Simulation Study on the Impact of Building Orientation Variation on Annual Energy Consumption in Hefei Area

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Abstract. Under the background of increasingly serious energy crisis, promoting the development of building energy conservation can effectively alleviate the problem of an energy shortage, ensure stable economic development, and energy-saving design has gradually become a major component of building design. In this study, the numerical simulation method was used to take a building with typical features in Hefei as the research object, and the Ecotect energy analysis software was used to systematically analyze the influence of different orientations on the annual building energy consumption. The study found that the impact of building orientation on energy consumption showed a significant linear relationship. As the outdoor temperature increased, the cooling load gradually increased, and the heating load gradually decreased. Among them, the total energy consumption load was the smallest when the building orientation was southwest 15°, and the total energy consumption load was the largest when the building orientation was east-facing. The research results provide a reference for the energy-saving design of buildings in different orientations in the Hefei region.

1. Foreword

In building energy-efficient design, it is important to ensure sufficient sunlight in winter while avoiding the main wind direction, and at the same time, to ensure that there is not too much sunlight entering the building in summer, and to make full use of natural ventilation. The geographical location of the building, the surrounding environment, and the local climate characteristics are all important factors that affect the early planning and design of the building. There is an inseparable relationship between building orientation and building energy consumption[1-2]. Researching the "optimal orientation" of a building is an important aspect of energy-efficient design.

Currently, the situation for building energy conservation in China is very severe. In the past few decades, the government has established a series of standards and regulations for residential building energy conservation. However, there are still many shortcomings in promoting the application of residential building energy conservation. The vast majority of existing buildings in China are high-energy-consumption buildings, and there are still many problems with residential building energy conservation. The situation is not optimistic, and a lot of work is needed to truly achieve the expected energy conservation effect[3]. The goal of building energy conservation is to reduce building energy consumption and achieve higher energy utilization efficiency.

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The primary consideration for building energy-saving design is the building orientation. The reasonable building orientation should be combined with local climate conditions and geographical location, fully utilizing natural resources to improve building energy-saving effects[4]. Through the use of DesigBuilder energy consumption simulation software, Tian Yuefeng et al[5]. simulated the energy consumption of standard residential buildings with different orientations under different energy-saving standards in Xi'an, and concluded that the optimal orientation for energy-saving of standard residential buildings under all energy-saving standards is a southwesterly direction of 15°. Zhang Fan[6] analyzed the orientation of low-rise, multi-story, or high-rise buildings in the Chaoshan area from different aspects such as solar radiation and human comfort, and found that the building orientation should preferably be oriented toward due south, followed by southeast, and then southwest if conditions permit. The orientation of due east and due west should be avoided as much as possible to achieve a certain energy-saving effect. Ji Weidong et al[7] used DesignBuilder software to analyze the energy consumption of dormitory buildings in cold regions and believed that the best orientation is due south, and the suitable orientation range is south to the southeast with a deviation of 15°. The least favorable orientation range is northwest with a deviation of 45° to 60°. Mao Yimo et al[8] studied the optimal orientation of residential buildings in

Guangzhou and believed that residential buildings in Guangzhou are more suitable for orientations within the range of 5° southwest to 10° southeast. Sun W[9] found that the optimal building orientation in Lhasa is due south or a southwesterly direction of 10°, which can obtain more solar energy radiation in winter, avoid excessive solar radiation heat (west-facing) in summer, and the building can use natural ventilation for cooling and dehumidification. At present, most studies explore the impact of building orientation on building energy consumption from different aspects such as energy-saving standards, enclosure structure, building height, and air conditioning energy consumption[10-15]. However, there is less research on the impact of building orientation on building energy consumption in summer and winter in hot and cold regions from the aspects of temperature and solar radiation[16-18]. This article researches the geographical location, climate characteristics, and energy-saving aspects of the Hefei region and discovers the impact of various factors such as sunshine and solar radiation on building energy consumption, namely the impact of building orientation on building energy consumption.

Hefei is located in central China and belongs to the subtropical monsoon climate zone. The temperature varies significantly throughout the year, with an average temperature of -5℃ and a minimum temperature of -10℃ during the coldest three months, and an average temperature of 35℃ and a maximum temperature of 40℃ during the hottest three months. Figure 1 shows hourly temperature changes throughout the year. Overall, Hefei has distinct four seasons and large diurnal temperature variation[19].

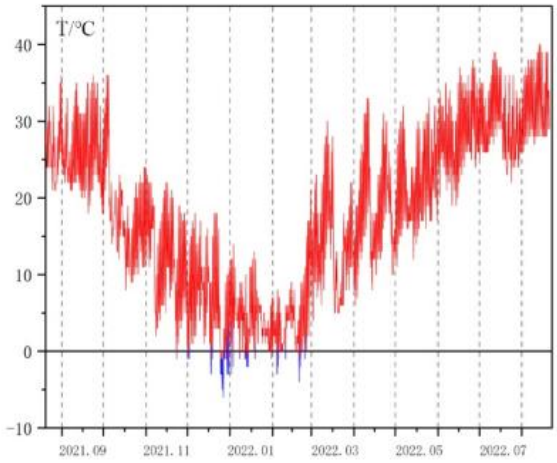

Fig. 1. Hourly temperature changes throughout the year

The wind direction in Hefei is influenced by atmospheric circulation. Being located in a typical subtropical monsoon region, there are distinct monsoons throughout the year, and the four seasons are characterized significantly. In the summer and autumn, the prevailing winds are mainly from the southeast, while in the spring, the prevailing winds are mainly from the northwest. Generally, the wind speed is between 3 and 5 on the Beaufort scale[20-21]. Figure 2 shows the hourly wind speed changes throughout the year, and Figure 3 shows the wind direction distribution.

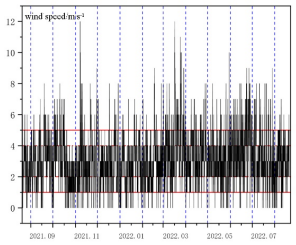

Fig. 2. annual hourly wind speed

Fig. 3. annual Anemograph

The annual total radiation intensity in the Hefei region is 1253 kWh/m², which has relatively abundant solar energy resources. The monthly total radiation intensity is highest in July, reaching 154 kWh/m², and lowest in December, only 60 kWh/m². The difference between the highest and lowest months is 94 kWh/m². In China, the solar radiation intensity is mainly concentrated from April to September, accounting for *64*% of the total annual radiation[22].

2. Architectural Models

2.1.Architectural model setup

To study the impact of a single directional change in building orientation on air conditioning heating and cooling energy consumption in Hefei, a representative building in Hefei was selected with the same building structure and interior layout, and the main rooms' windows were oriented to the south. The energy consumption of the building was analyzed. On this basis, the window-to-wall ratio of each direction was set to 35% to ensure that the window-to-wall ratio of each direction remained unchanged when the orientation changed. To study the impact of building orientation on building energy consumption, a residential building in Hefei with the highest temperature in August was selected for thermal environment analysis and hourly solar radiation analysis. A numerical simulation was carried out to obtain the monthly energy consumption of the residence. By sorting and analyzing the monthly energy consumption of different building orientations, the optimal building orientation for minimum building energy consumption was obtained. Combined with the actual situation of residential communities in Hefei, decentralized air conditioners were used for heating during the simulation, and household heat pump air conditioners were used with a rated energy efficiency ratio of 2.3 under heating

conditions and 1.9 under heating conditions, with an indoor winter calculated temperature of 18°C. When the outdoor temperature reached 28°C in summer, it was set to cooling conditions, and the indoor design temperature was 26°C[23-24]. Eight different building orientations were selected as shown in Table 1 to construct the calculation model. The residential room height was set to 4m, and the total building area was 307.846m². The building environment simulation software Ecotect was used for modeling, and a 3D model was generated as shown in Figure 4.

Table 1. Model settings

Working condition	Directions	Working condition	Directions
1	East	5	West
2	South	6	North
3	15° South by East	7	15° North by East
4	15° South by West	8	15° North by West

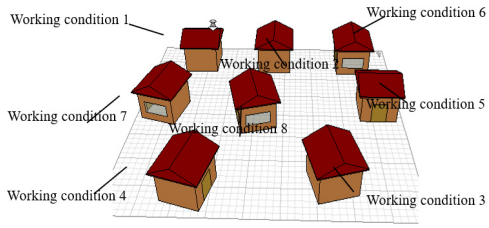

Fig. 4. 3D model drawing

2.2.Envelope setting

The parameters of the building envelope structure in the model are set according to the thermal transmission coefficient limit values of the building envelope structure in the Anhui Province "Green Design Standard for Civil Building" DB34/T 4250-2022. The materials and thermal transmission coefficients used in the model's envelope structure are shown in Table 2.

Table 2. Structure and Thermal Parameters of the Building Envelope

Type Name	Structure and Selected Materials	Heat Transfer Coefficient (W/m²·K).
External Wall	Ordinary Aerated Concrete Wall	0.95
Roof	Sloping roof (expanded polystyrene board)	0.5
Floor Slab	Insulated and moisture-proof ground	1.56
Window	Double-layer aluminum alloy window	2.91
Door	Energy-saving exterior door	3.03
Ceiling	Cement mortar floor (cement slurry)	1.34

The thermal parameters of the enclosure structure materials used in the model are shown in Table 3.

Table 3. Thermal Parameters of Enclosure Structure Materials

Component	construction method	thickness (mm)	thermal conductivity (W/m²·K)	U-value (W/m²·K)
exterior wall	polymer mortar	20	0.93	0.9
	special interface treatment adhesive	0	1	
	ordinary aerated concrete	200	0.19	
	lime, cement, mortar	20	0.87	
Sloping roof.	asphalt shingle	0	1	0.48
	Roofing felt	0	1	
	Synthetic polymer waterproof coating	2	1.05	
	Cement mortar.	20	0.93	
	Reinforced concrete.	120	1.74	
	Expanded polystyrene board.	70	0.042	
	Reinforced concrete.	120	1.74	
	Lime, cement, mortar	10	0.87	
Floor slab.	C20 fine stone concrete	40	1.51	5.75
	Extruded polystyrene board	10	5.56	
	Environmentally friendly waterproof coating	0	1	
	Concrete of C15 strength grade	80	1.28	
	Compacted clay 1	100	1.16	
Window	Flat glass	5	0.76	

	Heat Flow Horizontal (Vertical) 10mm	12	5.56	2.47
	Flat glass	5	0.76	
Door	The thermal flow direction of pine and spruce is perpendicular to the wood grain	25	0.14	2.55
Ceiling	Concrete mortar 1	20	0.93	1.34
	Polystyrene particle insulation material	30	0.06	
	Cement mortar	20	0.93	
	Reinforced concrete	120	1.74	

2.3.Indoor parameter settings for buildings

Taking residential buildings as an example, indoor disturbances are generally divided into three categories: personnel movement, equipment heat, and lighting heat. In Ecotect, when setting internal disturbances, the concept of "circadian rhythm" is introduced to reflect the hourly changes in internal disturbances, considering the movement of indoor personnel and the opening and closing of lighting equipment. For office workers, the hourly room occupancy rate is shown in Tables 4 and 5. The occupancy rate is 0 from 23:00 to 6:00 on working days, and 100% from 7:00 to 8:00 and 18:00 to 22:00. The occupancy rate is 50% during other periods, but on weekends, the occupancy rate is 0 from 23:00 to 6:00 and 100% during the rest of the periods.

Table 4. Hourly occupancy rate of residential buildings during working days annotated

Time	Occupancy rate	Time	occupancy rate
1:00	0	13:00	50%
2:00	0	14:00	50%
03:00	0	15:00	50%
04:00	0	16:00	50%
05:00	0	17:00	50%
06:00	0	18:00	100%
07:00	100%	19:00	100%
08:00	100%	20:00	100%
09:00	50%	21:00	100%
10:00	50%	22:00	100%
11:00	50%	23:00	0
12:00	50%	24:00	0

Table 5. The occupancy rate on weekends by an hour in residential buildings

Time	Occupancy rate	Time	Occupancy rate
01:00	0	09:00	100%
02:00	0	10:00	100%
03:00	0	11:00	100%
04:00	0	12:00	100%
05:00	0	13:00	100%
06:00	0	14:00	100%
07:00	0	15:00	100%
08:00	100%	16:00	100%

2.4.Internal disturbance setting

The main indoor design parameters include indoor temperature, indoor humidity, lighting and thermal disturbance. The simulation calculation related parameter settings are shown in Table 6.

Table 6. Indoor parameter settings

Name	Occupancy level	Sensible heat gain	Latent heat gain	Illuminance
Parameter	320W	5W/m^2	2W/m^2	300lx

3. Building Simulation Analysis

3.1.The Impact of Building Orientation on Heating Load(HL)

The data simulated for HL under eight working conditions are summarized and compiled, and the HL variation curves for each working condition are obtained based on the table data, as shown in Figure 5.

It can be seen that the minimum monthly HL under the eight operating conditions is 0. The maximum monthly HL under different conditions is concentrated in January and gradually decreases from January. The HL is 0 from May to September and gradually increases from October. Analysis of solar radiation shows that solar radiation gradually increases from January to August, and decreases after August. The maximum solar radiation in August is 24,960 Wh/m², which is also the highest HL of the year. The minimum solar radiation in January is 10,947 Wh/m². January is the month with the lowest temperature and the least radiation throughout the year. The temperature gradually rises after January, and from May, the temperature is generally high. Solar radiation is mainly concentrated from April to September. The HL gradually decreases as the building receives more solar radiation and light. When the temperature rises to a certain degree, the HL generated by the air conditioning is negligible. When the building orientation changes, the HL generated by the different solar radiation and light received inside the building is also different, and the monthly HL may vary. The monthly HL of Condition 1 is the highest among all conditions, but its annual HL is the highest among the eight conditions. The maximum monthly HL of Condition 8 is the highest among the eight conditions, but its annual HL is the lowest.

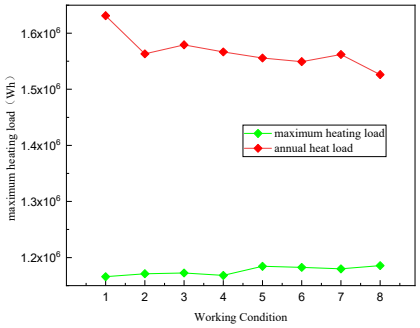

Fig. 5. Variation of CL under Different Operating Conditions

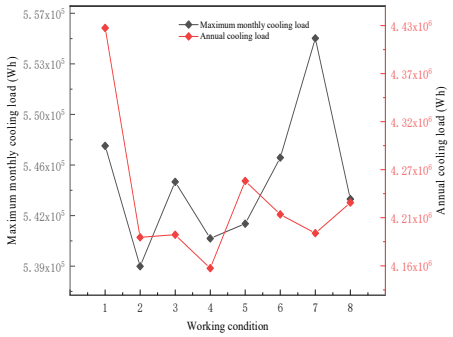

Fig. 6. Variation of HL under Different Operating Conditions

3.2.The impact of building orientation on cooling load (CL)

From Fig. 6, the maximum monthly cooling load (CL) for different conditions is concentrated in July, with the CL gradually increasing from May to reach its peak in July, and then gradually decreasing to 0 from July onwards. The CL for January to March and November to December is 0 for the entire year. Solar radiation is mainly concentrated from April to September, and the CL gradually increases with the increase in solar radiation and illumination inside the building. As the temperature gradually rises, the CL generated by the air conditioning also increases. When the building orientation changes, the CL generated by the different solar radiation and illumination inside the building also changes, resulting in more or fewer changes in the monthly CL. The monthly CL for Condition 7 is the highest among all conditions, and the maximum monthly CL for Condition 1 is the largest among the 8 conditions.

3.3.The impact of building orientation on total energy consumption

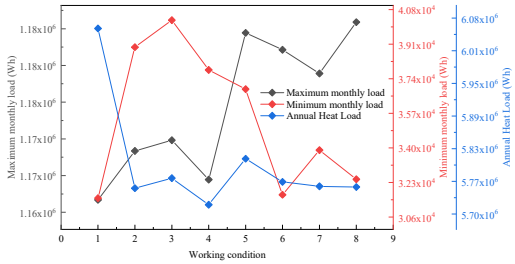

Fig. 7. Maximum monthly load, Minimum monthly load and Annual HL variation chart

From the Fig. 7, it is obvious that the maximum monthly load of the building under Scenario 4 is lower than all other scenarios, and the annual energy consumption of Scenario 4 is the lowest, while that of Scenario 1 is the highest. The annual load of Scenario 4 is about 5.52% lower than that of Scenario 1, and the total HL and total CL are about 4.12% and 6.50% lower respectively than those of Scenario 1. Under the same conditions, the summer solar radiation of Scenario 4 is lower while the winter solar radiation is higher, while it is the opposite for Scenario 1. Therefore, Scenario 1 has the highest energy consumption among the eight simulated scenarios throughout the year. In addition to affecting the building's heat gain from solar radiation, the orientation also has a great impact on the air infiltration heat transfer through the gaps of doors and windows. Different orientations have different air infiltration heat transfer through gaps of doors and windows. For the same residential building, the energy consumption of an east-west oriented building is significantly higher than that of a north-south oriented building. Therefore, to reduce the annual energy consumption, it is advisable to use a north-south orientation to avoid the dominant wind direction. Hence, the annual energy consumption of a north-south oriented building is generally lower than that of an east-west oriented building.

4. Conclusion

This article provides a theoretical analysis and energy consumption simulation study on the impact of building orientation on energy consumption in residential buildings in Hefei. The findings are as follows:

When other related factors are kept constant, building orientation has a significant linear relationship with building energy consumption. When building orientation changes, energy consumption also changes more or less accordingly. Total energy consumption gradually increases between 125° to 155° (southwest to southeast) and 90° to 125° (east to southwest), and gradually decreases between 155° to 345° (southeast to northeast). The total energy consumption load is the smallest at a building orientation of southwest.

Under the same conditions, the annual cold load is the smallest at a building orientation of southwest, while the annual HL is the largest at a building orientation of northwest. In summer-winter transitional regions, energy-efficient buildings need more heat in winter and less heat in summer. Therefore, residential buildings in Hefei are suitable for a north-south orientation, and the main room windows should face southwest to southeast.

This research used energy consumption simulation software to analying the relationship between residential building orientation and energy consumption. However, due to the fragmented and complex nature of actual energy consumption data, short research time, and limited ability to obtain survey information, the simulation results were not verified by actual measurements, which has certain limitations. Furthermore, in China, the main sources of energy consumption simulation meteorological data are CSWD, CTYW, IWEC, and SWERA, each with different

parameters and weighting factors. This study used the CSWD meteorological database, which is inserted into the Ecotect, so different meteorological data sources may have some impact on the simulation results.

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