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# Comprehensive Benefit Analysis of Energy Saving Transformation of Hui-style Residential Buildings

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**Abstract**

*As traditional dwellings in southern Anhui, Huizhou style dwellings have been built for a long time, with serious aging structure, poor indoor thermal environment, and high building energy consumption, so there is an urgent need for energy-saving transformation of dwellings. This paper selects a traditional Huizhou style house in Shexian County, uses DeST to simulate the energy consumption, analyzes the energy-saving transformation of the envelope structure, quantitatively analyzes the energy-saving effect under different energy-saving schemes, and select the optimal energy-saving scheme based on the results of energy consumption simulation and the net present value method. After the renovation, the annual cumulative energy consumption of the building is reduced by 66.4%, the net present value during the life span is 13433.97 yuan. The energy-saving renovation is of practical significance to the improvement of energy saving.*

***Keywords:*** *Net present value；hot summer and cold winter zone；energy-saving renovation；energy consumption*

Since the reform and opening up, China's economy has prospered and developed, and the rise of construction industry makes China's construction volume reach the first in the world [1]. According to statistics, in 2017, China's rural building area accounted for 33.99% of the national building area, and the energy consumption of rural houses except heating was 223 million standard coal, accounting for 23.55% of the national building energy consumption [2]. The high energy consumption of traditional folk houses undoubtedly exacerbated the shortage of non renewable resources and brought a great burden on the environment, which is an urgent problem to be solved in the development of building energy conservation in China, Therefore, a large number of scholars pay attention to the energy-saving transformation of traditional residential buildings in rural areas. The use of new materials and technologies is the main way to transform existing buildings [3], which is mainly reflected in the reinforcement and heat preservation of enclosure structure. It is found that the best heat preservation thickness of exterior walls in hot summer and cold winter areas is 14~50mm[4-5], which can be improved by adding external windows and shading in summer, but the heat gain capacity of external windows to the south is far greater than the heat dissipation capacity, so attention should be paid to controlling the building shape while increasing the ventilation of external windows [6], and the use of glass materials with low light transmittance can improve the indoor environment of buildings[7]. The utilization of clean energy can bring great environmental benefits. Using natural resources such as solar energy, soil thermal inertia and wind energy instead of primary energy not only has good economic benefits, but also protects the ecological environment [8]. As a country where building energy conservation started earlier, Germany's building renovation not only involves energy conservation, but also includes indoor and outdoor environment renovation, including the utilization of solar energy resources, optimization of heating and power supply, etc., and also extends to the coordination of the surrounding environment of the community [9-10].

Using software to calculate building energy consumption and analyze the feasibility of the scheme is the trend of building energy-saving transformation. British scholars use EnergyPlus and TRNSYS energy consumption simulation software to analyze the factors affecting building energy consumption and put forward zero energy

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consumption building optimization strategy [11]. EnergyPlus simulation can also analyze the factors affecting the energy-saving effect of outer wall structure [12]. Finnish scholars change building envelope variables and combine IDA ice building performance simulation software to systematically optimize residential buildings and reduce building carbon emissions [13]. BIM can effectively reduce the waste of building materials in the transformation process and avoid pipeline collision and other errors in the design process [14].

The above research on building energy efficiency provides a reference for Huizhou-style residential reconstruction, but the research on residential reconstruction combined with the geographical environment characteristics of Huangshan area is still less. As a building with local characteristics, the inheritance and development of traditional dwellings have attracted much attention. Studying the energy-saving strategy of Huizhou-style dwellings is not only conducive to responding to the concern of architectural disciplines on energy saving and environmental protection, but also reflects the protection, development and cultural inheritance of traditional dwellings. Based on the characteristics and energy-saving methods of Huizhou traditional residential buildings, this paper puts forward the energy-saving renovation scheme of residential buildings and analyzes the energy-saving effect and economy of the scheme.

## 1 Research method

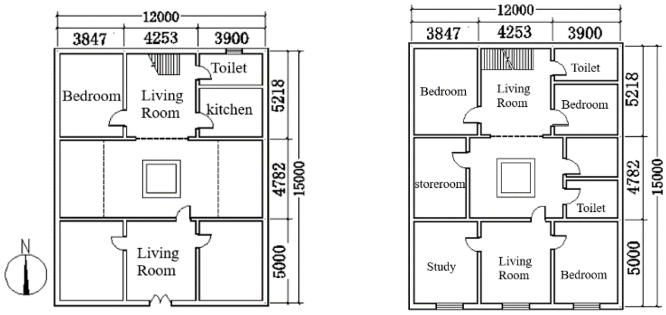
Through the field investigation of Huipai folk houses in Shexian County, Huangshan City, it is found that the traditional folk houses still in use have the problems of serious external wall weathering, poor building tightness and high operation energy consumption due to their long construction age. Most of the local folk houses are single buildings with 2 ~ 3 floors, and the shape coefficient is much higher than that of urban buildings. The structural characteristics of folk houses are thick exterior walls, thin roofs, weak thermal insulation performance of thin roofs and partitions, and most of the windows are wooden window frames and single-layer glass. The wood has been eroded by wind and rain for a long time, reducing the compactness of wood plates and increasing the splicing joints between plates, which greatly reduces the thermal insulation of external windows, Due to the historical and cultural factors in Huizhou and the influence of the Huizhou school, the building facade rarely opens windows or small windows. Shexian county is mostly cloudy and rainy, the ultraviolet ray is weak, and the interior is usually very dark [15]. In addition, the local residents' awareness of energy conservation is not strong, resulting in the residential houses far from reaching the energy conservation standard.

Summarize the investigation results, select representative residential buildings as the reconstruction objects, and use the DeST energy consumption simulation software developed by Tsinghua University to calculate the annual cooling and heating load of buildings before and after the reconstruction. On the basis of the existing envelope structure of residential houses, the concrete reconstruction scheme is to add insulation layers to the external walls and roofs, change the materials of external windows, calculate the energy-saving rates of different schemes by software, and determine the best scheme by combining the net present value of the schemes.

## 2 Overview of folk houses

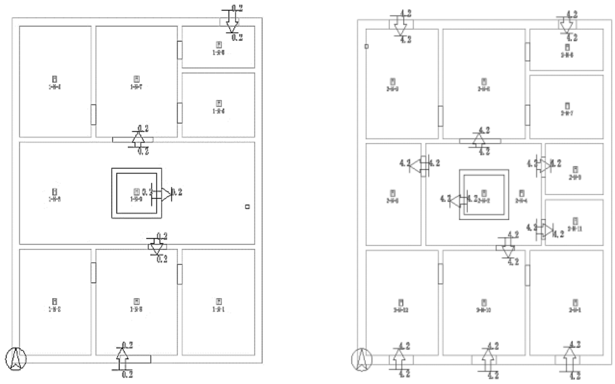
### 2.1 Residential layout

A traditional folk house with a patio in the ancient city of Shexian county is selected for modeling analysis. The folk house has two floors, facing south, with a total area of 360m2. The plan is shown in Fig. 1. 1、 The height of the second floor is 3.6m. The first floor only has windows in the toilet, and the second floor is located in the South and north directions. All rooms except the living room have external windows, with a size of 1.2m × 1.5m, toilet window size 0.9m × 0.9m, the roof is slope roof, and the building shape coefficient is 0.432. The staircase is connected to the living room and treated as a living room. The floor, interior wall and ceiling of the patio room are set as virtual enclosure structure, and ventilation is set from the patio to the indoor room. Establish dest model, as shown in Fig. 2.




（a）First floor plan （b）Second floor plan

Fig.1 Floor plan of traditional residential buildings



（a）DeST floor plan （b）DeST second floor plan

Fig.2 DeST model

### 2.2 Parameter selection

#### 2.2.1 Exterior protected construction

Si Pengfei [16] deduced and calculated the heat transfer coefficient of the empty bucket wall through the mathematical formula, and summarized the average heat transfer coefficient formula of the empty bucket wall as follows:

$$K = K_k A + K_s B \qquad (1)$$

Where: K - average heat transfer coefficient of wall, w / (M2 · K);

- heat transfer coefficient of hollow wall, w / (M2 · K);

- heat transfer coefficient of overlapping brick wall, w / (M2 · K);

A - proportion of hollow wall in the whole wall;

B - proportion of overlapping brick wall in the whole wall.

By substituting the measured temperature data into the calculation, the heat transfer coefficient of the outer wall of the residential building is about 0.7W / (M2 · K). In order to ensure the accuracy of DeST model, an air layer is added to the outer wall structure to make the heat transfer coefficient close to 0.7W / (M2 · K); The roof of fold houses is a traditional beam raft Watchboard firewall mud shingle structure, with poor thermal insulation effect; The doors and windows of folk houses are made of wood, and the glass is ordinary 6mm single-layer glass. See Table 1 for the methods and thermal parameters of some components.

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Tab.1 Residential component materials and thermal parameters

| Type of enclosure structure | Material Science | Heat transfer coefficient / w / (M2 · K) |
|---|---|---|
| Wall | Plastering 20mm + green brick 290mm + air 20mm + plastering 20mm | 0.684 |
| Outer window | Wooden window frame + 6mm single glass | 4.46 |
| Pitched roof | Fir rafter 75mm + Watchboard 18mm + wood mud 20mm + green tile | 1.443 |
| Floor | Plank 60mm | 0.429 |

**2.2.2 Indoor thermal disturbance**

Tab.2 Indoor thermal disturbance

| Room function | | living room | Bedroom | Kitchen | Toilet |
|---|---|---|---|---|---|
| Lamplight | Maximum thermal disturbance of headlights /( W/m2) | 9 | 9 | 8 | 8 |
| Equipment | Maximum equipment thermal disturbance /( W/m2) | 9.7 | 12.7 | 38 | 5 |
| Personnel | Number of personnel | 4 | 2 | 3 | 1 |
| | Heat production by personnel /( W/m2) | 53 | 53 | 60 | 60 |
| | Personnel humidity/[g/(h person)] | 61 | 61 | 102 | 102 |

**3 Proposal and comparison of energy-saving schemes**

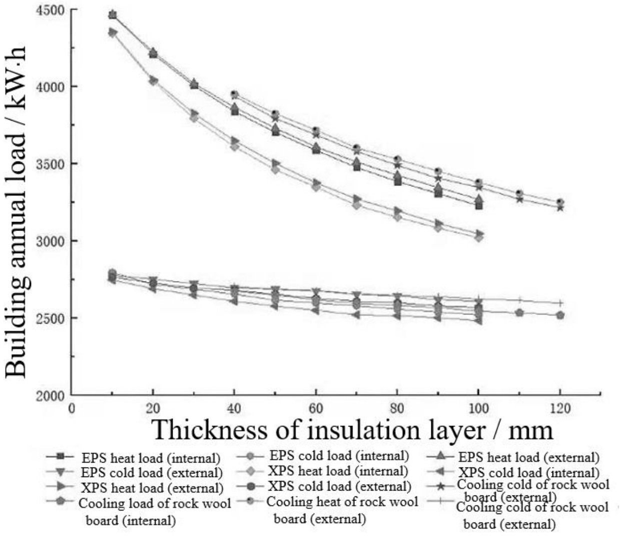
**3.1 Energy-saving scheme of enclosure structure**

**3.1.1 External wall**

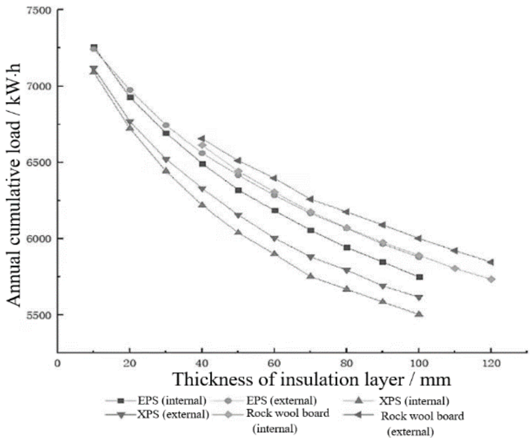
It is found that the application of external wall thermal insulation is better in severe cold and cold areas, and both internal and external thermal insulation can be used in hot summer and cold winter areas. The energy consumption simulation of external wall thermal insulation of Hui-style residential buildings is carried out, and the effect of internal and external thermal insulation and thermal insulation layer thickness on building energy consumption reduction is analyzed. On the premise of meeting the requirements of JGJ134-2010 "Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Areas" for external wall parameters, the insulation materials are polystyrene board (EPS) and extruded polystyrene board (XPS), with the thickness ranging from 10 mm to 10~100mm；; The thickness of rock wool board ranges from 40 mm to 120 mm, and the simulation results of energy consumption are shown in Fig. 3.

The results show that with the increase of the thickness of thermal insulation plate, the annual cumulative load of the building decreases to a great extent. The effect of external wall transformation on building thermal insulation is very obvious. Compared with the heat load, the cooling load of the building decreases slowly, because the Huangshan area has a long time in summer, high temperature and high air conditioning refrigeration demand. On the contrary, the time in winter is short and the heating demand is low. Due to the reduction of external wall heat transfer coefficient, The improvement of heat storage capacity can reduce the energy consumption of harmonious heating in time and space at extreme temperature. All three kinds of insulation boards have good energy-saving effect, among which EPS and XPS boards have the best energy-saving effect, with the maximum energy-saving efficiency of 4.4%

and 6.0% for each 10mm increase in insulation thickness, and rock wool board has the worst energy-saving effect. The energy consumption curve of EPS and XPS boards tends to be flat after the external insulation thickness reaches 70mm, and the energy-saving effect is limited. Because the prices of the two boards are relatively low, EPS and XPS boards with the thickness of 70mm are selected as the better energy-saving scheme for external walls.




（a）Relationship between annual cooling and heating load and insulation layer thickness



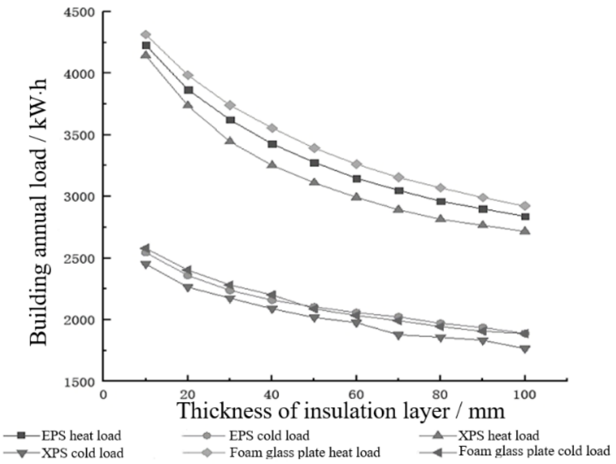

（b）Relationship between annual cumulative load and insulation layer thickness

Fig.3 Relationship between building

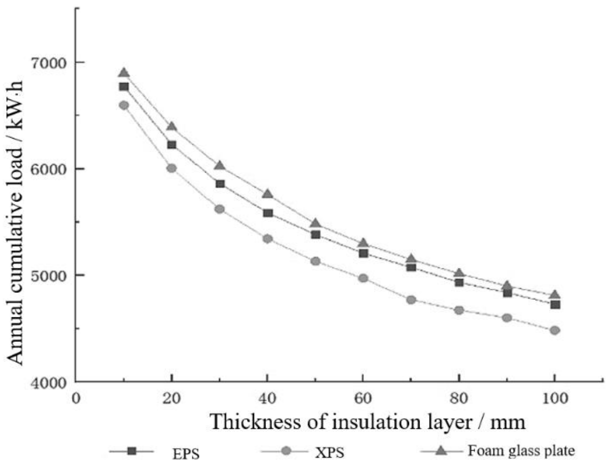
**3.1.2 Roof**

The roof of folk houses has been eroded by wind and rain for a long time, which makes the tiles and boards seriously weathered. The thin roof is difficult to play the role of building thermal insulation. Therefore, in addition, three kinds of insulation materials are selected as polystyrene board, extruded polystyrene board and foam glass panel. The thickness range is 10~100mm, and the simulation results are shown in Fig. 4.

It can be seen from Fig. 4 that with the increase of the thickness of insulation board, the annual cumulative load is obviously reduced, and the roof is an extremely important component in building insulation. XPS insulation board has the best energy-saving effect, with the maximum energy-saving rate of 12.9% for every 10mm increase in insulation thickness, followed by EPS board with the maximum energy-saving rate of 10.5% for every 10mm, and foam glass board has the worst energy-saving effect. After the thickness of XPS board reaches 70mm, the energy consumption curve gradually becomes flat, and the energy saving rate is very low. The energy saving effect of EPS board is limited after the thickness of 80mm and 90mm. Because XPS board is hard enough to be used as roof insulation material and the prices of the two boards are low, XPS board with 70mm thickness and EPS board with 80 mm and 90 mm thickness are selected as the better energy saving schemes for roofs.




（a）Relationship between cold and heat load and insulation layer thickness




（b）Relationship between cumulative load and insulation layer thickness

Fig.4 Relationship between building load and thickness of roof insulation layer

### 3.1.3 Exterior window

The external windows of residential houses are wooden window frames plus single layer of 6mm glass. There is only a small window in the bathroom on the first floor and a large window on the second floor. The ventilation of the first floor of residential houses is poor, the window frames are severely weathered and the gap between the walls is large, so it is difficult for single layer of glass to isolate the outdoor extreme temperature. Therefore, different types of glass materials are selected for residential houses, and the energy consumption of each window type is calculated and analyzed to analyze its energy saving efficiency. The influence of different glass materials on building energy consumption is shown in Table 3.

Low-E glass can highly filter medium and far infrared rays and highly transmit visible light, so that the building can ensure daylighting effect and reduce indoor and outdoor heat exchange. It can be seen from table 3 that Low-E glass window has good energy-saving effect. Among them, Low-E film coated glass window and Low-E film coated glass window with inert gas have the lowest energy consumption, and the energy-saving rate is 6.50%, The second is high transmittance Low-E film coated glass window, with an energy-saving rate of 6.4%. Because there are few windows in residential buildings, the materials of external windows have little influence on energy consumption, and the rural areas where residential buildings are located should give priority to the scheme economy. Considering the high demand of residential lighting, high-permeability glass windows coated with Low-e film and 6mm+12mm air +6mm glass windows are selected as the best scheme for energy saving of external windows.

Tab.3 Influence of window type on building energy consumption

| Programme | Annual cumulative total load / kW · H | Annual cumulative total load of original building / kW · H | Energy saving rate /% |
|---|---|---|---|
| 6 + 12 air + 6 | 7169.99 | 7572.16 | 5.30% |
| 6 + 9 air + 6 | 7188.59 | 7572.16 | 5.10% |
| Low-E coated hollow glass 6 + 9 + 6 (high permeability type) | 7087.75 | 7572.16 | 6.40% |
| Low-E coated hollow glass 6 + 9 + 6 (low transmittance type) | 7076.66 | 7572.16 | 6.50% |
| Low-E coated hollow glass 6 + 9 + 6 (inert gas) | 7077.99 | 7572.16 | 6.50% |
| Vacuum + Low-E coated glass 3 + 0.1 + 3 | 7124.88 | 7572.16 | 5.90% |
| Vacuum glass 3 + 0.1 + 3 | 7205.23 | 7572.16 | 4.80% |

### 3.2 Energy consumption simulation orthogonal test

In order to verify the mutual influence of different energy-saving schemes of structures, the energy consumption simulation orthogonal test was carried out for the better energy-saving schemes of exterior walls, windows and roofs. See Table 4 for the better scheme of enclosure structure and Table 5 for the orthogonal test. Calculates the building energy consumption of 12 schemes in Table 5, and the results are shown in Table 6. From Table 6, it can be seen that by adding insulation layers to the exterior walls and roofs and changing the window materials to improve the overall thermal insulation performance of the building, the annual cumulative energy consumption of the building is obviously reduced. According to the energy-saving schemes combined with different energy-saving methods, the annual cumulative load energy-saving rate is 62.8%~68.8%, among which scheme 6 has the best energy-saving effect, with the energy-saving rate as high as 68.8%, followed by scheme 5 and scheme 3, all of which are higher than 68%.

Tab.4 Better energy-saving scheme of enclosure structure

| Scheme variable | | Content | Unit Price |
|---|---|---|---|
| Exterior wall | $W_1$ | 70mm XPS external insulation | 460/$m^3$ |
| | $W_2$ | 70mm EPS external insulation | 410/$m^3$ |
| Roof | $R_1$ | 80mm EPS insulation board | 410/$m^3$ |
| | $R_2$ | 90mm EPS insulation board | 410/$m^3$ |
| | $R_3$ | 70mm XPS insulation board | 460/$m^3$ |
| Glass type | $G_1$ | Low-E coated hollow glass 6 + 9 + 6 (high permeability type) | 120/$m^2$ |
| | $G_2$ | 6mm + 12mm air + 6mm | 80/$m^2$ |

Tab.5 Orthogonal table

| Plan | External wall | Roofing | Exterior window |
|---|---|---|---|
| 1 | $W_1$ | $R_1$ | $G_1$ |
| 2 | $W_1$ | $R_1$ | $G_2$ |
| 3 | $W_1$ | $R_2$ | $G_1$ |

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| | | | |
|---|---|---|---|
| 4 | $W_1$ | $R_2$ | $G_2$ |
| 5 | $W_1$ | $R_3$ | $G_1$ |
| 6 | $W_1$ | $R_3$ | $G_2$ |
| 7 | $W_2$ | $R_1$ | $G_1$ |
| 8 | $W_2$ | $R_1$ | $G_2$ |
| 9 | $W_2$ | $R_2$ | $G_1$ |
| 10 | $W_2$ | $R_2$ | $G_2$ |
| 11 | $W_2$ | $R_3$ | $G_1$ |
| 12 | $W_2$ | $R_3$ | $G_2$ |

Tab.6 Orthogonal simulation results

| Plan | Accumulated annual heat load/kw h | Accumulated annual cooling load/kw h | Total annual cumulative load/kw h | Energy saving rate% |
|---|---|---|---|---|
| 1 | 1451.30 | 1090.02 | 2541.33 | 66.5% |
| 2 | 1393.49 | 1081.39 | 2474.88 | 67.4% |
| 3 | 1381.10 | 1044.16 | 2425.26 | 68.1% |
| 4 | 1463.50 | 1050.72 | 2514.22 | 65.6% |
| 5 | 1325.34 | 1053.09 | 2378.43 | 68.7% |
| 6 | 1327.28 | 1045.14 | 2372.42 | 68.8% |
| 7 | 1671.13 | 1150.95 | 2822.08 | 62.8% |
| 8 | 1623.39 | 1150.41 | 2773.80 | 63.5% |
| 9 | 1618.69 | 1118.80 | 2737.49 | 63.9% |
| 10 | 1561.02 | 1108.45 | 2669.47 | 64.8% |
| 11 | 1551.79 | 1066.26 | 2618.05 | 65.5% |
| 12 | 1497.27 | 1057.28 | 2554.55 | 66.4% |

**3.3 Net present value method analysis**

According to General Principles for Design of Civil Buildings (GB50352-2005)[17], the ancient Huizhou area is a hot summer area and cold winter area, which is a national non-heating area. Therefore, the cold and heat sources of residential buildings are all air conditioners, and the main operating cost is electricity. The net present value method is used to compare the economy of energy-saving schemes. After market research, the discount rate is set at 4.35%, the local electricity charge standard of Shexian County is 0.5 yuan/kW h, and the service life is 20 years. According to the net present value formula:

$$NPV = \sum_{t=1}^{n}(CI - CO) \cdot (1 + i)^{-t} \quad (2)$$

Where: NPV - net present value, yuan;

CI - annual cost savings, yuan;

Co - initial investment cost, yuan;

I - discount rate,%;

T - service life, years.

The calculated net present value of each scheme is shown in Figure 5. The net present value of 12 energy-saving schemes is greater than zero, and the schemes are all feasible. Among them, the net present value of scheme 3/6/12 is larger, and the transformation cost and annual income of scheme 3/6/12 are calculated by dynamic and static payback period calculation formulas, and the results are shown in Table 7. The static investment does not consider the influence of time on capital, while the dynamic payback period considers the influence of time and discount rate.

The dynamic payback period starts to generate discount rate, $R = 1/(1+i)^n$, from the second year of reconstruction. According to Table 7, among the three schemes with higher net present value, scheme 12 has the highest economic benefit. Although the net present value is slightly lower than that of scheme 6, this scheme has the shortest payback period, the lowest initial investment and easier acceptance by local residents. Considering energy saving and economy comprehensively, scheme 12 is selected as the best energy-saving scheme for residential building envelope, with the energy-saving rate of 66.4%, static and dynamic payback periods of 8.15 and 10.32 years respectively, and the energy-saving rate meets the requirements and economic benefit.

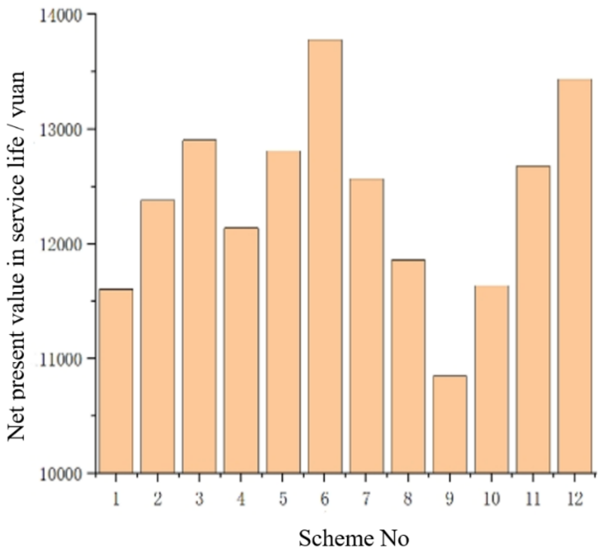


Fig.6　Vet present value of envelope reconstruction scheme

Tab.7　Economic comparison of different energy saving schemes

| Project | Option 3 | Option 6 | Programme 12 |
|---|---|---|---|
| Initial investment / yuan | 21976.3 | 22041.3 | 20533.7 |
| Annual cost savings / yuan | 2583.4 | 2654.8 | 2518.7 |
| Net present value in service life / yuan | 12899.9 | 13778.1 | 13434 |
| Static investment payback period / year | 8.5 | 8.3 | 8.2 |
| Dynamic payback period / year | 10.9 | 10.56 | 10.3 |

**4 Conclusion and prospect**

(1) Through investigation, it is found that the traditional Hui-style houses have been built for a long time, with old components, severe weathering of the envelope, high building energy consumption and large space for energy-saving renovation. Renovating the envelope of houses according to the specifications will bring considerable economic and environmental benefits.

(2) Using DeST software to calculate the cooling and heating load of residential buildings under different energy-saving schemes, it is found that the energy-saving efficiency of 12 energy-saving schemes is high, and there is little difference, among which the highest energy-saving efficiency of scheme 6 is 68.8%, which shows that strengthening the heat preservation of envelope can effectively reduce the energy consumption of heating and cooling in buildings, and the energy-saving efficiency is high, which contributes to the green development of residential buildings.

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(3) Comparing the economic benefits of the schemes with the net present value method, the benefits of schemes 6 and 12 are the highest within the service life. Due to the low initial investment and short payback period of scheme 12, it is more acceptable for the rural areas where the residential houses are located. Therefore, it is determined as the best energy-saving scheme. The energy-saving rate of the scheme is 66.4% and the net present value within the service life is 13433.97 yuan.

At present, there are still some problems in the energy-saving of traditional residential buildings. First, residents have insufficient idea of building energy-saving renovation, and rarely take the initiative to propose or refuse renovation. Residents should fully understand the great improvement of comfort and economy of residential buildings after renovation. Secondly, due to the long payback period and high cost of residential renovation, the government can give appropriate subsidies to encourage residential renovation, and at the same time, it can actively promote the progress of building energy-saving technology and reduce the renovation cost. Through the efforts of all parties, Hui-style dwellings will be developed towards comfortable living, energy saving and environmental protection.

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