Effect of Enclosed Balcony on Indoor Thermal Environment of Rural Buildings in Qinba Mountain Area

Yiyun Zhu*, Yanyan Qiu and Xiaoling Cui
School of Civil and Architectural Engineering, Xi’an University of Technology, Xi’an, China

*Corresponding author

Abstract. Qinba mountainous area, located in hot summer and cold winter areas, has special climatic conditions. Preliminary tests found that the balcony has a positive effect on improving the indoor thermal environment. The rural dwellings of Huguangying in Hanzhong were selected as the research object, and DesignBuilder was used to analyze the influence of balcony depth, shading measures and thermal parameters of transparent envelopment structure on the indoor thermal environment by adding enclosed balconies. The simulation results show that the average heat gain of the optimized balcony increased by about 4.6% in winter and decreased by about 7.3% in summer, among which, the temperature of the southward bedroom increased by about 2.0℃ in winter, the temperature of the southward bedroom decreased by about 3.0℃ in summer during the day and the temperature at night increased slightly. The results fully illustrate the thermal insulation effect of closed balcony and its applicability to improve indoor thermal environment in Qinba Mountain.

1. Introduction
Hot summer and cold winter are densely populated and economically developed, with hot summer and cold winter, small temperature difference between day and night, and high perennial humidity. Qinba Mountain area is located in the Qinling and Bashan area in the upper reaches of Hanshui river. Its climate zone is located in the north of the hot summer and cold winter area, close to the cold area. Special geographical position and terrain conditions lead to more typical and changeable climate characteristics in this area. Under this special climate environment, the rural buildings in Qinba Mountain area are still generally poor in indoor living environment due to simple envelope structure and single layout form[1-2]. In order to respond to China's policies of promoting the construction of new countryside, it has become an urgent problem to improve the rural living environment according to local conditions. Preliminary investigation and test results of rural buildings in Qinba Mountains show that in the process of renewal and development of building forms, the enclosed balconies added by residents in the southern direction of the second floor play a positive role in improving the indoor thermal environment[3]. In terms of thermal design, regions with hot summer and cold winter should take into account both winter insulation and summer heat protection[3]. At present, in the study of the indoor thermal environment of rural buildings, most scholars mainly study the heat transfer and thermal performance of the envelope under dynamic thermal disturbance[1, 4-7], passive ventilation technology[8-9] and other aspects. There are few studies on the influence of balconies on the indoor thermal environment. Since the balcony plays an important role in the use function and spatial layout, and it has a direct impact on the room's heat gain and natural ventilation effect[10], therefore, a typical rural building in Huguangying village, Hanzhong, was selected to reasonably design the balcony with DesignBuilder and analyze its influence.
on the indoor temperature. The research results can provide theoretical reference for energy saving design of new-type rural buildings in Qinba Mountains and exploration of heating and heat protection system suitable for the climate characteristics of Qinba Mountains.

2. Test Data Analysis

In January and July 2017, we used TESTO 175-H2 self-recording thermobytrometer, HIOKI multi-channel temperature and heat flow tester and JTDL-4 solar radiation meter to collect data on the indoor thermal environment of a house in Hanzhong Huguangying village with no closed balcony. The floor plan and test results are shown in figure 1 to figure 3.

![Figure 1. Floor plan of typical dwellings.](image)

![Figure 2. Variation of indoor temperature and humidity in typical dwellings.](image)

![Figure 3. Variation of outdoor solar radiation intensity.](image)

*Note: Sitting room 1 means sitting room on the first floor, bedroom 2 means bedroom on the second floor, the rest are the same.

Due to residents' different living habits and changes in the ambient temperature at night, residents mainly burn stoves for heating at night. According to the data, although the living room on the first floor has a higher temperature at night, the temperature difference between the north and the south is large, about 2.2°C, and the temperature drops rapidly in the early morning. The test results in summer show that the indoor temperature fluctuation is greatly affected by the outdoor temperature variation in dwellings without balconies under natural ventilation conditions. Combined with the test results of the second floor rooms in winter, the indoor thermal environment of the second floor rooms is poor in winter and summer.

According to the National Solar Radiation Zoning Data Sheet, the solar energy resource in Qinba Mountains is the fourth region. And the solar radiation test results show that the sunshine duration in this region is relatively long, about 10 hours, and the solar radiation intensity in winter is relatively low, but there is still a certain utilization space in building heating[11-14]. The solar radiation intensity in summer is high, so certain shading measures should be taken.

In January and August 2014, we respectively collected data on a dwelling with closed balconies to the south in Caotang village, Xuwang town, Hanzhong. The test results show that, the balcony plays a certain role in heat insulation, in summer daytime. And night temperature is higher, therefore, night ventilation should be strengthened in summer to reduce the bedroom temperature at night. In winter daytime, the balcony as a heat collection space, effectively improve the temperature of the south
bedroom. And the insulation role of the balcony to ensure that the bedroom temperature at night did not plunge, thus improving the comfort level at night in winter. In general, the closed balcony as a transition space, although its temperature fluctuations larger, but it has a certain thermal insulation effect, effectively ensure the stability of indoor temperature, to improve the indoor thermal environment has a positive role.

3. Build Physical Models

3.1. Validation of the Model

According to the residential floor plan, the original residential building model was established with Design Builder. In addition, the simulation results are compared with the measured data to verify the correctness of the structural model. Considering the influence of the first-floor heating measures on the indoor temperature and humidity in winter, the data of the first-floor rooms in winter are not used. Due to the great influence of solar radiation on the southward room in summer, the indoor temperature of the southward room was mainly concerned during the model verification. Data comparison is shown in figure 6.

3.2. Determine the Balcony Size

Based on the original building model, closed balconies were added in the south direction with a depth of 0.9m, 1.2m, 1.5m and 1.8m respectively and the glass was a single-layer glass. The optimized building model is shown in figure 7. Under different depths, the temperature changes of balcony and bedroom on the first floor in winter and summer are shown in figure 8 and figure 9 respectively.
By comparing the temperature of the balcony, it can be concluded that the balcony with a depth of 0.9m has higher temperatures in winter and summer, but from the perspective of functional use, in order to have enough comfortable living space, the balcony depth should be greater than 0.9m. And in the winter as the depth of the balcony increases, the temperature of the balcony shows a downward trend, so the depth of the balcony should not be too large. In addition, the temperature changes in the bedroom in winter and summer show that in the winter, the effects of the four different depth balconies have similar effects on the indoor temperature, but in the summer, the 1.2 m wide balcony has a certain effect on reducing the indoor night temperature. Based on the above analysis, it is determined that the suitable balcony depth range is 1.2m~1.5m. In this study, the balcony with a depth of 1.2m is selected for analysis and research.

3.3. Shading Design

Since the solar radiation intensity is high in summer, a sun visor is added outside the balcony to reduce the influence of solar radiation on the indoor thermal environment. The angle and length of the sun visor are set according to the solar height angle, and the maximum solar height angle of each month is shown in figure 10. In order to not only effectively block the sunlight in summer but also ensure the heat collection of the balcony in winter, the sun visor is designed with a sun angle of 70°. The closed balcony section is shown in figure 11.
4. Standard Solar Heat Gain (SSG)

The outer window of the enclosed balcony, as a transparent envelope structure, accounts for a large proportion of the total area of the outer protective structure, reaching more than 70%. Therefore, the outer window in the balcony becomes the main component of the indoor room to get hot and lose heat, and has a great influence on the indoor thermal environment. Therefore, double glazing is used instead of single glazing, and its influence on indoor thermal environment is concerned. SSG can directly reflect the heat gain from the solar radiation through the transparent enclosure. The sun path diagram in DesignBuilder in January shows that the sunshine directly into the bedroom at 10:00-15:00 in winter. Therefore, the period of 10:00-15:00 is selected to calculate the SSG of the balcony corridor through the transparent enclosure in winter and summer, and to compare with the indoor heat gain of the original building.

The SSG of the transparent envelope is

\[
SSG = \left( I_{Di} \tau_{Di} + I_d \tau_d \right) + \frac{R_e}{R_e+R_i} \left( I_{Di} \alpha_{Di} + I_d \alpha_d \right)
\]

Where:
- \( \tau_{Di} \): transmittance of glass to direct solar radiation at an incident angle of \( i \);
- \( \tau_d \): transmittance of glass to scattered solar radiation;
- \( \alpha_{Di} \): absorption rate of glass to direct solar radiation with incident angle \( i \);
- \( \alpha_d \): absorption rate of glass to solar scatter radiation;
- \( I_{Di} \): direct radiation intensity of the sun hitting the surface of the glass, the angle of incidence is \( i \), W/m²;
- \( I_d \): Solar scatter radiation intensity incident on the glass surface;
- \( R_e \): Heat transfer resistance of the outer surface of the glass;
- \( R_i \): Heat transfer resistance of the inner surface of the glass.

\( R_e \) and \( R_i \) take 0.04 (m²·K)/W and 0.11 (m²·K)/W[15] respectively according to the surface characteristics in the heat transfer resistance of the inner and outer surfaces.

4.1. The Transmittance and Absorption Rate of Glass

The transmittance and absorption rate of glass are related to the incident angle \( i \) of the sun, for vertical walls:

\[
\cos i = \cos h \cdot \cos \varepsilon
\]

The solar altitude angle “\( h \)” and the solar azimuth angle “\( \varepsilon \)” of the wall on January 15 and July 27 at 10:00-15:00 in Hanzhong were found in the meteorological database[16].

The total transmittance and total absorption rate of double-layer glass (3mm thick on both sides and 6mm inter air layer) are calculated by the following equation:

\[
\tau_0 = \frac{\tau_1 \tau_2}{1-\rho_1 \rho_2}
\]

\[
\alpha_0 = \alpha_{c1} + \alpha_{c2} = \alpha_1 \left( 1 + \frac{\tau_1 \rho_2}{1-\rho_1 \rho_2} \right) + \alpha_2 \frac{\alpha_1 \alpha_2}{1-\rho_1 \rho_2}
\]
Where: $\tau_1, \tau_2$ is transmittance of 3mm ordinary glass; $\rho_1, \rho_2$ is reflectivity; $\alpha_1, \alpha_2$ is the absorption rate. Refer to the value of the above three parameters of 3mm ordinary glass at different incident angles in "Building Thermal Process", and use interpolation method to calculate the value. The results are shown in the following table.

**Table 1. Transmittance and absorption rate of double glass.**

|       | time       | $h/°$ | $\varepsilon/°$ | $i/°$ | transmittance | reflectivity | absorption rate | transmittance | absorption rate |
|-------|------------|-------|-----------------|-------|---------------|--------------|----------------|---------------|----------------|
|       | January    |       |                 |       |               |              |                |               |                |
|       | 10:00      | 20    | 38.82          | 42.84 | 0.77          | 0.09         | 0.14           | 0.59          | 0.92           |
|       | 11:00      | 25.63 | 37.24          | 0.78  | 0.08          | 0.14         | 0.61           | 0.93          |
|       | 12:00      | 10.22 | 34.37          | 0.78  | 0.08          | 0.13         | 0.62           | 0.93          |
|       | 13:00      | 35    | 6.62           | 0.78  | 0.08          | 0.13         | 0.61           | 0.93          |
|       | 14:00      | 34    | 23.55          | 0.77  | 0.08          | 0.14         | 0.60           | 0.92          |
|       | 15:00      | 28    | 38.16          | 0.76  | 0.09          | 0.14         | 0.58           | 0.91          |
|       | July       |       |                 |       |               |              |                |               |                |
|       | 10:00      | 48    | 30.03          | 54.60 | 0.73          | 0.11         | 0.15           | 0.53          | 0.88           |
|       | 11:00      | 10.88 | 60.60          | 0.70  | 0.13          | 0.15         | 0.49           | 0.85          |
|       | 12:00      | 26.44 | 72.20          | 0.63  | 0.18          | 0.16         | 0.41           | 0.78          |
|       | 13:00      | 75    | 19.7           | 0.60  | 0.20          | 0.16         | 0.38           | 0.75          |
|       | 14:00      | 70    | 48.48          | 0.60  | 0.21          | 0.16         | 0.37           | 0.74          |
|       | 15:00      | 59    | 70.37          | 0.57  | 0.23          | 0.16         | 0.34           | 0.72          |

*a Note: underlined numbers represent negative numbers.*

4.2. Solar Radiation Intensity.

1. Direct solar radiation intensity

The direct solar radiation intensity of vertical plane $I_{DV}$

$$I_{DV} = I_{DN} \cos h \cos \varepsilon$$

(5)

Where: $I_{DN}$ is the normal solar radiation intensity.

2. Scattering solar radiation intensity

The solar scattered radiation on the surface of building envelope includes three parts: sky scattered radiation, ground reflected radiation and atmospheric long-wave radiation.

(1) Vertical sky scattering radiation $I_{dv}$

$$I_{dv} = \frac{1}{2} I_{dh}$$

(6)

Where: $I_{dh}$ is the solar scattering intensity in the vertical plane.

(2) The radiation intensity of the ground reflection on the vertical wall $I_{RV}$

$$I_{RV} = \frac{1}{2} \rho_G I_{SH}$$

(7)

Where: $I_{SH}$ is the total solar radiation intensity received by the horizontal plane, $I_{SH} = I_{DH} + I_{dH}, \rho_G$ is the average reflectivity of the ground, the value is 0.2.

(3) Atmospheric long-wave radiation $I_B$

$$I_B = C_b \left( \frac{T_e}{100} \right)^4 \varphi$$

(8)

Where: $C_b$ is the radiation constant of the black body, the value is 5.67W/m$^2$·K$^4$, for the vertical wall, $\varphi$ is 0.5, and $T_e$ is the sky equivalent temperature.

Substituting the above calculation results into equation (1), the heat gain of the balcony air on January 15 and July 27, and the heat gain of the original building indoor air through the single-layer glass are obtained, and the result is shown in figure 13. It can be seen that the heat of the air in the balcony in winter is about 5% higher than that of the original building. In the summer, due to the sun visor blocking the direct sunlight, the heat gain of the balcony is about 10% lower than that of the original building.
south. Based on the above results, increasing the absorption rate of glass and reducing its transmittance are conducive to improving the thermal insulation performance of the balcony. In addition, shading measures in summer also play an important role in reducing the indoor temperature.

Figure 13. Comparison of SSG results before and after optimization.

5. Simulation Results and Analysis
By comparing the temperature of each room before and after optimization (figure 14), it can be found that the indoor temperature fluctuates steadily after adding a balcony. The closed balcony has a significant effect on the indoor temperature increase in winter. The average temperature of the southward room is about 2.0°C higher than the original simulation result, and the temperature at night is about 3.2°C higher, so the comfort level at night is significantly improved. However, the room layout is not conducive to the even distribution of temperature and there are many components of heat loss in the north direction, resulting in a low temperature in the north direction and a large temperature difference between the north and the south. In summer, the maximum temperature of the south-facing bedroom in daytime is about 3.1°C lower than that of the original building. The temperature at night is basically unchanged, but the temperature at night increases after optimization of the north-facing living room. Therefore, night ventilation should be strengthened in summer to reduce night temperature.

In addition, the balcony air layer has a certain delay effect on the fluctuation of bedroom temperature. The original building indoor temperature reaches the peak at about 17:00, while the optimized bedroom temperature reaches the peak at about 19:00. At the same time, the air layer also has a certain role of heat preservation and insulation, which ensures that the indoor temperature does not plummet after night in winter, and the indoor temperature increases less during the period of maximum solar radiation in summer. Overall, the heating way that increases enclosed balcony is applicable in this area and the effect is relatively apparent.

Figure 14. Comparison of indoor temperature before and after optimization.

6. Conclusion
1. Reasonable depth of the balcony is the prerequisite for effective performance of thermal insulation. Comparing and analyzing the temperature changes of the balcony in different depths in winter and
summer and its influence on the temperature of the adjacent bedroom, and from the perspective of the use function, it is finally determined that the reasonable depth of the enclosed balcony is 1.2m~1.5m.

2. In the Qinba Mountain area, the solar radiation is high in summer, and certain shading measures should be taken. Based on the local sunshine conditions, combined with the change of the sun's height angle, the balcony is designed with external sunshade to determine the visor angle of 20° and the length of the board is 1m, which can effectively shield the sun in summer without affecting the winter heat collecting effect.

3. The thermal parameters of the transparent envelope have a great influence on the indoor thermal environment. On the basis of shading, the sunlight absorption rate of the outer window is increased and the transmittance is decreased, so that the heat gain of the balcony in winter is increased by about 5% compared with the original building, the average temperature of the south bedroom is increased by about 2.0°C, and the temperature at night is increased by about 3.2°C. The heat gain of the summer balcony is about 7.3% lower than that of the original building. The maximum temperature in the south bedroom is reduced by about 3.0°C.

4. The analysis of indoor temperature in summer found that the temperature in the living room increased slightly due to the diffusion of high-temperature air during the day and the radiant heat transfer and convective heat transfer of the envelop. Therefore, indoor ventilation should be strengthened at night to improve the overall comfort of the room.

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