Energy-Saving Transformation Design of Existing Residential Buildings in Qinba Mountainous Areas

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Abstract. Through investigation, it is found that some existing buildings in Qinba Mountain have high energy consumption and poor indoor thermal comfort. The cost of demolishing and rebuilding is relatively high. Therefore, it is an important issue for the current urban residential development to study suitable local reconstruction strategies. Taking an old community in Hanzhong City of Qinba Mountain as an example, the field test of indoor and outdoor thermal environment in winter and summer was carried out for one house. The current situation of indoor thermal environment in Qinba mountain city buildings in winter and summer was analyzed. The environmental conditions are not ideal. This article uses DesignBuilder software to carry on the comprehensive transformation design to the wall of this existing building, the roof, the outer window and so on, and carries on the simulation analysis to its indoor thermal environment, the result shows that the enclosing structure has a greater influence on the thermal environment of the local building; the transformation model was obtained: 30mm EPS insulation layer was added to the wall, 50mm EPS insulation layer was installed on the roof, and plastic window (6+13A+6) was used as the outer window. After the renovation, the indoor temperature was increased by 11%-21%. This result can provide a certain theoretical reference for the energy-saving reconstruction of the existing residential houses in the Qinba Mountains.

1. Introduction
Most existing buildings in China's second and third-tier cities were built in the 1980s and 1990s. Due to the extensive production mode of the construction industry and the imperfection of relevant regulations, there are generally problems such as poor indoor thermal environment and low energy saving level. With the improvement of living standards, residents' requirements for indoor thermal environment are also increasing, and the building energy consumption is significantly increased[1]. In recent years, many domestic scholars have carried out a large number of research on energy-saving transformation of old buildings in cold regions and severe cold area[2,4], and have carried out large-scale transformation of existing buildings in the practical application process.

Shaanxi province lies across the Qinling mountains. Guanzhong and northern Shaanxi are cold areas to the north of the Qinling mountains, while southern Shaanxi is hot in summer and cold in winter to the south of the Qinling mountains. The cities covered include Hanzhong, Ankang and Shangluo. Hot summer and cold winter areas belong to non-heating areas, and conventional theory holds that they consume less energy in winter. According to the existing regulations[5], research on energy saving transformation mainly focuses on heat protection in summer. However, southern Shaanxi is close to Qinling mountains and adjacent to cold regions. Its indoor temperature is bleak,
cold and humid in winter, and its thermal comfort is poor. Relevant scholars have done little research on winter insulation in this region, let alone taking into account the difference with other regions with the same climate, and there is no corresponding measures suitable for local climate characteristics. In recent years, the desire of local residents for winter heating is getting higher and higher, and the energy consumption for heating is rising sharply. Therefore, it is very necessary to study the winter insulation structure of residential buildings in southern Shaanxi. Here, the old residential buildings in Hanzhong are taken as the research object and tested and investigated.

2. Status quo and analysis of indoor thermal environment

2.1. Thermal parameters of the tested house

The test house is a six-story brick and concrete building built in the 1990s in downtown Hanzhong. The test house selects the standard floor house with the largest proportion of the whole building, the family model is two rooms, two halls, one kitchen and one bathroom, the bedroom is in the south, the kitchen and the dining room are in the north, the height is 2.6 meters. The walls of the house are 240mm thick clay bricks with no insulation layer. The window is ordinary single layer glass, aluminum alloy window frame. The roof is non-accessible. The layout diagram of measuring points is shown in figure 1. The thermal parameters of the peripheral protective structure[6] are shown in table 1.

| Retaining structure | Contexture                                                                 | Heat transfer coefficient/(W·(m²·K)⁻¹) | Heat transfer coefficient required by code/(W·(m²·K)⁻¹) |
|---------------------|---------------------------------------------------------------------------|----------------------------------------|--------------------------------------------------------|
| Exterior wall        | 240mm thick core clay brick, 20mm thick cement mortar surface inside and outside | 2.04                                   | 1.5 (D>2.5)                                            |
| The roof             | 40mm fine stone concrete, waterproof layer, 20mm cement mortar, 100mm thick floor | 3.91                                   | 0.8 (D≤2.5)                                            |
| Exterior window      | Single glass aluminum alloy push and pull outer window, 6mm thick ordinary glass | 6.40                                   | 2.5 (0.45<Window wall area ratio≤0.60)                 |
| Floor                | Prefabricated round hole plate 120mm+ cement mortar 20mm                   | 2.85                                   | 2.0                                                    |

2.2. Analysis of thermal environment in winter

2.2.1. Solar radiation intensity. The test results of solar radiation are shown in figure 2. According to the figure, the maximum value of the total solar radiation on the test day is 488.7W/m², and the maximum value of the scattered radiation is 168.3W/m². Local solar energy resources in winter are not
2.2.2. Indoor and outdoor air temperature. The test results of outdoor air temperature and bedroom air temperature are shown in figure 3. According to the figure, the maximum outdoor air temperature is 14.8 °C, the minimum is 4.1 °C, the temperature difference is 10.7 °C, and the average temperature is 7.7 °C. The temperature fluctuation range of bedroom 1 is 1.4 °C, and the average temperature is 9.5 °C. The temperature fluctuation range of bedroom 2 was 2.1 °C, and the average temperature was 9.5 °C. The test results showed that the indoor temperature was generally low, but the temperature fluctuation was small. The temperature fluctuation of bedroom 2 was slightly larger than that of bedroom 1. This is because the indoor heat gain of each room mainly depends on the passive heat collection of the south window, and the indoor temperature is significantly affected by the fluctuation of outdoor air temperature and the change of solar radiation intensity. The balcony, as the transition area between bedroom 1 and the outdoor, can effectively help the bedroom keep warm. The lowest temperature of the three measurement points all appeared at 8:00 am, which was because the local solar radiation increased significantly from 10:00 am.

![Figure 2 Solar radiation test results](image1)

![Figure 3 Outdoor, bedroom air temperature](image2)

2.3. Analysis of summer thermal environment

2.3.1. Solar radiation intensity. The solar radiation test results are shown in figure 4. According to the figure, the maximum value of the total solar radiation on the test day is 835.3 W/m², and the maximum value of the scattered radiation is 119.5 W/m². The heat mainly comes from direct sunlight, and the scattered radiation has little influence on the air temperature.

2.3.2. Indoor and outdoor air temperature. The test results of outdoor air temperature and bedroom air temperature are shown in figure 5. As can be seen from the figure, the maximum outdoor air temperature is 39 °C, the minimum is 27.6 °C, the temperature difference is 11.4 °C, and the average temperature is 32.5 °C. Bedroom 1 has a temperature fluctuation range of 0.8 °C and an average temperature of 29.2 °C, while bedroom 2 has a temperature fluctuation range of 1.6 °C and an average temperature of 29.7 °C. The temperature difference in bedroom 1 is less than that in bedroom 2, so the transition zone can also help with insulation. It can be seen from the data in the figure that Hanzhong is hot and stuffy in summer with high indoor temperature and small temperature difference, which needs to be improved to reach the expected temperature of residents.
2.4. analysis of research results

In December 2017 and July 2018, the research team conducted field research on dozens of old residential areas in Hanzhong. The analysis of winter and summer results is shown in table 2 and table 3. Through the statistical analysis of the investigation results, it is found that the indoor thermal environment is poor in winter. The investigated residents need to rely on air conditioners, electric heating, stoves and other auxiliary heating and dehumidification. A large number of households choose full-time heating, only a few households home temperature reached 18 °C. Satisfaction with indoor thermal environment is generally lower than that of central heating cities in northern China. Among them, 60% residents are willing to renovate their houses and expect the indoor temperature to be improved. However, in hot and humid summer, the indoor temperature is generally higher than 30°C, so air conditioners and electric fans are needed to reduce the temperature. It not only consumes a lot of energy, but also pollutes the local environment. Only 22% of the households surveyed thought their indoor thermal environment was at a comfortable level.

| Table 2 Analysis of winter survey results |
|------------------------------------------|
| **Summary of winter research results (%)** |  |
| heating system | System/Room | The | Expected indoor | Renovation attitude |
| Air conditioner | 24 | 5°C-10°C | 43 | 10°C-15°C | 22 |
| Electric warming | 46 | 11°C-15°C | 43 | 16°C-20°C | 67 |
| Stove | 30 | 16°C-20°C | 14 | 21°C-25°C | 11 |
| All day | 43 | Comfort | 15 | Willing to | 60 |
| Daytime | 33 | Discomfort | 16 | Reluctant | 17 |
| Hand cranking | 23 | General | 69 | Indifferent | 23 |
| Night | 24 | Stove | 16 | 21°C-25°C | 11 |

| Table 3 Analysis of summer survey results |
|------------------------------------------|
| **Summary of summer research results (%)** |  |
| Cooling method | System/Room | Feeling of indoor thermal environment | Discomfort | Expected indoor temperature | Renovation attitude |
| Air conditioner | 60 | General | 43 | 16°C-20°C | 0 |
| Fan | 18 | Comfort | 22 | 21°C-24°C | 13 |
| Hand cranking | 23 | Willing to | 11 | 25°C-28°C | 79 |
| Others | 0 | Reluctant | 3 | 29°C-32°C | 7 |
| Above30°C | 48 | Indifferent | 79 | 21°C-25°C | 0 |

Therefore, it is an urgent problem for local residents to improve the indoor thermal environment and put forward the reconstruction plan of existing houses to adapt to the local environment.
3. Model establishment and enclosure structure design

3.1. Model building

Based on the actual envelope data, the original model was established in DesignBuilder software and simplified into three layers, as shown in figure 6. The simulation results of the original model and the actual test results have some errors, but within a reasonable range.

3.2. Enclosure structure design

It can be seen from the test results that the indoor temperature in hot summer and cold winter areas is relatively cold, and the building insulation is needed as well as auxiliary heating equipment. When the building envelope has good thermal performance, the energy consumption of equipment required to maintain the indoor thermal environment will be reduced. The renovation of the old house in the process of use needs to be carried out under the condition of basically not affecting the life of the residents, and should not occupy the indoor usable area as far as possible.

3.2.1. Exterior wall. The existing exterior wall is 240mm thick core clay brick, without insulation layer, and coated with cement mortar. In order not to affect the normal life of the residents, the use of external insulation practices for external insulation renovation. Among the common thermal insulation materials in China, inorganic materials include rock wool, glass wool, inorganic light aggregate thermal insulation mortar, organic materials include cork, rice husks, and various new thermal insulation materials of foam plastics include polystyrene foam particles, EPS, XPS, rigid foam polyurethane, etc. EPS insulation board is adopted here[10], with the thickness of 20 mm, 30 mm, 40 mm, 50 mm, 60 mm, 70 mm, 80 mm, 90 mm and 100 mm respectively. A total of 9 conditions, the analysis of the optimal thickness.

3.2.2. External window. The existing outer window is 6 mm thick ordinary single layer glass, aluminum alloy push-pull window. Due to the large gap air permeability and large heat transfer coefficient of glass, window frame, etc., the solar radiation of the outer window can effectively increase the indoor temperature in winter, but its heat transfer loss and cold air permeability loss will lead to the decrease of the indoor temperature, thus leading to the reduction of the thermal insulation performance of the window. Considering the economic factors and practical effects, plastic steel hollow glass Windows (6+13A+6) and hot-break aluminum alloy ordinary hollow glass windows (6+13A+6) were selected for the outer Windows[11].

3.2.3 Roof. The existing roof is reinforced concrete slab with no insulation structure and is hung with clay walls for drainage. Slope roof has good thermal insulation performance. It forms a good layer of air insulation to avoid direct sunlight. It has good insulation performance in summer, but little effect in winter. Therefore, it is necessary to set up insulation layer to increase its thermal insulation function in winter. Insulation layer material selection EPS insulation board[12]. The thickness was taken as 30mm, 40mm, 50mm, 60mm and 70mm respectively. The optimal thickness was analyzed under 5 working conditions.

3.3. Analysis of simulation results

3.3.1. Analysis of exterior wall. By changing the thickness of the insulation layer of the external wall, the simulation results are shown in figure 7 and figure 8. As can be seen from the figure, adding insulation layer can effectively increase indoor air temperature in winter. However, too thick insulation...
board will lead to temperature rise in summer, so it is advisable to choose EPS insulation board with a thickness of 30 mm.

3.3.2. Analysis of exterior window: By simulating the exterior window under two working conditions, the obtained results are shown in figure 9 and figure 10. As can be seen from the figure, only changing the exterior window has a relatively small impact on the indoor temperature in winter. The temperature of the two bedrooms using the ordinary heat-broken aluminum alloy hollow glass Windows (6+13A+6) was increased by 0.1-0.2 °C compared with the original model, while that of the two bedrooms using the plastic steel hollow glass Windows (6+13A+6) was increased by 0.2-0.3 °C. Because the shading is not considered, the two exterior window reconstruction schemes have no effect on the indoor temperature in summer. Therefore, plastic steel hollow glass windows (6+13A+6) were selected for comprehensive transformation.

3.3.3. Analysis of roof: The simulation results of changing the thickness of roof insulation layer are shown in figure 11 and figure 12. The addition of insulation layer on the roof can improve the indoor thermal environment to some extent. However, with the increase of thickness, the effect of temperature change is not obvious. The indoor temperature increases slightly in winter and decreases slightly in summer. Considering the change of indoor temperature in winter and summer, the thickness of roof insulation layer in the comprehensive transformation is selected as 50 mm.
3.4. Analysis of comprehensive transformation

To sum up, the comprehensive transformation measures include adding 30mm EPS insulation board to the exterior wall, 50mm EPS insulation board to the roof, and replacing the exterior window with plastic steel hollow glass window (6+13A+6). The simulation results are shown in figure 13 and figure 14. The results showed that the temperature of bedroom 1 was increased by 1.5 °C in winter, and that of bedroom 2 was increased by 1.3 °C, with obvious improvement effect. Indoor air temperature rises slightly in summer. Compared with before modification, it was increased by 0.1 °C -0.2 °C.

4. Conclusions

(1) Local solar radiation lasts about 7 hours a day. The original building envelope has poor thermal performance, and the indoor temperature is greatly affected by solar radiation and outdoor temperature.

(2) Adding insulation layer in the envelope can effectively improve the thermal insulation performance, improve the indoor thermal environment and enhance the indoor thermal comfort. The comprehensive transformation plan is to add 30mm insulation layer on the exterior wall, 50mm insulation layer on the roof and plastic steel hollow glass window (6+13A+6) for the exterior window.

(3) Compared with the original model, the indoor thermal environment of the model after comprehensive transformation is improved. In winter, the indoor temperature increases by 1°C to 2°C, which is 11% to 21% higher than that of the original model.

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