On Optimization Design of Sunshade Components for Qinba Mountain Buildings

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Abstract. Improving indoor thermal comfort and reducing building energy consumption are the main ways to realize sustainable development of buildings. In view of the phenomenon of indoor overheating in traditional buildings in Qinba mountain area in summer, it was proposed to add sunshade components to the south-facing Windows for improving indoor thermal comfort. Ecotect software was utilized to study the influence of common shading components and shading louvers under different parameters on solar radiation in the south-oriented window. The results demonstrated that the shading louver has the best shielding effect on the integrated radiation. Finally, ANSYS.CFX was used to study the influence of shading louvers with different blade widens and angles on natural ventilation. Considering the influence of louver parameters on radiant heat gain and natural ventilation, it was recommended to choose louvers with a width of 200 mm and an Angle of 30°, which can effectively block 70% of the solar radiation heat gain of the south window and increase the ventilation potential by up to 15%.

Keywords: Qinba mountain architecture, sunshade component, natural ventilation, numerical model.

1. Introduction

In recent years, with the rapid advance of urbanization in China, the energy demand of rural buildings has been greatly increased. Hence, the passive energy saving technology of rural buildings has become the focus of contemporary scholars. For a long time, rural buildings rely on experience to build. The construction mode of rural buildings has gradually fallen behind, unable to meet the requirements of energy-saving design standards and sustainable development of buildings.

Qinba mountains are located in the north of Ba Mountain and the south of Qinling Mountains, which are hot-summer and cold-winter zone. It forms the regional environmental characteristics of hot and humid in summer and cold and humid in winter. The design of the building in this area focuses on heat protection in summer. Although local buildings have formed a climate-adaptive construction mode with summer cooling as the core under the inheritance of long-term experience, it still cannot meet the requirements of indoor thermal comfort in summer. Therefore, it is necessary to study the passive thermal insulation design of Qinba mountain buildings.

Building shading and natural ventilation is considered to be an economical and effective passive technology. Many scholars have conducted a series of detailed researches on building shading. Window
shading performance is related to shading equipment [1] and building orientation [2]. Kim et al. [3] pointed out that horizontal shading components are the most energy-saving in hot summer and cold winter areas. Dong et al. [4] utilized Energy plus to simulate energy consumption of buildings with horizontal louver shading components, the results showed an annual energy saving of 3.2%. Invidiata and Ghisi [5] studied four shading systems of a house in southern Brazil from the aspects of energy and cost, and the results showed that double open wooden shutters and PVC roller shutters were the most suitable. External shading components can reduce cooling energy consumption, while heating energy consumption increases slightly [6]. In order to reduce the amount of solar radiation entering through the external window, Luca [7] summarized suitable shading components with different facade orientations. The existing research promotes the development of architectural shading, but most of the research is universal and mainly focuses on urban buildings or public buildings [8]. The external boundary conditions of the building cannot be the same as those of the rural buildings, nor can it adapt to the specific climatic conditions of the Qinba Mountains, so it cannot be closely combined with the regional properties of the building. The optimal design of shading components doesn’t consider the impact on natural ventilation, and the research focuses on hot areas in the south [9,10], while few studies focuses on rural buildings in high latitude areas in the north.

1.1. Research Aims
This paper selected the typical buildings in Qinba Mountains as the subject, and the indoor thermal environment of the typical buildings was tested, and the factors affecting the indoor thermal environment are analyzed. Ecotect was used to study the influence of different shading components on the radiant heat gain of the south window, and ANSYS.CFX software was used to optimize the design of louver parameters under natural ventilation, so as to maximize the shading function of louver and provide reference for the shading design of local buildings.

1.2. Case Study Description
Hanzhong is located in Qinba mountain area. The research team selected typical buildings in Huguangying village of Hanzhong for testing (Figure 1). The building faces south. The size of the bedroom is 3.3 m × 3.8 m, and the size of the living room is 4.7 m × 6.6 m. The south-facing bedrooms on the first and second floors are equipped with 1.8 m × 1.8 m single-glass aluminum alloy Windows, the north living rooms on the first and second floors are equipped with 2.4 m × 2.4 m single-glass aluminum alloy Windows. The form of roof is slope roof, and the external wall is 240 mm brick wall without insulation layer.

Figure 1. The typical building
2. Methods

2.1. Field Experiment

The test was conducted July 27-29, 2017. The weather was clear during the test. The test included indoor air temperature, humidity and solar radiation intensity. Self-measuring thermohygrometers were used to measure air temperature. The air temperature and humidity were measured by TR-72U self-recording thermohygrometers with the test accuracy of ±0.2°C, and the test was carried out continuously for 24 hours with the data collection interval of 1 hour. Solar radiation was measured using the TBD-1 shading band in coordination with the TBQ-2 total radiation meter. The measuring range of the radiation meter was 0-2000 W/m², the sensitivity coefficient was 8.789 μV/(W·m⁻²), and the data collection interval was 1 h, the measuring point was located in an outdoor space with no shielding around. The layout plan and measuring point distribution diagram of folk dwellings are shown in Figure 2.

![Layout plan and measuring point distribution diagram](image)

**Figure 2.** Arrangement of measuring points. (a) the first floor, (b) the second floor

2.2. Numerical Analysis

Solar radiation directly into the room through the window is the main cause of indoor overheating in summer [11,12]. Shading components outside Windows could block some radiant heat, thereby reducing the influence of radiant heat on indoor temperature. Most of the local buildings have Windows in the north and south. Since the northern solar radiation heat is the minimum, considering that the northern solar radiation could reduce the winter heating load, this paper only considered the external shading components in the south direction.

2.2.1. The Influence of Different Shading Components on the Radiation Heat. The shading components studied in this paper were: horizontal, vertical, integrated and horizontal louver shading [13,14]. Shading components are shown in Figure 3. The size of fixed sunshade for this simulation was c=600mm, b=1800mm; The width of the louver w=100mm, 200mm and 300mm, the ratio of spacing to width was 1:1, the distance between the center axis of the louver and the wall was 200mm, and the angle of the louver was 30°, 45°, 60°, 75°, 90°.
In this study, Ecotect was used to simulate the solar radiation energy received by the southern window in summer, and studied the external shading coefficient to evaluate the shielding effect of different shading components on the solar radiation received by the southern window. The simulated geographical location was Hanzhong, and the meteorological data of Hanzhong area were adopted. The simulation time was from 8:00 to 18:00 in summer (June 1-August 31). The master bedroom of a typical building was selected as the research unit for the simulation building. The building faced south. The height was 3.3 m, the plane size was 3.4 m × 4.0 m. The window size was 1.8 m×1.8 m, the windowsill height was 0.9 m and the position were in the middle.

2.2.2. Influence of Louver Parameters on Natural Ventilation. Building shading components would guide or block the natural wind entering the room, and properly designed, they could promote the ventilation of the building [15]. Therefore, the structure and size of shading facilities have a great influence on indoor ventilation. The three-dimensional finite element software ANSYS.CFX was used to study the influence of louver shading on indoor ventilation and determine the optimal parameters of the louver to maximize the shading function of the louver.

In order to simplify the calculation amount of the model, the model of the building adopted is a simple two-storey building, with three rooms on each floor, the size of which was 3.4 m × 4 m × 3.3 m. The window size was 1.8 m×1.8 m, the height of the windowsill was 0.6 m. Louver shading was added to the first and second floor, as shown in Figure 4. The outfield model adopted in this paper was that the upstream area, the downstream area and the width were 3, 10 and 5 times of the building width respectively, and the height was 4 times of the building height. The incoming wind direction was perpendicular to the windward side of the building.
Since the incoming wind speed was greatly affected by topography and height, the incoming wind speed was determined by the gradient wind function, and the expression was:

\[ V_h = V_0 \left( \frac{h}{h_0} \right)^n \]  

(1)

Where: 
- \( h_0 \) — Reference height and wind speed at reference height, generally given by meteorological data, usually 10m
- \( V_0 \) — Wind speed at reference height
- \( V_h \) — Wind speed at height \( h \)
- \( n \) — Ground roughness coefficient is set at 0.16

According to wind speed data in Hanzhong, the average wind speed in summer was 1.7m/s. Since the research object was rural buildings, the ground roughness coefficient was \( n = 0.16 \), and the wind speed gradient function was shown in Figure 5. As shown in Figure 6, the wind pressure of each point on the windward side was the same in both rooms, so the wind pressure of the left room can represent the wind pressure of both sides.
3. Results and Discussion

3.1. Test Results and Analysis

The test of solar radiation includes total solar radiation and solar scattered radiation. Figure 7 shows the test results. The test time was the effective sunshine time of the day from 8:00 to 18:00. The peak of the total solar radiation intensity is 938 W/m², and the average total radiation intensity is 665.4 W/m². Direct radiation accounted for about 82.3% of the total radiation. According to the test data, the local summer solar radiation intensity was strong, too much solar radiation into the indoor would cause rapid rise of indoor temperature, and reduced indoor thermal comfort. Hence, local dwellings need to strengthen shading measures to reduce the impact of solar radiation on indoor temperature.

![Figure 7. Solar radiation intensity](image)

The indoor and outdoor temperatures of residential buildings were tested respectively. The test results are showed in Figure 8. The average temperature of the living room on the first floor, the bedroom on the first floor, the bedroom on the second floor and the living room on the second floor are 29.2, 29.4, 30.8 and 31.4 respectively. The test results show that indoor overheating was severe in the summer, and it can be seen that the temperature of the second floor was significantly higher than the temperature of the first floor due to the lack of thermal insulation of the roof. The peak temperature in the south-facing room occurred at around 3 pm, while the highest temperature in the north-facing room occurred at around 6 pm, which indicated that the south-facing room temperature was greatly affected by the solar radiation intensity.

![Figure 8. Air temperature changes during the test](image)
The measured data showed that there was overheating phenomenon in local residential buildings in summer, and the indoor temperature was affected by solar radiation larger. Solar radiation heat through the window directly into the indoor in summer couldn’t be ignored. Therefore, the shading design of Windows was proposed.

3.2. Analysis of the Numerical Results

3.2.1. Radiant Heat Gain. Figure 9 shows the influence of different shading components on radiation heat gain. It can be seen from the figure that in the fixed sunshade, the shading efficiency of comprehensive sunshade is more significant, with the shading coefficient of 0.45, followed by the horizontal sunshade with the shading coefficient of 0.62, and the shading efficiency of the vertical sunshade is not ideal, with the shading coefficient of 0.83. Among them, horizontal shading had a better shielding efficiency against direct solar radiation, which was due to a higher south-facing solar height Angle. The solar radiation shielding ability of the horizontal solar visor is stronger when the solar height Angle is higher. The blocking efficiency of synthesis shading was the sum of the blocking efficiency of horizontal shading and vertical shading. Horizontal louver shading had the most significant effect on total solar radiation shielding efficiency, and the louver shading effect of different widths had little difference. Among them, 300mm louver had the best shading effect and the shading coefficient was 0.29. The shading effect of 200mm louver was second, with the shading coefficient of 0.31. The 100mm louver had the lowest shading effect and the shading coefficient was 0.33. Therefore, the louver shading was more suitable for south window than fixed sunshade.

Figure 9. Southern window receives solar radiation energy

Figure 10 shows the influence of shading Angle and width of louver on thermal gain of south window. Shading coefficient decreased with the increase of louver width. The louver with the same blade width decreased first and then increased with the increase of louver inclination Angle. Among them, the shading coefficient of 200 mm and 300 mm louvers was the smallest when the louver inclination Angle was 45°, which is 0.27 and 0.30 respectively. When the slant Angle of 100mm blade width was 30°, the shading coefficient was the smallest which was 0.33.
3.2.2. Natural Ventilation Potential. The influence of louver Angle and louver width on natural ventilation of buildings was discussed, and the pressure difference between windward and leeward sides $\Delta P$ was taken as the evaluation index of natural ventilation potential, so as to seek the optimal louver parameters.

When the width of the louver was 200mm, the influence of the louver on the natural ventilation of the building when the louver inclination Angle was 15°, 30°, 45°, 60° and 75° was discussed respectively. It can be seen from Figure 11 that the inclination Angle of the louver was 45°, the windward static pressure was significantly higher than that of other louvers, and only when the inclination Angle of the louver was 45°, the windward static pressure was positive. The static pressure on the leeward side was all negative pressure, and the negative pressure value of the rooms on both sides was larger than that of the middle room, and that of the room on the first floor was larger than that of the room on the second floor. When the slant Angle of the louver was 45°, the negative pressure was the least. The second-floor room pressure difference $\Delta P$ was larger than the first floor, the two sides of the room pressure difference $\Delta P$ was smaller than the middle room, indicating that the ventilation potential of the second floor was larger than the ventilation potential of the first floor, the ventilation potential of the middle room was larger than the two sides of the room. When the louver inclination Angle changed from 15° to 60°, as the louver inclination Angle increased, the pressure difference $\Delta P$ first increased and then decreased. When the louver inclination Angle increased to 75°, the pressure difference $\Delta P$ changed little. When the slant Angle was 45°, the pressure difference $\Delta P$ was the largest. The natural ventilation potential was the largest.
Figure 11. Influence of slant Angle on wind pressure on building surface. (a) Windward static pressure, (b) leeward static pressure, (c) Pressure difference

As can be seen from Figure 12, the static pressure value on the windward side first increased and then decreased with the increase of the louver width, that was to say, the static pressure value of blade width was the largest at 200 mm, and was significantly higher than other blade widths. The static pressure value of the second floor was significantly higher than that of the first floor, and the static pressure value of the middle room was slightly higher than that of the two sides. The negative pressure on the leeward side was not significantly affected by blade width, and was the largest at 200 mm. The pressure difference first increased and then decreased with the increase of the louver width. When the blade width was 200 mm, the pressure difference was significantly higher than other blade widths. That was, when the blade width was 200 mm, the ventilation potential was the largest. The ventilation potential of the two side rooms was smaller than that of the middle room, and the ventilation potential of the second floor was obviously higher than that of the first floor. Therefore, when the louver width was 200 mm and the louver inclination Angle was 45°, the natural ventilation potential of the building was the largest.
Figure 12. Influence of louver width on wind pressure on building surface. (a) Windward static pressure, (b) leeward static pressure, (c) pressure difference

The wind pressure distribution of the optimized louver components and the building surface without shading was compared, as shown in Figure 13. With louver shading, the windward pressure value was larger than that without shading, and the effect of the second layer was more obvious. The leeward negative pressure value was slightly smaller than that without shading. The pressure difference was larger than that without shading, and the effect of the second layer was more obvious, with the pressure difference increasing by up to 15%. Therefore, the indoor ventilation potential was larger when the louver shading component is added.
4. Conclusion

Through field test and simulation analysis, the following conclusions are drawn:

(1) There was overheating phenomenon in the measured building, which is greatly affected by solar radiation, so it was proposed to add external shading components to the south-facing Windows.

(2) Among the fixed sunshades, the comprehensive sunshade had the best shading effect. Louver shading had the best shading effect on the total solar radiation, with shading coefficient between 0.29 - 0.33. With a blade width of 200 mm and a louver Angle of 30°, the building had the greatest potential for natural ventilation.

(3) Considering the influence of the solar radiation and the natural ventilation, it is recommended to choose the louver with a width of 200 mm and a dip Angle of 30° to shade the louver, which can effectively block 70% of the solar radiation heat of the south window and increase the ventilation potential by 15%.

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