Experimental study on Reconstruction of rural Building Envelope in Hebei

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ABSTRACT: Taking rural buildings in Hebei as an example, the reconstruction experiment was carried out. After a survey on the status quo of buildings in rural areas of Hebei province, it is found that the thermal performance of the envelope structure is poor. Then, an experimental model is established by using DeST software, and relevant parameters are calculated to simulate the contribution rate of energy conservation. It is concluded that the envelope material with superior thermal insulation performance is conducive to promoting the development of rural low-carbon buildings in Hebei Province. According to the above conclusions, the simulation experiment of the rural building envelope is carried out, the method of comparison experiment is used to calculate the relevant parameters, and the thermal performance coefficient of the reconstructed envelope structure is compared with that of the traditional building. It is concluded that the reconstructed building is more in line with the local building energy saving standards, with higher energy saving, and more suitable for extensive application in the rural building renovation.

1. INTRODUCTION

According to relevant research reports, in 2018, the rural per capita building area of 47.3 square meters, rural building construction energy consumption and the related total carbon emissions are respectively 0.27.8 million t standard coal and 252 million tCO2, rural building operation energy consumption is 216 million tons of standard coal, the related total carbon emissions are 480 million tCO2, it can be seen that, The problems of energy saving and environmental protection of buildings in rural areas need to be further solved.

Based on the investigation and analysis of rural buildings in Hebei, this paper found the shortcomings of building envelope structure in energy saving and low carbon. First, the DeST energy consumption simulation software was used to establish a model to calculate the contribution rate of energy saving of the roof and external wall under the specific solar radiation absorption coefficient and heat transfer coefficient, so as to carry out simulation verification analysis. Combined with the analysis theory, the renovation design of the envelope structure was studied, and two experimental buildings A and B were established to conduct the experimental comparison of the envelope structure. The experimental results were used to verify whether the renovated building envelope has energy-saving properties, so as to provide relevant experimental reference for the rural low-carbon building renovation design in Hebei.

2. ANALYSIS ON THE PRESENT SITUATION OF RURAL ARCHITECTURE IN HEBEI

The distribution of rural areas in Hebei is dense and uniform. Villages and towns are relatively far from urban areas, and there are abundant renewable resources around villages and towns. In rural housing construction, due to economic and technical restrictions, the envelope structure of old rural buildings can meet the building energy conservation design standards of very few houses [7].

Through the investigation and analysis of the rural areas in this region, it is found that the existing buildings in rural areas are mostly self-built by farmers, and the thermal performance of the original building envelope materials is poor, which will lead to the increase of villagers' demand for other heating resources, resulting in excessive energy consumption in rural areas, which is not conducive to the efficient construction of ecological rural areas in the long run.

3. ANALYSIS OF SIMULATION EXPERIMENTAL DATA OF ENVELOPE STRUCTURE

This paper uses DeST software to model the traditional buildings in rural areas of Hebei province and lists the thermal parameters of their enclosures, and makes a simulation analysis of their energy conservation.

First of all, the use of spectral method, the simulation

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of the building's exterior wall, roof, solar radiation absorption coefficient measurement, the use of spectrophotometer with integrating ball accessories can accurately measure the material in each wavelength of the reflection ratio, the radiation illuminance of the sunlight at each wavelength for the weight coefficient calculation average, can obtain the total reflection ratio, Then, the solar radiation absorption coefficient is calculated according to the formula $\alpha_s = 1 - \rho_s$ (ρ_s is the solar reflection ratio, α_s is the solar radiation absorption coefficient). First, the baseline scan is carried out with the reference whiteboard, and then at the test point, when the wavelength is λ_i, the spectral reflection ratio relative to the standard whiteboard can be expressed as:

$$\rho_s = \frac{\sum_{i=1}^{n} \rho_{0\lambda i}\rho_{b\lambda i}E_s(\lambda_i)\Delta\lambda_i}{\sum_{i=1}^{n} E_s(\lambda_i)\Delta\lambda_i} \quad (1)$$

Where $\rho_{0\lambda i}$ = wavelength is λ_i standard whiteboard spectral reflection ratio; $\rho_{b\lambda i}$= wavelength for λ_i test site (external wall, roof) relative to the standard whiteboard spectral reflection ratio [1].

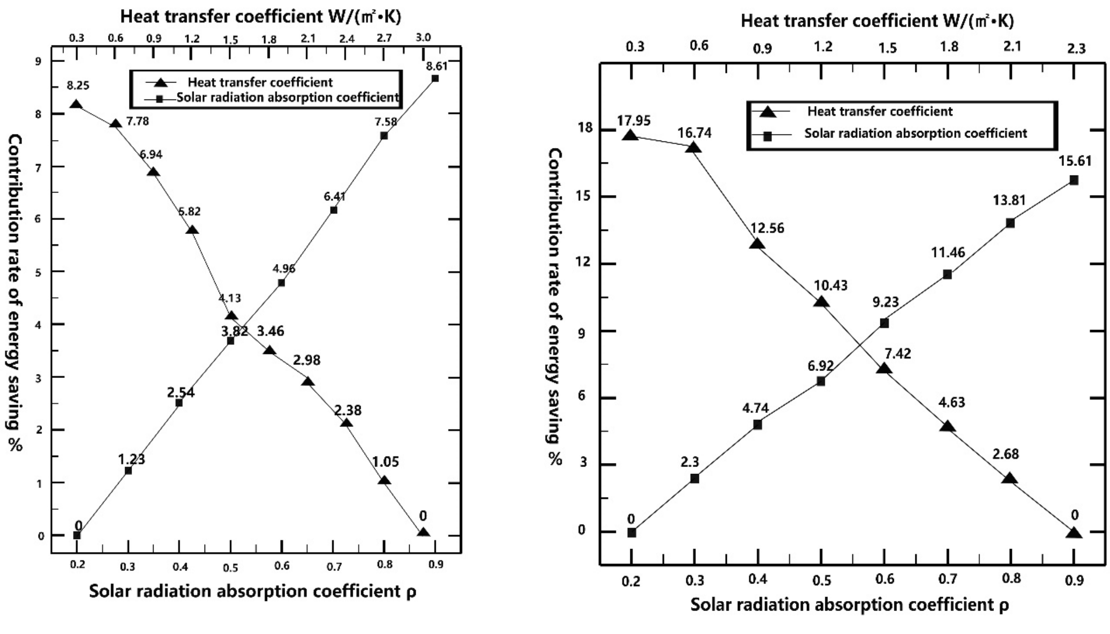
Secondly, the heat transfer coefficient of the outer wall and roof of the simulated building is calculated. The calculation methods are shown in Equations (3) and (4) [5].

Finally, the energy saving contribution rate of the external wall and roof of the simulated building under the conditions of specific solar radiation absorption coefficient and specific heat transfer coefficient is calculated as follows:

$$ECR = (Q_n - Q_0)/Q_0 \quad (2)$$

Where ECR= contribution rate to energy saving; Q_n= building energy consumption value after a parameter change; Q_0 = energy consumption value of standard model to be set.

Through the above modeling and simulation calculation, the simulation coefficient analysis diagram of exterior wall and roof is obtained, as shown in Figure 1 [4]. It can be seen from the experimental data in Figure 1 that with the increase of heat transfer coefficient of external walls and roofs of rural buildings, the energy-saving contribution rate curve shows a downward trend, while with the decrease of heat transfer coefficient, the energy-saving contribution rate curve shows an upward trend. When the heat transfer coefficient is between 0.6 W/(㎡·K) and 1.5 W/(㎡·K), the energy-saving contribution rate curve decreases rapidly. When the heat transfer coefficient is less than 0.6 W/(㎡·K), the energy-saving contribution rate is in a steady rise. Increasing the solar radiation coefficient of exterior wall and roof can effectively improve the energy-saving contribution rate of the building, and the energy-saving effect is positively correlated with reducing the heat transfer coefficient of exterior wall and roof. It can be seen that external walls and roof enclosures with superior thermal insulation performance can promote the transformation of low-carbon buildings in Hebei.



(a)Roof coefficient simulation analysis (b)External wall coefficient simulation analysis

Figure 1. Simulation analysis of the performance of rural building envelope in Hebei

4. SIMULATION EXPERIMENT OF ENCLOSURE STRUCTURE RENOVATION

Two traditional rural buildings A and B are selected as experimental objects. A is the traditional building that has not been transformed, and B is the comparison experiment house that has been transformed after the envelope design.

4.1. Experiment room size and material setting

The dimensions of the interior space of laboratory A and B are 1.8m×1.8m×2.5m (length × width × height); East wall door, size is 1.8m×0.6m; The north and south walls have Windows, with a size of 0.4m×0.5m, as shown in Figure 2 [2]. The enclosure materials of A are traditional hollow brick, green tiles and wood-framed glass in rural areas, as shown in Table 1. In building B, energy-saving materials such as XPS board and thermal insulation slurry are selected for combination experiment, as shown in Table 2, and relevant structures are shown in Figure 3 [9].

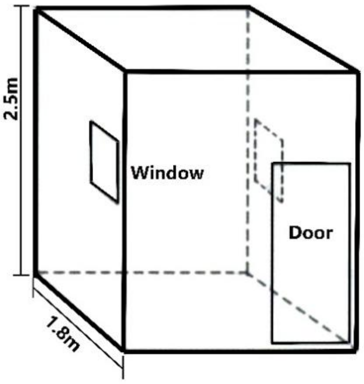


Figure. 2 Schematic diagram of the structure size of the experimental room

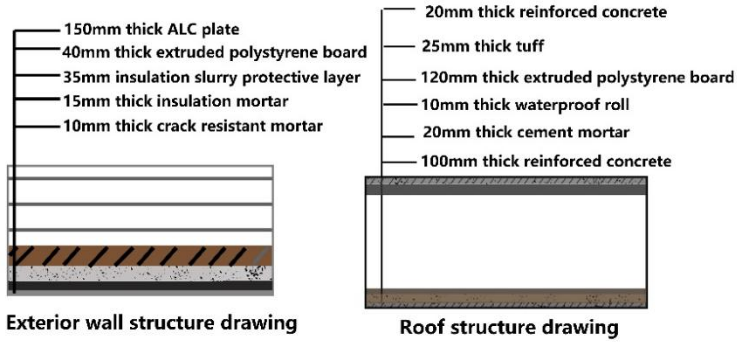


Figure. 3 Reconstruction diagram of related structure of Building B

4.2. Thermal calculation of envelope structure

The heat transfer theory commonly used in the calculation of building thermal engineering and building energy conservation is "steady-state one-dimensional flat wall heat transfer", and the heat transfer coefficient of its main section is calculated according to equations (3) and (4) [3]:

$$K = 1/R_0 \quad (3)$$

$$R_0 = 1/\alpha_i + \Sigma(d/\lambda) + 1/\alpha_e \quad (4)$$

Where K = heat transfer coefficient of flat wall, W/(㎡·K); α_i、α_e=the heat transfer coefficient of the inner and outer surface of the enclosure structure, W/(㎡·K); λ=the thermal conductivity of the material in the enclosure structure, W/(㎡·K); d= thickness of the material in the enclosure structure, m [6].

The relevant parameters of different envelope materials in traditional test house A and reference test House B were obtained through calculation. The correlation coefficients of envelope materials of traditional rural building A without transformation are shown in Table 1 [8]. The data related to the envelope structure of the renovated rural building experiment room B are shown in Table 2. After the transformation of the outer wall of building B, its heat transfer coefficient reached 0.322 W/(㎡·K), the heat transfer coefficient of the roof can reach 0.291 W/(㎡·K), the heat transfer coefficient of the outer window can reach 1.7 W/(㎡·K), thermal performance compared with the traditional building A, energy saving rate is higher [10].

Table 1. Envelope material and heat transfer coefficient of rural traditional Building A

Exterior wall material	Heat transfer coefficient	Roof material	Heat transfer coefficient	Exterior window material	Heat transfer coefficient
Hollow brick	0.79W/(㎡·K)	Green tile 6mm	0.22W/(㎡·K)	Wood-framed glass window	5.03 W/(㎡·K)
Common hollow block	0.59-0.64 W/(㎡·K)	Polystyrene plate 84-139mm	0.041 W/(㎡·K)	PVC Glass window	4.89W/(㎡·K)
Porous brick (non-clay)	0.50-0.68W/(㎡·K)	Expanded perlite 179-309mm	0.057 W/(㎡·K)	Aluminium alloy glass window	5.90 W/(㎡·K)

Table2. Thermal performance parameters of the envelope structure of rural building B after renovation

Reconstruction area	Material name	Thickness	Thermal conductivity W/(m·K)	Heat transfer coefficient W/(㎡·K)
Outer wall	ALC plate	150mm	0.11	0.322
	XPS plate	40mm	0.029	
	Insulation stock protective layer	35mm	0.814	
	Insulation stock screed	15mm	0.930	
	Crack resistant mortar + Finishing layer	10mm	0.814	
Roof	Reinforced concrete	20mm	1.547	0.291
	Tuff	25mm	0.256	
	Extruded polystyrene board	100mm	0.033	
	Waterproof coil	-	-	
	Cement mortar	20mm	0.930	
	Reinforced concrete	100mm	1.740	
Exterior window	Coated wood framed Low-E glass window	-	-	1.7

5. CONCLUSION

According to the investigation and analysis, the thermal performance of rural traditional building envelope structure in Hebei region does not meet the requirements of energy-saving design standards in the region. Farmers' demand for winter heating and building operation energy consumption are gradually increasing, which is not conducive to ecological rural construction in the long run.

The traditional rural building modeling, its envelope structure simulation experiment data analysis, through the building roof, external wall energy-saving contribution rate calculation, compared with the relevant data, it is concluded that the insulation performance superior envelope material, which is conducive to reducing the rural building energy consumption in Hebei area, improve the villagers living environment.

According to the relevant conclusions drawn from the simulation experiment data of the envelope structure, the simulation experiment of the envelope structure transformation is carried out. Through the method of comparative study, the thermal coefficient calculation and comparative study are carried out on the envelope materials of the traditional building and the renovated building. It is determined that the envelope structure of the renovated building is more in line with the local building energy conservation standards and has higher energy conservation compared with the traditional building. It is more suitable for extensive application in rural building renovation.

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