Study on ventilation optimization design method of rural residential buildings in Guanzhong——A case study of red brick house project in Ezi village, Xianyang

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Abstract. Guanzhong region of Shaanxi province has a continental monsoon climate of warm temperate zone, with hot in summer and cold in winter. Therefore, the strategies of traditional houses dealing with wind environment are mainly ventilation in summer and wind protection in winter. Due to the limitation of technical and economic conditions, winter heating has always been the core problem of rural houses, so people usually adopt a relatively closed space layout to strengthen the windproof performance of buildings, but also lead to poor indoor ventilation in summer. With the development of social economy, rural residents have higher requirements for living quality, so it is very important to improve ventilation efficiency in summer under the condition of ensuring wind protection in winter. Taking the red brick house project in Ezi village as a practical case, in order to improve indoor wind pressure ventilation and thermal pressure ventilation efficiency, the project introduces double-height space and skylight that commonly used in urban buildings into rural houses, providing reference for the construction of similar residential buildings in Guanzhong area.

1 Background

Guanzhong refers to the Weihe river alluvial plain at the north foot of the Qinling mountains in Shaanxi province, China. Traditional houses in Guanzhong usually adopt closed space layout to strengthen the windproof performance of the building, but it is not conducive to ventilation in summer. With the development of social economy, it is urgent to improve the indoor comfort of rural residential buildings, and optimizing the ventilation environment is one of the important measures.

This paper takes the design of red brick house in Ezi village, Xianyang city, Shaanxi province as an example to improve the natural ventilation conditions by optimizing the courtyard form, adjusting the plane layout and adding skylights.

2 Climate of Guanzhong

According to the meteorological data of Xi’an, Tongchuan, Baoji, Xianyang and Weinan city in Shaanxi province from 1961 to 2012, the Guanzhong region was dry in winter and spring, with concentrated precipitation in summer, which the average precipitation is 265.7mm. The average summer temperature is about 25°C, the highest temperature can reach more than 40°C, and the average winter temperature is about 1°C.

3 Ventilation of traditional houses

3.1 Construction features

Under the special natural conditions and cultural background, traditional houses in Guanzhong form a...
unique spatial pattern, which directly affects the ventilation of buildings.

3.1.1 Narrow courtyard

Due to the shortage of land, traditional houses in Guanzhong usually have smaller rooms and larger depths, and are enclosed in longitudinal courtyards, thus presenting the characteristics of "narrow courtyard ". The depth of the courtyard is about 22 m, and the width is about 9 m.\(^{3}\)\(^\text{(Fig.2)}\)

**Fig. 2. Guanzhong "narrow courtyard house".**

3.1.2 Typical plane

The conierge of "narrow courtyard house" in Guanzhong is about 5-7m in depth. It is the main place for processing agricultural products, storing sundry goods and entertaining guests. The depth of the wing rooms on both sides of the courtyard is generally no more than 3m, which are mostly used for living, kitchen and storage functions.\(^{4}\) The courtyard is the main activity space. The width depends on the size of the middle compartment of the principle room, and the length depends on the number of wings, which is usually in a ratio of 1.3 to 1.4. The principle room is usually three rooms in width and about 5-7m in depth. It is the main living room.\(^{\text{(Fig.3)}}\)

**Fig. 3. Typical plane of "narrow courtyard house".**

3.2 Ventilation simulation

3.2.1 Selection of simulation software

Butterfly is the software selected for this ventilation simulation, which is a plug-in of Rhino.Grasshopper software. Its operating principle is to use open source CFD software for simulation analysis. Butterfly software retains modeling logic completely by means of visual battery pack coding, which is extremely convenient for wind field optimization.\(^{4}\)

3.2.2 Setting of simulated conditions

First of all, the research model was established on the basis of the Guanzhong "narrow courtyard house", (Fig.4) the wind was selected for the north east (average wind speed was 2 m/s), the height of 1.5 m place was chosen for analysis of the main section, and finally five points (A, B, C, D, E) were identified as the analysis object.

**Fig. 4. The model of "narrow courtyard house".**

3.2.3 Analysis of simulation

By analyzing the cloud image of wind pressure and wind speed (Fig. 5,6), the wind pressure difference between the northeast corner of the house and the courtyard center (C) is about 3Pa, which provides good wind pressure and ventilation conditions. However, due to the relatively closed layout of the house, the air flow cannot directly enter the courtyard and the interior. Finally, the wind speed at point C is less than 0.6m/s, and the wind speed at A, B, D and E is basically 0m/s. This approach effectively avoids the cold air entering the room in winter, but also hinders the natural ventilation of the room in summer. People can only use mechanical equipment such as fans for ventilation, but it also leads to the problem of increased energy consumption.

**Fig. 5. Cloud image of wind pressure.**

**Fig. 6. Cloud image of wind speed.**

4 Ventilation mode and strategie in house

Ventilation is very important to the comfort of living, good ventilation environment not only can take away indoor excess water vapor, improve human body comfort, but also can effectively reduce indoor temperature in summer. Generally speaking, when the outdoor wind speed is less than 1m/s, the human body can hardly feel the existence of wind; When the wind speed is between 1m/s and 5m/s, the human body feels comfortable; When the wind speed is greater than 5m/s, the human body feels uncomfortable. There are three common natural ventilation modes: wind pressure ventilation, thermal pressure ventilation and compound ventilation.

**4.1 Ventilation mode**

(1) Wind pressure ventilation

Wind pressure ventilation is a phenomenon that air flows from the windward side to the leeward side
because the wind pressure on the windward side is higher than that on the leeward side. Wind pressure ventilation efficiency is determined by building form, orientation, plane layout, etc.

(2) Thermal pressure ventilation
Thermal pressure ventilation is a phenomenon in which air moves upward because the temperature in the lower part of a room is higher than that in the upper part. Usually the efficiency of thermal pressure ventilation is proportional to the height difference of the outlet.5

(3) Compound ventilation
In the actual situation, wind pressure ventilation and thermal pressure ventilation often exist at the same time, which is not a simple superposition, but mutually promote and cooperate with each other.6 (Fig.7)

4.2 Ventilation strategy

(1) Improve outdoor wind speed
In the design of outdoor environment, the wind speed in the courtyard can be effectively adjusted by changing the form, space proportion and building scale of the courtyard.
(2) Ensure the indoor unobstructed
In the layout of the house, smooth ventilation paths can be organized by changing the functional arrangement and partition wall position to reduce the obstacles to air flow.
(3) Add indoor skylights
In section design, the principle of thermal pressure ventilation can be effectively utilized to promote indoor ventilation by increasing indoor height difference and adding skylight.

5 Ventilation design of red brick house in Ezi Village

5.1 Brief introduction
The project is located in Xianyang city, Shaanxi province. Due to the poor lighting and ventilation conditions of the original house, the owner considers to build a new house. The base is 35.1 m in the north-south direction and 9 m in the east-west direction. The red brick house continues the narrow courtyard layout of Guanzhong traditional house, and introduces modern universal technologies such as skylights to create good indoor ventilation conditions.

5.2 Ventilation design

5.2.1 Layout of courtyard
The main entrance is located in the southeast corner, and the site is divided into two courtyards by the conierge and the main house. The front yard is the main living area, with landscape tree pool, which can meet the needs of daily rest, entertainment, drying grain and so on. The backyard is a storage area. The setting of the conierge, courtyard wall and plants can effectively reduce the wind speed in the courtyard and regulate the microclimate.

5.2.2 Layout of the main house
The main room adopts a symmetrical plane layout, with a complete narrow hall in the middle of the plane and bedrooms, living rooms and kitchen on both sides, so as to avoid interrupting the air flow and facilitate the natural ventilation of the room. (Fig.8,9,10)

5.2.3 Skylight ventilation
Narrow hall, toilet and kitchen are equipped with skylights to facilitate thermal pressure ventilation and enhance air flow. The windows are low-E hollow glass made of aluminum alloy frame, and the open area is strictly controlled. The windows are opened in summer for natural ventilation, and closed in winter to resist the outside cold wind. (Fig.11,12)

5.3 Ventilation simulation

5.3.1 Setting of simulated conditions
First of all, the research model was established according to the project. (Fig.13) the wind was selected for the north east (average wind speed is 2 m/s), the height of 1.5 m place was chosen for analysis of the main section, and finally eight points(A, B, C, D, E,F,H,E) were identified as the analysis object.
5.3.2 Simulation analysis

By analyzing the cloud image of wind pressure and wind speed (Fig.14,15), the wind pressure difference between the northeast corner of the house and the courtyard center (G) is about 3Pa, which provides good wind pressure and ventilation conditions. Due to the existence of outdoor courtyard and indoor atrium, air flow can run through the whole building. The wind speed of courtyard (A and G) is 0.3-0.9m/s, indoor wind speed of narrow hall (D), living room (F) and master bedroom (E) is 0.3-0.6 m/s, and that of secondary bedroom (point B and C) is 0-0.3m/s.

6 Conclusion

In the past, people usually adopt a relatively closed space layout to strengthen the windproof performance of buildings, but also lead to poor indoor ventilation in summer. With the development of social economy, people have a higher demand for living quality and building energy saving. As the most energy-saving and efficient way of ventilation, natural ventilation is gradually paid attention to by people. By analyzing the ventilation problems of traditional "narrow courtyard house" in Guanzhong, this paper proposes the ventilation optimization design method combined with the actual project and draws the following conclusions:

1) In Guanzhong area, the dominant wind direction in summer is the same as that in winter, which is northeast. Therefore, the ventilation efficiency in summer should be improved on the premise of ensuring wind protection in winter.

2) The overall layout of the yard should adopt the front and back yard style. Through the gatehouse and the wall, the outdoor wind speed can be reduced to the comfortable range of human body, which is also conducive to the formation of indoor ventilation.

3) The interior layout of the building should create a complete ventilation corridor by retaining the middle corridor and reducing the shielding of the interior partition wall, which is conducive to organizing the wind pressure ventilation. At the same time, skylights can be added to organize thermal pressure ventilation with indoor wind pressure difference.

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