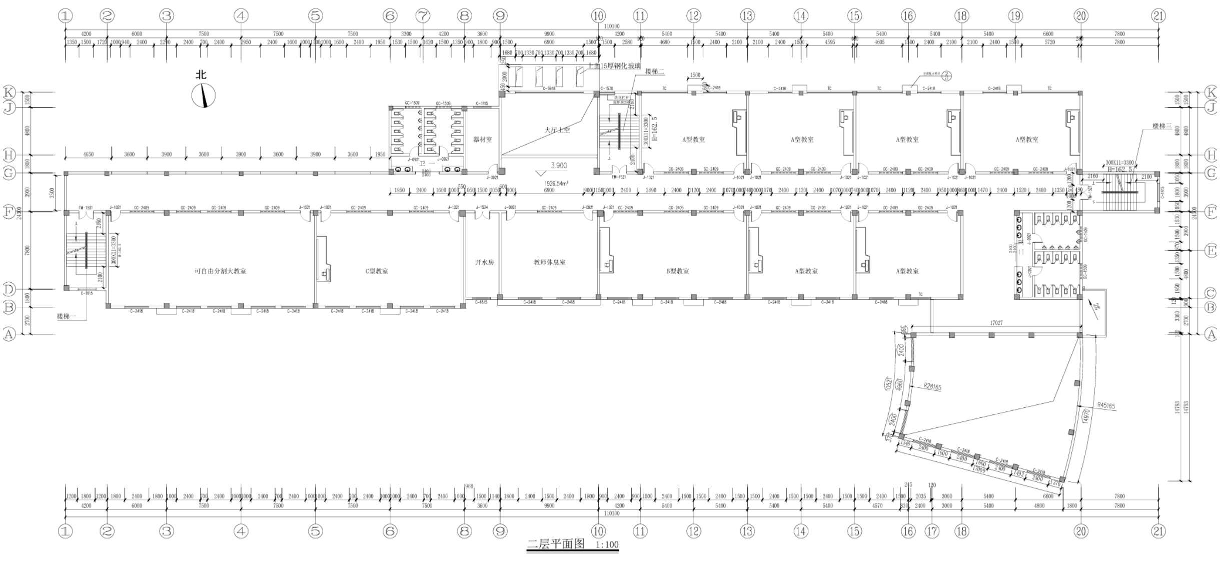

Figure 2: Standard Floor Plan (Scale 1:100)

Given the distinctive climate of Chongqing, a representative city in the HSCW region, it was selected as the research site for this study. The city's combination of hot, humid summers and cold winters presents unique challenges for maintaining energy-efficient indoor environments. Table 1 presents the key outdoor meteorological parameters critical for designing energy-efficient buildings in this region. These parameters align with the "Thermal Design Code for Civil Buildings" (GB50176-2016), which classifies China into various thermal climate zones and mandates that buildings comply with both summer insulation and winter thermal protection requirements to ensure year-round energy efficiency (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2016).

Table 1: Thermal Design Outdoor Meteorological Parameters for Chongqing

Parameter	Value
Longitude (°E)	106.47
Latitude (°N)	29.58
Altitude (m)	259
Average Temperature of the Coldest Month (°C)	8.1
Average Temperature of the Hottest Month (°C)	28.4
Heating Degree Days (HDD18) (°C·d)	1089
Cooling Degree Days (CDD26) (°C·d)	217
Design Outdoor Temperature for Heating (°C)	5.5
Lowest Recorded Average Daily Temperature (°C)	2.9

2.2 Simulation Software Selection and Application

Building performance simulation (BPS) is a vital method for evaluating energy-related outcomes in architectural designs. EnergyPlus was selected for this study as the primary BPS tool because of its validated algorithms, comprehensive HVAC modelling capabilities, and suitability for sub-hourly energy analysis. It supports parametric evaluations of design variables such as building orientation, envelope performance, and system operations. The simulation was conducted using the Chinese Standard Weather Data (CSWD) for Chongqing, incorporating hourly parameters, such as temperature, humidity, solar radiation, and wind speed, to accurately represent the HSCW regional climate. The output provided detailed energy consumption data to assess the relationship between the building orientation and energy performance in the selected case study.

2.3 Model Development and Parameter Settings

A comprehensive EnergyPlus model of the teaching facility was developed to examine the influence of orientation on energy consumption. This model incorporates the architectural and structural details of the building, as illustrated in Figure 3. The simulation integrated the building envelope properties, thermal characteristics, operational schedules, and HVAC system settings to accurately represent the real-world conditions. The simulation parameters were defined based on the field survey results and relevant national standards. Table 2 summarises the key thermal and operational settings, which reflect common configurations for educational buildings in the HSCW region, in accordance with the Design Standard for Energy Efficiency of Public Buildings (GB 50189-2015).

The internal gains included a lighting power density of 11 W/m² and an equipment power density of 15 W/m², with an occupant density of 0.75 persons/m². Cooling was activated when the indoor temperature exceeded 26 °C and heating was below 18 °C. Split air-conditioning systems with a coefficient of performance (COP) of 4 were used. Thermal comfort was assessed using the Fanger PMV–PPD model, incorporating seasonal clothing insulation values (0.5 clo in summer, 1 clo in transitional seasons, and 1.5 clo in winter) and light metabolic activity levels. The CO_2 generation rate was set at 3.82×10^{-8} m³/s·W based on standard assumptions for indoor human activity. Occupancy was set from 08:00 to 18:00 on weekdays, and the HVAC systems operated during the same period.

Climatic data were obtained from the Chinese Standard Weather Data (CSWD) for Chongqing, which provides hourly records of dry-bulb temperature, relative humidity, solar radiation, and wind speed, ensuring an accurate representation of the HSCW climate conditions.

To enhance the credibility of the simulation model, validation was conducted through internal consistency checks and parameter benchmarks. All model inputs, including thermal transmittance values and internal loads, were defined based on field investigations and aligned with national standards (GB 50189-2015). Since this study focused on a comparative analysis of orientation effects rather than absolute energy prediction, the model was not calibrated against the monitored data. However, the simulation results were reviewed to ensure that they fell within reasonable and expected ranges for typical university buildings in the HSCW region, thereby supporting the reliability of the model for orientation-based performance evaluation.

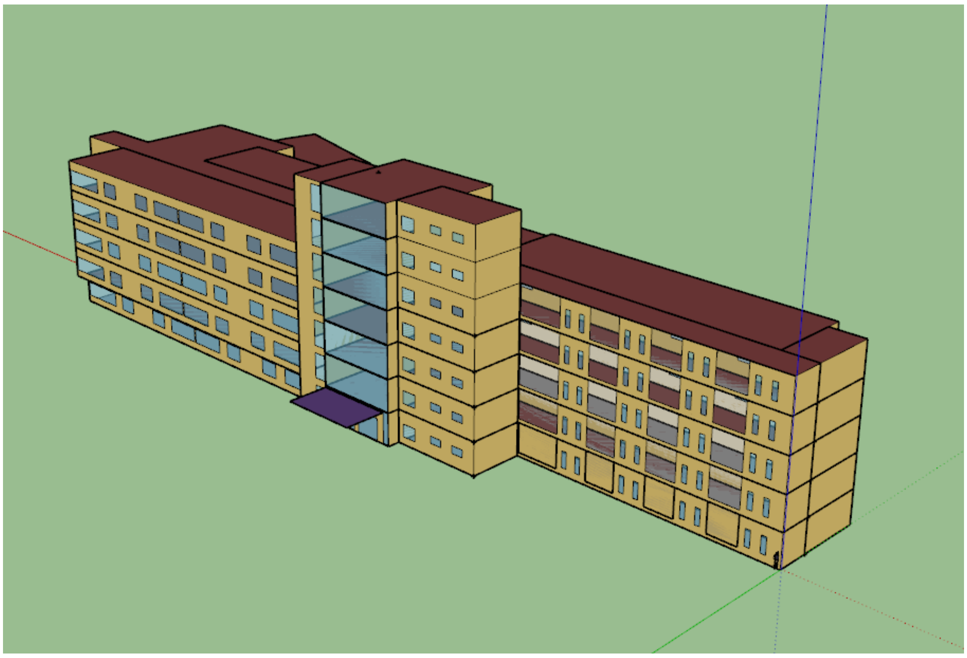

Figure 3: Axonometric View of the Teaching Building Created in the Software

Table 2: Building Parameter Settings

Parameter	Value
External Wall Thermal Transmittance (U-value)	2.2 W/(m^2·K)
Roof Thermal Transmittance (U-value)	1.8 W/(m^2·K)
Window Thermal Transmittance (U-value)	5.5 W/(m^2·K)
Lighting Power Density (LPD)	11 W/m^2
Equipment Power Density (EPD)	15 W/m^2

2.4 Evaluation Metrics

Evaluation metrics are essential for analysing building energy consumption, as they determine how the results are interpreted and applied. The primary metric used in this study is Energy Use Intensity (EUI), which measures the energy consumed per square meter of building area, expressed in kilowatt-hours per square meter (kWh/m^2). The EUI enables a standardised comparison of energy efficiency across buildings of different sizes and has been widely adopted in building energy efficiency standards and research (Cao et al., 2016; Han et al., 2014; Kneifel, 2010; Litardo et al., 2021; Porse et al., 2016; Wong & Zhou, 2015).

This study specifically analysed three key metrics: cooling energy consumption per unit area (kWh/m^2), heating energy consumption per unit area (kWh/m^2), and total HVAC energy consumption per unit area (kWh/m^2). These metrics were selected to quantify both the overall energy efficiency and the seasonal variation in energy demand associated with different building orientations. The separate analysis of heating and cooling energy consumption enabled a detailed understanding of the orientation impacts across different seasons, whereas the total HVAC energy consumption provided a comprehensive measure of annual energy performance.

2.5 Rules for Orientation Changes

In the simulation process, building orientation was the only parameter that was adjusted, while all other factors remained constant. The building orientation was represented by the "North Axis" parameter in the EnergyPlus Input Data File (IDF). The default North Axis value was set to zero, indicating that the building faced the true north. By modifying the North Axis value, the building's rotational angle relative to the north can be adjusted.

In this study, the building orientation was altered at 15-degree intervals, with values ranging from 0° to 360°. After each orientation adjustment, the corresponding IDF file was saved and EnergyPlus was used to calculate the energy consumption for each orientation. These simulations allowed for a comprehensive analysis of how orientation affects energy consumption, providing the data necessary to optimise the building design for energy efficiency. The 15-degree interval was selected to ensure a balanced coverage of different orientations while maintaining a manageable computational load. The building orientation was rotated in 15° increments from 0° to 360° following a commonly used resolution in building simulation studies. This step size ensures adequate sensitivity to performance variations while maintaining a manageable computational demand.

3. RESULTS

Based on the established building model, parameter settings, and systematic orientation changes, comprehensive energy consumption data were calculated and analysed for each building orientation. The simulation results encompassed the heating energy consumption, cooling energy consumption, and total HVAC energy consumption per unit area across 24 different orientations, ranging from 0° to 345° at 15° intervals. Table 3 presents these detailed energy consumption metrics, providing a quantitative foundation for understanding the relationship between the building orientation and energy performance in China's HSCW climate zone.

The energy consumption patterns were visualised through sequential plots (Figures 4-6), demonstrating the variation in heating, cooling, and total HVAC energy consumption across different orientations. Additionally, a radar chart (Figure 7) was employed to provide a comprehensive visualisation of the relationship between the orientation and energy consumption, offering an intuitive understanding of the optimal and unfavourable orientations for energy efficiency.

Table 3: Energy Use Intensity (EUI) for Different Orientations

Orientation(°)	Cooling Energy（kWh/m^2）	Heating Energy（kWh/m^2）	Total HVAC Energy（kWh/m^2）
0	28.36	31.02	59.38
15	29.35	30.80	60.15
30	30.01	30.80	60.81
45	30.68	30.59	61.27
60	31.05	30.59	61.64
75	32.27	30.16	62.43
90	32.61	30.16	62.77
105	32.16	29.71	61.87
120	32.20	29.26	61.46
135	31.74	28.82	60.56
150	30.38	28.77	59.15
165	30.23	28.52	58.75
180	30.18	28.37	58.55
195	29.92	29.28	59.20
210	30.82	29.73	60.55
225	30.93	30.18	61.11
240	31.63	30.43	62.06
255	32.20	30.68	62.88
270	32.83	30.18	63.01
285	31.82	30.64	62.46
300	31.23	30.69	61.92
315	29.48	30.89	60.37
330	28.93	31.11	60.04
345	28.63	31.19	59.82

3.1 Heating Energy Consumption

Figure 4 displays the variation in heating energy consumption across different building orientations. The results show that the north-facing orientation (0°) experienced the highest heating demand, while the south-facing orientation (180°) had the lowest. This pattern is explained by the fact that in the Northern Hemisphere, the north-facing façade receives minimal solar radiation during winter, leading to significant heat loss. In contrast, the south-facing façade benefits from maximum solar exposure, effectively reducing reliance on heating systems.

Intermediate values were observed for the east (90°) and west (270°) orientations, reflecting the limited solar radiation received by these facades during winter mornings and evenings. These findings underscore the importance of passive solar design strategies in reducing winter heating loads, especially in cold climates such as HSCW regions. By optimising the building's orientation to maximise the winter solar heat gain, significant energy savings can be achieved.

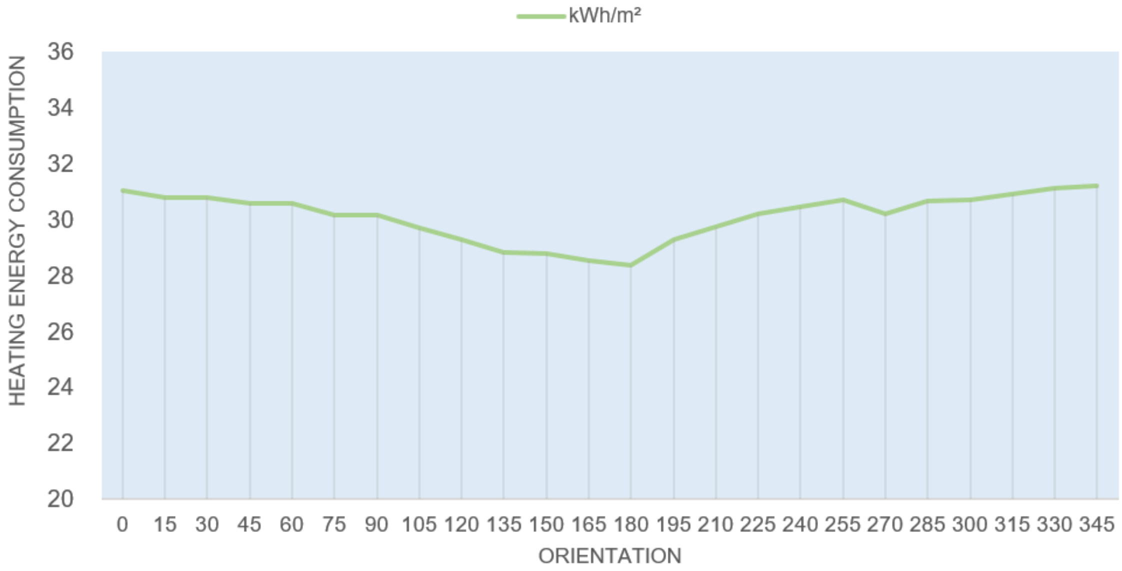

Figure 4: Per-Unit-Area Heating Energy Consumption

3.2 Cooling Energy Consumption

Figure 5 illustrates the cooling energy consumption across orientations. The results revealed that the west-facing orientation (270°) consumed the most cooling energy, followed by the south-facing orientation (180°). This is because the west-facing façade receives intense solar radiation during summer afternoons, while the south-facing façade is exposed to direct sunlight throughout the day. These high levels of solar heat gain increase the indoor temperatures and lead to a greater demand for cooling to maintain thermal comfort.

On the other hand, the north-facing orientation (0°) showed the lowest cooling energy consumption, as it received the least amount of solar radiation during the day. The east-facing orientation (90°) also exhibits a relatively low cooling demand because the morning sunlight is less intense than that of the afternoon sun. These results highlight the critical role of solar heat gain in determining cooling loads and emphasise the need for effective shading strategies for south- and west-facing facades in the HSCW regions.

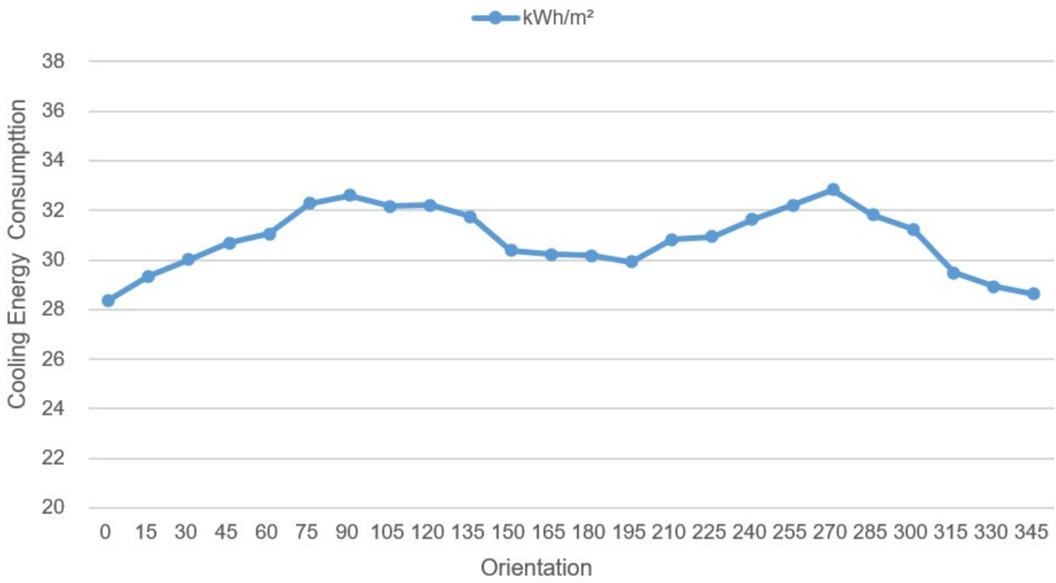

Figure 5: Per-Unit-Area Cooling Energy Consumption

3.3 Total HVAC Energy Consumption

Figure 6 presents the total HVAC energy consumption for each orientation, combining both heating and cooling demands. The lowest total HVAC energy consumption was observed for the south-facing orientation (180°), whereas the highest was recorded for the west-facing orientation (270°). The difference between these two orientations amounts to 7.62%, highlighting the substantial impact that orientation has on the overall energy performance.

The combined heating and cooling energy demand reflects the seasonal interplay between solar radiation and a building's energy needs. For example, the south-facing orientation benefits from significant solar gain in winter, reducing heating loads, while its cooling demand in summer remains manageable compared with the west-facing orientation. These findings emphasise the importance of optimising building orientation to balance the heating and cooling requirements throughout the year, particularly in regions with both hot summers and cold winters, such as the HSCW region.

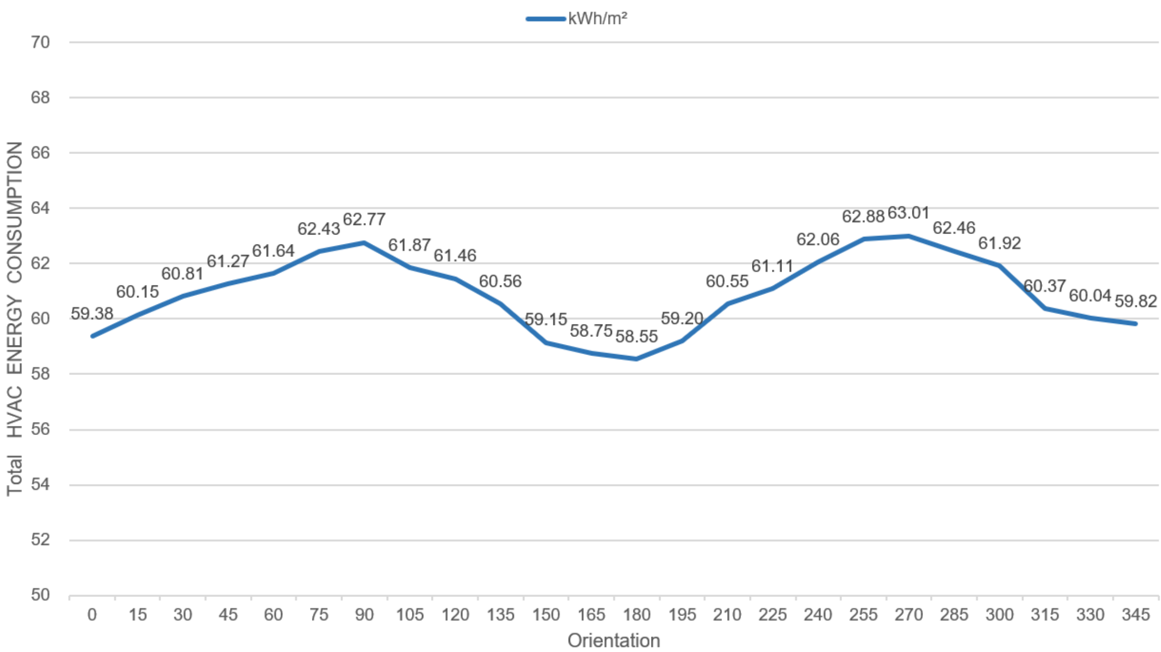

Figure 6: Per-Unit-Area Total HVAC Energy Consumption

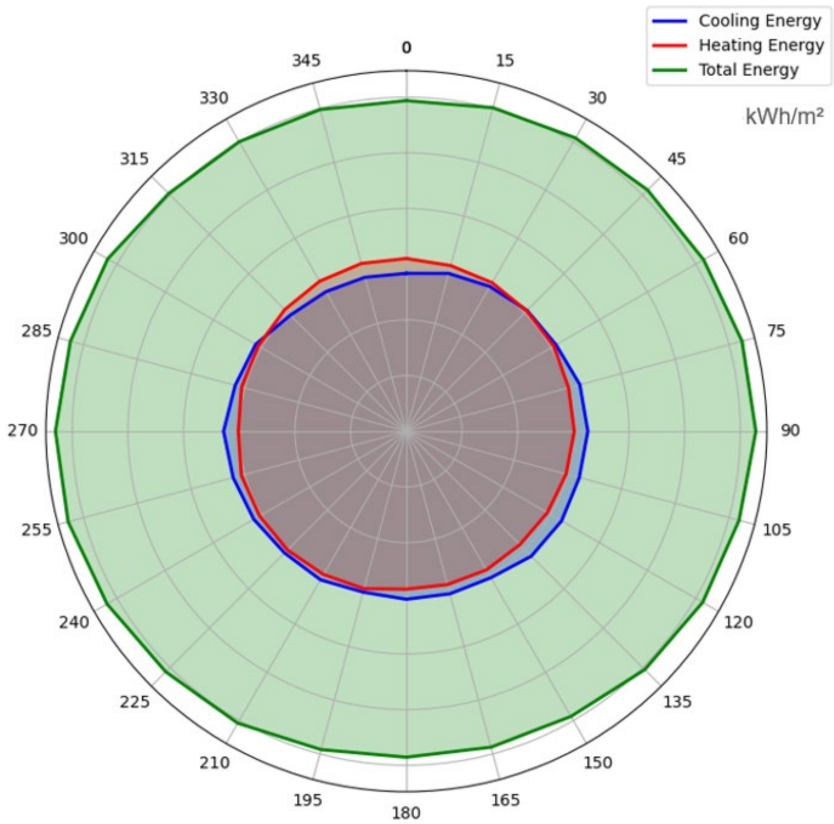

Figure 7: Radar Chart of Per-Unit-Area Energy Consumption as a Function of Orientation

4. DISCUSSION

4.1 Correlation Between Orientation and Heating Energy Consumption

The findings in Figure 4 clearly show that the heating energy consumption was lowest for the south-facing orientation (180°) and highest for the north-facing orientation (0°). This is consistent with passive solar design principles, which emphasise maximising solar gain in winter to reduce heating energy consumption. In the Northern Hemisphere, south-facing facades receive the most solar radiation during colder months, significantly lowering the heating demand. Conversely, north-facing facades are exposed to minimal solar radiation, leading to higher energy consumption for heating (Hamdani et al., 2014; Sung & Kim, 2019).

To optimise the heating energy efficiency in cold climates such as the HSCW region, architects and builders should prioritise maximising solar gain for south-facing facades. Specific strategies could include designing larger, energy-efficient windows on the south facade to capture more sunlight during winter and employing advanced insulation materials to retain this heat. Additionally, passive solar design features, such as thermal mass walls and properly oriented glazing, can help absorb and store solar energy, reducing the need for mechanical heating systems.

The observed slight increase in heating energy consumption for the east (90°) and west (270°) orientations highlights the role of solar radiation angles in the heating efficiency. Although these orientations receive less solar radiation during winter mornings and evenings, strategies such as optimising the window-to-wall ratio on these facades and using reflective materials can mitigate the heat loss. Ultimately, aligning the building orientation with seasonal solar patterns is crucial for minimising the heating loads in regions with substantial winter heating requirements.

4.2 Correlation Between Orientation and Cooling Energy Consumption

Figure 5 shows that the cooling energy consumption is highest for the west-facing (270°) and south-facing (180°) orientations, largely because of the high levels of solar radiation these facades receive during the summer months. West-facing facades, in particular, are exposed to intense afternoon sunlight, increasing indoor temperatures and the need for cooling. Similarly, the south-facing facade is exposed to direct sunlight throughout the day, further increasing cooling energy demands (Kim et al., 2019; Piccioni et al., 2023).

For regions where cooling demands dominate, such as the HSCW regions during summer, design strategies that mitigate solar heat gain on west- and south-facing facades are critical. Builders can incorporate shading devices, such as external louvres, deep overhangs, or vegetation-based shading systems, to reduce solar exposure. High-performance glazing and reflective coatings can also be used to limit solar heat transmission through windows, whereas increasing ventilation can help dissipate excess heat. These passive cooling strategies can significantly lower cooling energy consumption, especially in buildings with large west- or south-facing facades (Chou et al., 2016; Heidari et al., 2021; Oliveira Panao & Gonçalves, 2011).

In contrast, the north-facing orientation (0°) had the lowest cooling energy consumption owing to its minimal exposure to solar radiation. The east-facing orientation (90°) also experiences a lower cooling demand, as the morning sun provides less intense solar heat compared to the afternoon sun received by west-facing facades. These results demonstrate that optimising the building orientation, coupled with appropriate solar control strategies, can significantly reduce the cooling energy consumption.

4.3 Correlation Between Orientation and HVAC Energy Consumption

The total HVAC energy consumption (Figure 6) reflects the combined heating and cooling demands, with the lowest consumption recorded for the south-facing orientation (180°) and highest for the west-facing orientation (270°). The 7.62% difference between these orientations demonstrates the significant impact of the building orientation on the overall energy performance. In HSCW regions, where both heating and cooling demands are substantial, optimising the orientation is essential to balance the energy needs throughout the year.

To achieve year-round energy efficiency, architects and urban planners should consider adopting a comprehensive approach to the orientation design. South-facing facades can be optimised for solar heat gain in winter by incorporating larger windows, whereas west-facing facades should be designed with solar control strategies to mitigate excessive heat gain in summer. In addition to passive design measures, incorporating advanced building systems, such as automated shading, dynamic glazing, and energy recovery ventilation systems, can further reduce HVAC energy consumption. These strategies not only enhance energy performance but also improve indoor thermal comfort for occupants (Lim et al., 2020; Mifsud et al., 2020; Radha, 2018). These findings underscore the importance of considering both seasonal and diurnal variations in solar radiation when designing buildings for energy efficiency.

4.4 Limitations and Future Work

This study had several limitations that offer opportunities for further research. First, the analysis focused solely on building orientation, whereas other influential factors, such as building form, envelope design, thermal insulation, and ventilation strategy, were kept constant. Although this approach helped isolate the impact of orientation, it did not fully reflect the complexity of actual building design. Future studies could incorporate additional parameters, including the window-to-wall ratio, shading configuration, and natural ventilation strategies, to provide a more holistic understanding of performance trade-offs.

Second, the simulation was conducted for a single university teaching building located in Chongqing, which represents a typical structure in the HSCW region. Although this provides context-specific insights, the generalisability of the findings is limited. Additional case studies across different building types and climatic zones would help validate the orientation-energy relationship under diverse conditions.

Moreover, it is important to acknowledge that, in many real-world contexts, building orientation is not entirely flexible. Urban planning regulations, road networks, adjacent buildings, and irregular plot geometries often constrain the positioning of a building. In such scenarios, optimal orientation may be difficult or impossible to achieve. Furthermore, orientation is one of the many interacting factors that influence energy consumption. The envelope insulation levels, HVAC system efficiency, infiltration rates, and occupant behaviour also play significant roles. Therefore, future research should consider multi-variable simulation or optimisation frameworks that account for these practical constraints. This enhances the applicability of orientation-related guidance to real architectural and urban design practices.

5. CONCLUSION

This study systematically investigated the relationship between building orientation and HVAC energy consumption in educational buildings in China's HSCW climate zone. Through detailed EnergyPlus simulations of a representative teaching building in Chongqing, this research quantitatively demonstrates the significant impact of building orientation on energy performance. The findings confirm that building orientation substantially influences the total HVAC energy consumption, with the south-facing orientation (180°) achieving optimal energy performance at 58.55 kWh/m², whereas the west-facing orientation (270°) exhibited the highest consumption at 63.01 kWh/m². This 7.62% variation in energy consumption primarily results from differential solar radiation exposure across orientations, which is particularly evident in the intense afternoon solar gain on west-facing facades during cooling seasons.

The investigation revealed complex interactions between the building orientation and seasonal energy demands, reflecting the unique challenges of the HSCW climate zone. The superior performance of south-facing orientations stems from their optimal balance of solar gains across seasons, benefiting from winter solar exposure, while maintaining manageable summer cooling loads through higher sun angles. Conversely, the poor performance of west-facing orientations results from excessive afternoon solar gain during cooling seasons combined with suboptimal solar exposure during heating periods. These findings demonstrate that orientation optimisation must consider both the heating and cooling requirements to achieve year-round energy efficiency, particularly in regions with significant seasonal temperature variations.

The research findings have significant implications for architectural practices and building energy standards in China's HSCW region. This study provides quantitative evidence through detailed simulation data supporting the optimisation of building orientation within ±15° of due south, contributing to the development of specific orientation design guidelines in building standards. The findings also emphasise the importance of integrating orientation-specific design strategies with other passive design measures to enhance overall building energy performance.

Although this study provides valuable insights into educational building design, certain limitations exist in the research scope. Future research could explore several directions: extending the analysis to different building typologies and climatic zones, investigating the integration of advanced technologies with orientation-based passive design strategies, and evaluating the economic implications of orientation optimisation in terms of construction costs and long-term energy savings. Further studies would help expand the applicability of the current findings and provide more comprehensive guidance for the construction industry.

This study contributes to the growing body of knowledge on building energy efficiency by providing empirical evidence on the effects of orientation on HVAC energy consumption. The findings support the development of more specific and effective building energy standards, while offering practical guidance for creating energy-efficient educational facilities in China's HSCW climate zone. This research ultimately demonstrates that careful consideration of building orientation during the early design stages can significantly impact energy efficiency, contributing to more sustainable building practices in regions with complex climatic conditions.

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