

# Thermal Performance and Energy-Saving Construction for Rural Architecture in Qinba Mountain Areas

Yiyun Zhu<sup>1</sup>, Jingzhu Zhao<sup>1,\*</sup>, Guochen Sang<sup>1</sup>, Qin Zhao<sup>1</sup> and Qun Zhang<sup>2</sup>

<sup>1</sup> School of Civil Engineering and Architecture, Xi'an University of Technology, Xi'an, Shaanxi, PR China

<sup>2</sup> School of Architecture, Xi'an University of Architecture & Technology, Xi'an, Shaanxi, PR China

\* Corresponding author

**Abstract**—The areas of Qinba Mountain locate between Qinling and Daba mountains, it's not hot in summer, but very clammy in winter. Focusing on the typical rural architecture, the paper analyzed the consumption of architecture heating affected by the parameters of heat transmission coefficient of envelope, also carried out optimal design for the architecture thermal performance. The results show that through the optimal design of envelope, the consumption value of heat transmission on the roof decreases from  $36.45\text{W/m}^2$  to  $6.29\text{W/m}^2$ , therefore, reduce the architecture heat consumption and improve the indoor thermal comfort of the rural architecture in winter in the region. The research method and conclusions in the paper can be used to guide the development of rural architecture in the region.

**Keywords**—Qinba mountain areas; rural architecture; heat consumption; energy saving construction; thermal performance analysis

## I. INTRODUCTION

The areas of Qinba Mountain locate between Qinling and Daba mountains, it is a region where the northwestern cold climate meet with the southern hot climate. The unique geographical position and hilly landscape create special climate characteristics such as it's not hot in summer but very clammy in winter [1]. Through the survey and measurement conducted in December of 2013 and January of 2014 on indoor thermal environment and architecture construction characteristics of rural dwellings in Hanzhong within Qinba Mountain areas, it has been found that the envelope of architecture is simple, the thermal performance is poor, it's very clammy in the rooms in winter and the thermal environment is a bit worse. If the solar energy can be well used through the reasonable architecture design to improve the quality of winter indoor thermal environment, it will surely play important roles in promoting the quality of winter indoor thermal environment, reducing energy consumption of heating, and protecting the environment for rural civilian dwellings in the areas of Qinba Mountain.

## II. THE CONSTRUCTION PARAMETERS OF THE TYPICAL ARCHITECTURAL INTRODUCTION

According to the in-situ survey and measurement data by the research team for the rural civilian dwellings in Hanzhong, the basic parameters of local and typical rural architecture are obtained. A typical layout of the rural dwelling is shown in Fig.

1 and parameters of architecture envelope are listed in Table 1. It can be seen that the construction of envelope for civilian dwellings in Hanzhong region is simple, the thermal performance is poor, which lead eventually to the present poor indoor thermal environment.

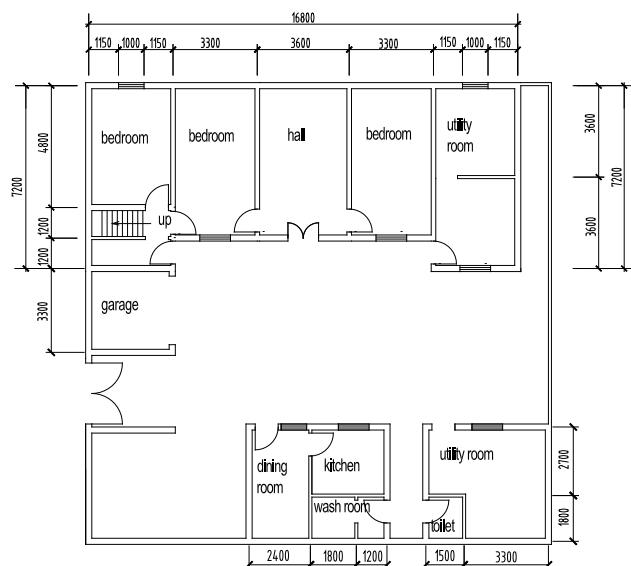


FIGURE I. THE LAYOUT OF TYPICAL RURAL DWELLING IN HANZHONG, SHAANXI PROVINCE

TABLE I. THE BASIC PARAMETERS OF ENVELOPE OF THE TYPICAL RURAL DWELLING IN HANZHONG, SHAANXI PROVINCE

Item	Construction method	Thickness (mm)	Coefficient of thermal conductivity (W/m·K)	Coefficient of heat transmission (W/m <sup>2</sup> ·K)	Area (m <sup>2</sup> )
Exterior wall	Mixed mortar plastering	20	0.93	2.04	S <sub>s</sub> : 42.72
	Solid clay brick	240	0.81		S <sub>E,W</sub> : 21.6
	Mixed mortar plastering	20	0.93		S <sub>N</sub> : 50.4

Continued

TABLE I. (CONTINUED)

Item	Construction method	Thickness (mm)	Coefficient of thermal conductivity (W/m·K)	Coefficient of heat transmission (W/m <sup>2</sup> ·K)	Area (m <sup>2</sup> )
Roof	Mixed mortar plastering	20	0.93	4.0	120.96
	Reinforced concrete	100	1.74		
	Mixed mortar plastering	20	0.93		
Window	Normal glass and wooden frame	Ration of window -wall towards the south	0.15	4.7	4.28

### III. STUDY OF THERMAL PERFORMANCE OF TYPICAL RURAL ARCHITECTURE

#### A. Determination of Calculating Parameters

##### a. Calculating Temperatures

Winter indoor calculating temperature for urban architecture in hot summer and cold winter areas should be 18°C in China[1]. The research team has found during survey and measurement that the peasants in Hanzhong mainly engage light physical labor in winter, they frequently come in and get out of the room, and wear a slightly thick outerwear while staying at home. There are some differences between urban residents and rural people in production and living styles, dressing habits, etc. Therefore, the winter indoor calculating temperature given by specifications is not suitable for rural architecture, which can not be regarded as indoor thermal environment index for rural architecture.

The subjective temperature refers to the satisfied temperature which is obtained through the change of activity amount and clothing combination when the air velocity is 0.1m/s, relative humidity is 50%. The subjective temperature that makes people feel comfortable can be calculated by certain and given thermal resistance value of clothing and metabolic rate. McIntyre [2] provided the calculation formula for indoor subjective temperature within allowable error range is:

$$t_{ob} = 33.5 - 3R_{clo} - (0.08 + 0.05R_{col}) \cdot M \quad (1)$$

of which,  $t_{ob}$  is subjective temperature(°C);  $M$  is metabolic rate of human body under different activity amount, (W/m<sup>2</sup>);  $R_{clo}$  is clothing thermal resistance (col), the following formulas can be used for calculations:

$$R_{cloM} = 0.113 + 0.727 \sum R_i \quad (2)$$

$$R_{cloF} = 0.05 + 0.727 \sum R_i \quad (3)$$

The metabolic rate of human body is about 100~120W/m<sup>2</sup>[3] when engaging light physical labor. With reference to survey materials on winter indoor thermal comfort level obtained by the research team in December of 2013 in Hanzhong, Shannxi province, considering the thickness of clothing and indoor activity amount in different age and gender, it can be obtained that the average value of metabolic rate  $M$  is 105W/m<sup>2</sup>, and the average value of clothing thermal resistance  $R_{clo}$  is 1.7col. Thus, the calculated value of winter indoor subjective temperature should be 11.1 °C for the rural residential architecture in Hanzhong region. However, referring to the differences between actual situation and supposed calculation condition, when indoor relative humidity is above 50%, the result will differ slightly, therefore, 12°C is regarded as indoor thermal comfort temperature.

In accordance with the *Typical Meteorological Database Handbook for Buildings*[4], the outdoor average temperature in December, January and February in Hanzhong region is 3.8°C, 3°C and 6.1°C respectively. It can be obtained from the design standard for energy saving of residential architecture in hot summer and cold winter areas, the heating period for residential architecture in Hanzhong region is from the first day of December to the 28<sup>th</sup> of February next year, the outdoor average temperature during heating period in Hanzhong is 4°C, this value can be regarded as outdoor calculation temperature.

##### b. Correction Coefficient of Envelope Heat Transmission Coefficient

Considering the factors such as solar radiation, sky radiation and absorption rate of envelope to solar radiation, the performance of envelope in different region and with different orientation differs greatly[5]. The correction coefficient of envelope heat transmission coefficient is adopted, it is a very important parameters in the process of thermal performance calculation for architecture. Using the calculation methods from references [6-8], the correction coefficient of envelope heat transmission coefficient in Hanzhong region is then calculated in the paper.

The effective heat transmission coefficient of envelope considers the heat loss caused by air temperature difference on the two sides of envelope, it also consider simultaneously heat gain caused by solar radiation and heat loss induced by sky radiation[8]. From envelope effective heat transmission coefficient formula:

$$K_{i,eff} = \varepsilon_i \cdot K_i \quad (4)$$

$$\text{Is } , \varepsilon_i = K_{i,eff} / K_i \quad (5)$$

According to reference[7], the calculation method for correction coefficient of the exterior wall heat transmission coefficient will be:

$$\varepsilon_w = 1 - T_{sol,eq} / (t_n - t_e) \quad (6)$$

$$T_{sol,eq} = \rho I / \alpha_e \quad (7)$$

of which,  $T_{sol,eq}$  is the equivalent temperature of solar radiation( $^{\circ}\text{C}$ );  $\rho$  is the absorption coefficient of solar radiation on external surface[9];  $I$  is the illuminance of solar radiation on vertical surface( $\text{W}/\text{m}^2$ );  $\alpha_e$  is the heat transfer coefficient of external surface( $\text{W}/\text{m}^2 \cdot \text{K}$ ). Through the calculation, the correction coefficients of heat transmission coefficient for several kinds of common wall surfaces in Hanzhong region are listed in Table 2.

TABLE II. CORRECTION COEFFICIENT OF HEAT TRANSMISSION COEFFICIENT

type	Lime-plastered wall	Cement-plastered wall	Red brick wall
Absorption coefficient	0.48	0.56	0.71
South	0.84	0.82	0.77
East	0.91	0.89	0.86
West	0.88	0.86	0.83
North	0.92	0.90	0.88

The calculation method for correction coefficient of the roof heat transmission coefficient is:

$$\varepsilon_r = 1 + (T_{s,eq} - T_{sol,eq}) / (t_i - t_e) \quad (8)$$

of which, the calculation for  $T_{sol,eq}$  is the same as in formula (7),  $T_{s,eq}$  is the equivalent temperature of sky radiation, which can be calculated according to the following formula[10]:

$$T_{s,eq} = \sqrt[4]{0.51 + 0.208\sqrt{e_a} \cdot T_a} \quad (9)$$

$e_a$  is vapor partial pressure in air ( $\text{kPa}$ );  $T_a$  is dry bulb temperature of outdoor air ( $^{\circ}\text{C}$ ). By calculation the equivalent temperature of sky radiation in Hanzhong is about  $3.64^{\circ}\text{C}$ . The correction coefficients of heat transmission coefficient for different kinds of roofs in Hanzhong are listed in Table3.

TABLE III. CORRECTION COEFFICIENTS OF HEAT TRANSMISSION COEFFICIENT FOR THE FLOOR

type	Gray tile roof	Red tile roof	Cement roof
Absorption coefficient	0.86	0.70	0.74
Correction coefficient	1.13	1.19	1.17

### B. Heat Consumption of Architecture

The calculation method for heat consumption of architecture is:

$$q_H = q_{HT} + q_{INF} - q_{IH} \quad (10)$$

$q_H$  refers to architecture heat consumption ( $\text{W}/\text{m}^2$ );

$q_{HT}$  refers to the capacity of heat transmission converting into unit building area within unit time and through envelope ( $\text{W}/\text{m}^2$ ); which includes the heat transmission capacity of opaque envelope and transparent envelope, that can be calculated according to the Equations (2), (3) and (4).

$q_{INF}$  refers to the heat consumption of structure air infiltration converting into unit building area and within unit time( $\text{W}/\text{m}^2$ );

$q_{IH}$  refers to the heat inside structure converting into unit building area and within unit time, the value  $4.3 \text{ W}/\text{m}^2$ [1] is adopted in hot summer and cold winter areas;

The capacity of heat transmission,  $q_{Hq}$ , converting into unit building area and within unit time, through opaque envelope (wall, roof and floor) can be calculated according to Equation 11:

$$q_{Hq} = \sum \varepsilon_{qi} K_{mqi} F_{qi} (t_n - t_e) / A_0 \quad (11)$$

where,  $t_n$ ,  $t_e$  are the indoor and outdoor calculating temperature ( $^{\circ}\text{C}$ ) respectively;  $K_{mqi}$  is heat transmission coefficient for envelope ( $\text{W}/\text{m}^2 \cdot \text{K}$ );  $\varepsilon_{qi}$  is the correction coefficient of heat transmission coefficient for wall and roof; in accordance with reference[11], the correction coefficient of ground-based heat transmission coefficient is  $0.36 \text{ W}/\text{m}^2 \cdot \text{K}$ ;  $F_{qi}$  is the area of envelope ( $\text{m}^2$ );  $A_0$  is the building area ( $\text{m}^2$ ).

The capacity of heat transmission  $q_{Hmc}$  converting into unit building area and within unit time, through exterior wall (window) is in accordance with the following formula:

$$q_{Hmc} = \sum q_{Hmc} / A_0 = \sum [K_{mci} F_{mci} (t_n - t_e) - I_{tyi} C_{mci} F_{mci}] / A_0 \quad (12)$$

$$C_{mci} = 0.87 \times 0.70 \times SC \quad (13)$$

where,  $K_{mci}$  is the heat transmission coefficient of window ( $\text{W}/\text{m}^2 \cdot \text{K}$ );  $F_{mci}$  is the area of window ( $\text{m}^2$ );  $I_{tyi}$  is the average solar radiant heat of outer surface of window (door)( $\text{W}/\text{m}^2$ );  $C_{mci}$  is the correction coefficient of solar radiation of window (door);  $SC$  is the overall shading coefficient of window; 0.87 is the solar radiation transmissivity of normal glass in 3mm thickness; 0.70 is the reduction coefficient.

$q_{INF}$ , the heat consumption of structure air infiltration converting into unit building area and within unit time can be calculated according to the following formula:

$$q_{INF} = (t_n - t_e) (C_p \cdot \rho \cdot N \cdot V) / A_0 \quad (14)$$

where,  $C_p$  is the specific heat capacity of air, the value  $0.28 \text{ Wh}/\text{kg} \cdot \text{K}$  is given;  $\rho$  is the air density ( $\text{kg}/\text{m}^3$ ), the value is given under condition of  $t_e$ ;  $N$  is ventilation rate, the value of  $1(1/\text{h})$ [1] is used for the rural residential architecture in hot summer and cold winter areas;  $V$  is ventilation volume( $\text{m}^3$ ), calculated from  $V=0.6V_0$ ,  $V_0$  is structure volume.

## IV. ANALYSIS OF ENERGY SAVING CONSTRUCTION FOR RURAL ARCHITECTURE

### A. Effect of Roof Heat Transmission Coefficient on Architecture Energy Consumption

From the analysis and calculated result, it can be found that the roof of the existing rural architecture has large heat transmission and consumption, which accounts for 64% of total architecture energy consumption. Reducing the heat transmission coefficient of roof is the main approach to decrease the heat consumption of roof. Two types of construction methods for the roof (with machine-made tile) of rural civilian dwelling are listed in Table 4, they are non-insulation roof and insulation roof. It can be obtained from Fig.

2 that the smaller the heat transmission coefficient is, the less the capacity of heat transmission and consumption. However, with the decrease of heat transmission coefficient, the gradient of roof heat consumption tends to be smaller. Compared with original roof ( $4.0 \text{ W/m}^2\text{·K}$ ), the heat transmission coefficient of the roof with non-insulation layer is smaller, and the heat

consumption of roof is decreased greatly. The insulation layer is added on to the roof, thus, when the heat transmission coefficient decreases to  $0.69 \text{ W/m}^2\text{·K}$ , the heat consumption can be decreased to  $6.53 \text{ W/m}^2$ . The insulation layer should be added to the roof for rural architecture[5], insulation roof with 40mm EPS should be adopted.

TABLE IV. THERMAL PERFORMANCE PARAMETERS AND ITS HEAT CONSUMPTION OF DIFFERENT ROOFS

Item	Construction method	Thickness s (mm)	Heat conduction coefficient (W/m <sup>2</sup> ·K)	Heat resistance (m <sup>2</sup> ·K/W)	Heat transmission coefficient (W/m <sup>2</sup> ·K)	Heat consumption of roof (W/m <sup>2</sup> )
Non-insulation layer roof	Cement tile	15	0.93	0.016	2.23	21.11
	Air layer	30	—	0.160		
	Cement mortar layer for lying tile	20	0.93	0.022		
	Cement mortar layer for leveling	20	0.93	0.022		
	Reinforced concrete	100	1.74	0.057		
	Mixed mortar plastering	20	0.93	0.022		
Insulation roof	Cement tile	15	0.93	0.016	1.16/0.90/0.75/0.69	10.98/8.25/7.10/6.53
	Air layer	30	—	0.160		
	Cement mortar layer for lying tile	20	0.93	0.022		
	Insulation board EPS	10/20/30/40	0.041	0.244/0.488/0.732/0.976		
	Cement mortar layer for leveling	20	0.93	0.022		
	Reinforced concrete	100	1.74	0.057		
	Ceiling air layer	200	—	0.170		
	Mixed mortar plastering	20	0.93	0.022		

Note: ① the thickness value of ceiling air layer is the converted value.

② the correction coefficient of heat conduction coefficient for insulation board EPS is 1.1.

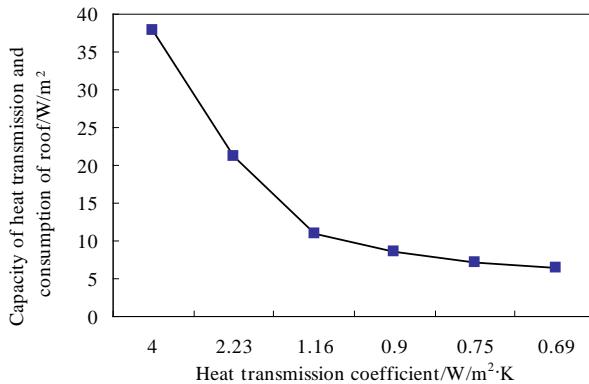


FIGURE II. THE HEAT TRANSMISSION COEFFICIENT AND THE CAPACITY OF HEAT TRANSMISSION AND CONSUMPTION OF ROOF

### B. Optimization for Thermal Performance of Architecture Construction

It can be found from the *Design Standard for Energy Efficiency of Residential Buildings in Hot summer and Cold Winter Zones*, the heating period for residential architecture in Hanzhong region is from the first of December to the 28<sup>th</sup> of February of following year, however, there is no fixed heating period for rural architecture, the heating is generally switched on intermittently, the thermal performance of architectural

envelope has obvious effect on the comfort level of indoor thermal environment. For the improvement of energy saving on roof of Hanzhong typical architecture model, insulated roof of 40mm EPS are recommended. The heat consumption is then calculated, the results are shown in Fig. 3.

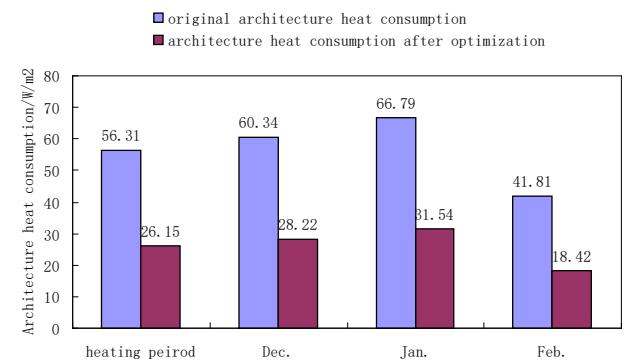


FIGURE III. COMPARISON OF HEAT CONSUMPTION BEFORE AND AFTER IMPROVEMENT

### V. CONCLUSIONS

The subjective temperature  $12^\circ\text{C}$  is regarded as the indoor calculation temperature for local rural dwelling in this paper. Through the calculation on heat consumption of a typical architecture model in Hanzhong, the results showed that the

architecture thermal performance of the local rural dwelling is poor, the architecture heat consumption is quite large.

The existing construction of roof is simple, the heat transmission coefficient is large, and the heat transmission and consumption in heating period accounts for 65% of total heat consumption. With the optimal design for architecture envelope, the heat transmission and consumption of roof in heating period is reduced by  $30.16\text{W/m}^2$ , Comparing with the original architecture, the optimized architecture heat consumption is reduced by 54%.

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