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Research on the Current Situation of Thermal Environment in Guanzhong Farmhouses and Strategies for Improving Human Settlement Environment

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Abstract: Energy is one of the most important factors that constrain global economic development, and it is the fundamental guarantee for national economic development and the circular development of various industrial links. Building energy conservation is the key to achieving energy conservation and emission reduction. The Guanzhong region is a typical cold winter and hot summer area, and in the development process, Guanzhong residential buildings have also formed a set of construction strategies suitable for the regional climate characteristics. Combining local unique construction techniques and materials, the building exhibits significant local characteristics. This study analyzed the climate characteristics and passive technologies in the Guanzhong region, and constructed a 3D model of typical rural houses. Based on field research, a green development strategy was proposed by comparing and analyzing the differences between actual monitoring of ventilation and lighting and mathematical simulation. This study contributes to promoting the improvement of regional living environment and sustainable development.

Keywords: Thermal Comfort; Passive Design; Rural Construction; Ventilation.

1. Introduction

In November 2020, the Central Committee of the Communist Party of China proposed in the Proposal on Formulating the 14th Five Year Plan for National Economic and Social Development and the Long-Term Objectives for 2035 that green production and lifestyle should be widely adopted, and carbon emissions should be steadily reduced after reaching their peak. At the same time, the development of green buildings and the promotion of efficient energy utilization will be clearly included in the national strategic planning. At present, among the existing buildings in China, high-energy consuming buildings account for 99%, and the annual construction area of new buildings in the country reaches 1.6-2 billion cubic meters, with high-energy consuming buildings accounting for about 95%. The "China Building Energy Consumption Research Report (2020)" released by the China Building Energy Conservation Association pointed out that the total energy consumption of the entire building process in China in 2018 was 2.147 billion TCE (Ton of Standard Coal Equivalent), accounting for 46.5% of the total energy consumption in the country; The total carbon emissions from the entire construction process in China are 4.93 billion tons of CO_2, accounting for 51.3% of the country's carbon emissions. Among them, carbon emissions from the production of building materials and the operation of buildings account for 28.3% and 21.9%, respectively. China is a major agricultural country with a large rural population [1-2]. As of 2019, the rural population in China was 552 million, accounting for 39.40% of the total population. As one of the main buildings in China, rural housing has a huge total area: in 2017, the total construction area of China was about 59.1 billion m^2, of which the construction area of rural housing was about 23.1 billion m^2. With the improvement of economic level, the energy consumption structure of rural residential buildings is constantly changing, and the energy consumption of rural residential commodities is showing a rapid growth trend. In 2017, the energy consumption of rural residential commodities in China reached 243 million TCE, accounting for 25.31% of the total energy consumption of building commodities in China. Its carbon emission ratio has reached 29% of China's building energy carbon emissions. Therefore, energy conservation and emission reduction in rural residential areas in China is an important component of implementing China's carbon neutrality and peak carbon action plan [3].

2. Research Area

The Guanzhong region is located in the central part of Shaanxi, with a length of about 360 kilometers from east to west and a total area of 39064.5 km^2. The Guanzhong urban agglomeration mainly includes cities such as Xi'an, Baoji, Xianyang, Weinan, and Tongchuan, and is the core of politics, culture, and economy in Shaanxi Province and even the northwest region. The region is developed in industry and agriculture, with a dense population. The average annual temperature is 6-13 ℃, with an annual precipitation of 500-800 mm, of which 60% is from June to September. It belongs to the second building climate zone in China's building climate zoning, with a warm temperate semi humid continental monsoon climate and a cold climate zone in the building thermal climate zoning.

3. Methodology

Using the method of typological design to construct

prototypes that reflect the spatial layout characteristics of buildings, and establishing BIM 3D models; Starting from the construction mode in the Guanzhong region, analyze the full lifecycle characteristics of rural housing and clarify its carbon emission characteristics at different stages. Based on BIM data processing and interaction functions, numerical simulation software such as CFD is used to simulate the ventilation performance of buildings from the aspects of individual building elements, wind direction, window opening form, opening area, and opening and closing conditions. The impact of different elements on the ventilation performance of buildings is analyzed; Select typical buildings for indoor and outdoor environmental monitoring, analyze their ventilation effects, and compare them with numerical simulation results to propose optimization measures for different building ventilation performance. Using numerical simulation software such as Ecotect, quantitative analysis was conducted on the indoor lighting coefficient and illuminance performance parameters of the building from the aspects of shading components, building orientation, window opening form, and area. The impact of different elements on the building's lighting performance was analyzed; Select typical buildings for indoor and outdoor environmental monitoring, analyze their shading and lighting effects, and compare them with numerical simulations to propose optimization measures for different building lighting performance.

4. Results

4.1. Environmental Characteristics and Passive Energy-Saving Technology

The study used Climate Consultant software to analyze meteorological data (CSWD) in the Guanzhong (Weinan) region, with meteorological monitoring station number 570360. The monitoring station is located at 34°18′ N and 108°55′ E, consistent with the climate data values and trends recorded in the Weinan Yearbook. Choose ASHRAE Basic Comfort Handbook 2005 as the comfort model, which belongs to the dynamic model and provides comfort ranges for winter and summer, with temperature slightly decreasing with increasing humidity. As shown in Figure 1, the blue area indicates that only 12.1% of the year the study area was in a relatively comfortable climate environment (approximately 1059 hours). The applicable passive design strategies are ranked in order of effective time as follows: (1) Heating and increasing humidity if necessary (40.1%); (2) Internal insulation system (21.1%); (3) Window shading (10.0%); (4) Fan ventilation (9.9%); (5) Cool down and reduce humidity if necessary (8.1%); (6) Passive solar heating using high thermal storage materials (5.8%); (7) Indirect evaporative cooling (5.7%); (8) Natural ventilation cooling (5.7%); (9) Reduce humidity (5.4%); (10) The nighttime cooling effect of building materials (4.6%); (11) Direct evaporation cooling (4.2%); (12) Passive solar heating using low heat storage materials (4.1%); (13) The use of high heat capacity materials (3.2%). Based on the climate characteristics of the Guanzhong region, some practical and feasible design guidance has been proposed, such as designing suitable window overhangs and installing adjustable sunshades, using light colored building materials and high emissivity roof materials, etc.

4.2. 3D Models Based on Typological Design

This research conducted on-site research in Xianyang, Weinan, Baoji and other places, and surveyed the basic parameters of rural houses (Figure 1). The newly-built homestead has an east-west width of about 10 meters, mostly 3 bays, and a north-south length of 20-30 meters. The plan is a narrow rectangular shape, covering an area of about 200-300 m^2. Generally single story or two-story single courtyard style residential buildings, the flow line is divided into gatehouse front yard main house backyard. The gatehouse is generally not occupied by people and serves as the main entrance and exit, as well as a storage room and also serves as a parking function. The front yard is an important area for daily living, and there are usually stairs near the courtyard wall that allow you to climb directly to the second floor. The main room is connected to the front and rear courtyards, and also serves as an aisle. The backyard is mostly an auxiliary space, including bathrooms and storage rooms [4]. Old style farmhouses have sloping roofs, and in recent years, new residential buildings have adopted flat roofs to meet the needs of crop drying and other factors. The floor height is generally 3.6 meters, and the structure is mainly composed of adobe brick walls, wooden beam tops, and brick concrete. The exterior walls are mainly made of 240 mm thick brick walls, with white ceramic tile finishes. The inner partition walls are made of 120 mm thick brick walls, and cement mortar is applied to the exterior of the bottom window walls. There are no insulation measures for the walls and roof structures.

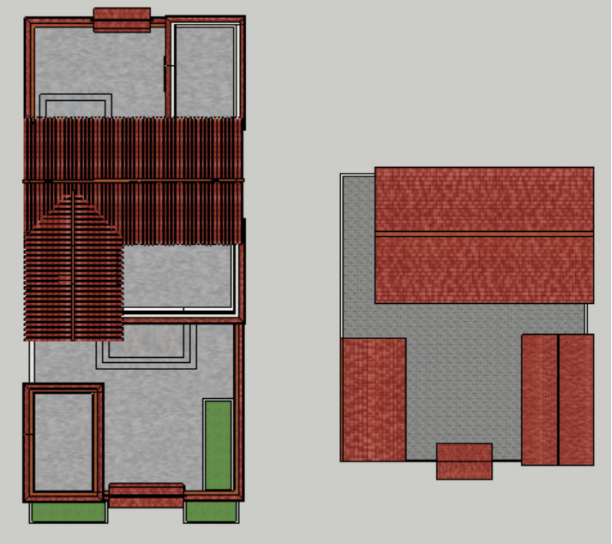
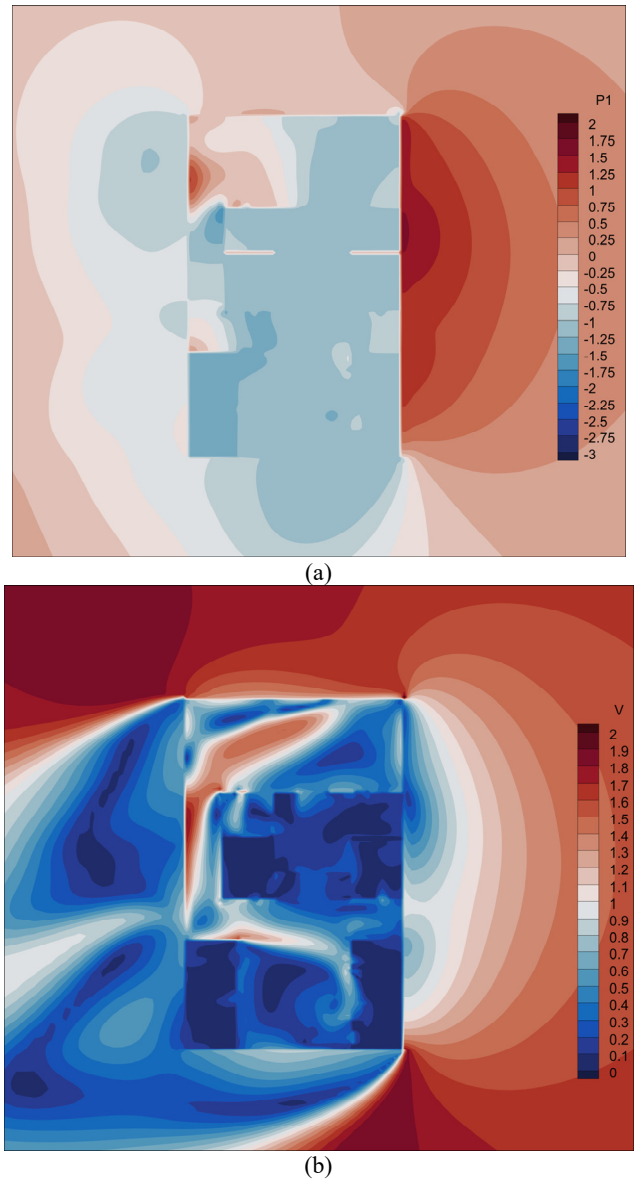


Figure 1. Rural Residential Plan in Guanzhong Area

4.3. Analysis of Ventilation and Lighting

Based on the BIM sustainable analysis platform, simulate the ventilation performance of buildings from various aspects such as individual buildings, wind direction and speed, window opening form, opening area, and opening and closing conditions. The prevailing wind direction in the Guanzhong area is 67.5° northeast, with an average annual wind speed of 2.58 m/s. The simulation results of the wind environment at an active height (z=1.5m) with the courtyard door closed, entrance doors, and windows open are shown in Figure 2. When the courtyard door is closed, the overall wind speed flows slowly, with a maximum value of less than 2m/s. Most indoor spaces have wind speeds below 0.5 m/s, and the indoor air in areas such as bedrooms is basically stagnant. The passage on the west side of the main building has a positive

effect on introducing airflow, forming a ventilation corridor with a wind speed of 1-2 m/s. This is of great significance for changing the thermal environment of the building and improving the comfort of the courtyard. For a single-story main house, the east courtyard wall hinders over 80% of the external airflow. In quiet or low wind areas, appropriately increasing the height of the main room or lowering the height of the courtyard wall can improve the ventilation environment inside the courtyard [5]. In addition, keeping the doors, rooms, and windows open during the hot summer season also has a significant effect on improving indoor ventilation.

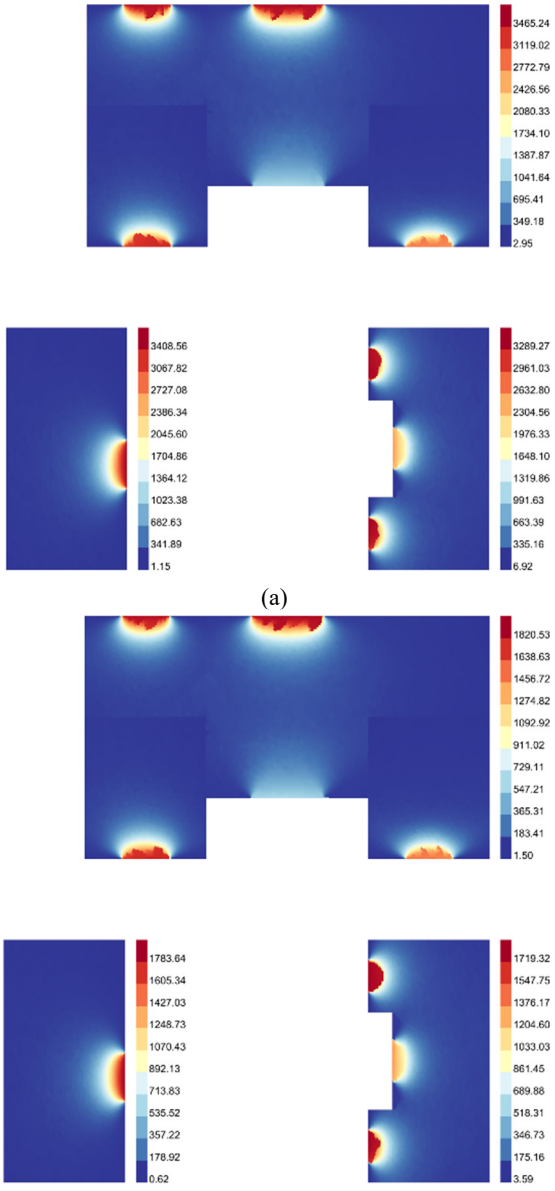


(a)

(b)

Figure 2. Simulation of ventilation performance of rural residential buildings in Guanzhong area (a) Wind pressure; (b) Wind speed

By selecting 8 points for on-site monitoring both indoors and outdoors, we found that the indoor simulation results were closer to the measured results, with an error of no more than 0.1 m/s for a single point; The outdoor simulation results show significant fluctuations, with an error of 0.2-0.3 m/s for a single point. This indicates that the outdoor environment is influenced by more factors and should be fully considered when analyzing and modeling. Based on cloudy lighting conditions, indoor lighting of a single-story main house was simulated from the aspects of shading components, building orientation, window opening form, and area. As shown in Figure 3, the building exhibits high illumination near the external walls, while the illumination at the center of the building is low. The maximum value on the summer solstice is 3465.24 lux, the minimum value is 1.15 lux, and the average illumination is 115.74 lux. The maximum value on the winter solstice is 1820.53 lux, the minimum value is 0.62 lux, and the average illumination is 45.58 lux. The maximum value of the daylighting coefficient is 18.4%, the minimum value is 1.6%, and the average value is 3.6%.



(a)

(b)

Figure 3. Analysis of Indoor Light Intensity (a) Summer Solstice; (b) Winter Solstice

Regional climate, building orientation, and spatial form are the main factors affecting the lighting environment. The natural light utilization rate of rural residential buildings in this project is relatively low, and the control method is simple. On the basis of ensuring the best orientation of the building, the lighting environment of rural residential buildings can be improved by setting up a lighting atrium, increasing the height of window sills, adding sunshade blinds, and setting up reflective panels.

5. Conclusion

This research combines theory with practice, obtains data through field research, and conducts simulation verification in a computer. Firstly, this project extracted the prototype features of rural housing in the Guanzhong area and constructed a universal 3D model, which is a beneficial exploration of the digital transformation of the construction industry and also provides technical support for the digital development of the group project; Secondly, this project explores the application of passive energy-saving technology in the Guanzhong area from the perspectives of ventilation and lighting performance, providing data support for the renovation of existing and new residential buildings; Finally, by calculating the carbon emissions of rural housing at each stage, emission reduction measures for rural housing in the Guanzhong region were proposed.

Acknowledgments

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