Research on Energy-Saving Renovation Design of Traditional Dwellings in Suzhou Water Town

Li Xueping, Liu Jiao
Xi'an University of Science and Technology, Shaanxi Xi'an, 710054

Abstract

Traditional dwellings in Suzhou have a long history, but there are some shortcomings in thermal environment and energy saving. In order to respond to the sustainable development strategy, this paper takes Suzhou traditional dwellings as the research object, analyzes the indoor and outdoor temperatures of typical days in winter and summer, and puts forward 16 renovation schemes by orthogonal experiments on the premise of protecting the style and features of dwellings. DeST software is used to simulate energy consumption, and the best scheme is selected by comprehensive economy and energy saving rate, and the indoor temperatures before and after renovation are simulated and compared. The research shows that the best renovation scheme is: 100mm EPS insulation board for exterior wall, 80mm EPS insulation board for roof and 9mm ordinary insulating glass for exterior window. After transformation, the energy saving rate is 38.6%, the net present value is 19,775.72 yuan, and the static investment payback period is 9.5 years. After renovation, the indoor temperature increased by 3.9℃ in winter and decreased by 2.1℃ in summer, which effectively improved the indoor thermal environment.

Keywords: *Traditional dwellings in Suzhou, Orthogonal experiment, DeST, Energy consumption simulation.*

1 Introduction

Suzhou traditional folk houses have a long history and have certain historical, cultural and social values. There are some shortcomings in the construction of residential houses, such as no thermal insulation layer on the exterior wall and roof, only a single layer of glass on the windows, poor overall thermal insulation performance of houses and poor living environment. While not destroying the appearance of residential houses, reducing the overall energy consumption of residential houses and improving the thermal environment are the key points of energy-saving design and transformation. Zhou Yuzhou and others [1] simulated the energy consumption of cold-tiled roofs of traditional villages in Zunyi area by computer, and proposed that adding local thermal insulation materials to roofs could reduce the energy consumption by about 42%, which provided a method for the protection of traditional villages in hot summer and cold winter areas. Wu Huilai, Liu Xiaozhe, etc. [2-3] studied and analyzed the external walls and "twisted-ring" roofs of traditional houses in Shanghai. Combining the merits of the original houses with modern heat preservation technology can reduce the energy consumption by 46%. Shu Chang, Yang Weiju, etc. [4-5] analyzed and studied the traditional skills of water town dwellings, and put forward that measures such as adding insulation layers to the external walls and roofs, raising the ground to prevent moisture, changing the window-wall ratio and window sill size can effectively reduce the annual energy consumption of dwellings, and provide ideas for energy-saving transformation of traditional dwellings. Cai Ruonan et al. [6] introduced the parameters affecting the performance of phase change materials for building envelope, used heat transfer model to optimize the influencing factors such as thermal comfort and energy saving of passive and active buildings, so as to reduce energy consumption, and summarized and compared the optimization methods based on Simulation and inverse problem. May Zune et al. [7] conducted thermal comfort simulation on the traditional passive design of houses in Myanmar and concluded that the traditional passive design can effectively reduce the indoor temperature, but it needs to be combined with modern technology to adapt to the global temperature rise. Phil Symonds, Tingley, Danielle densley and others [8-9] modeled the thermal environment of British houses and simulated the wall insulation materials with software. The use of new materials can greatly reduce the carbon recovery cycle and have better thermal insulation performance and energy-saving effect. Omar bourass et al. [10] concluded through simulation research that hollow brick, concrete block and straw rammed earth have good thermal insulation performance and low energy consumption. As the exterior wall material of Moroccan residence, it can greatly reduce the energy consumption of the whole house.

In this paper, taking Suzhou traditional dwellings as the research object, aiming at the existing problems of dwellings obtained from the measured indoor and outdoor temperature in winter and summer, the design scheme of energy-saving renovation is obtained by orthogonal experiment, and the best scheme is selected according to the

ISSN: 0010-8189

requirements of economy and energy-saving, which can be used as a reference for future energy-saving renovation of dwellings.

1 Overview of residential buildings and indoor thermal environment

1.1 Overview of folk houses

The residents are located in donghuaqiao lane, Pingjiang District, Suzhou, covering an area of 4000m2, with three 13m wide rooms, a rise of 7m and 9m deep. The seat faces south in the north and is narrow, long and deep as a whole. The patio is 8m long and 5m wide. The ground is slate, with moss growing all year round. The roof is a slope roof with a slope of about 15 °. It was originally Wang's residence during the reign of Kangxi, but now there is more living space. Residents divide the original hall, one household in each room, a total of 23 households. See Figure 1 for the plan of residential buildings.

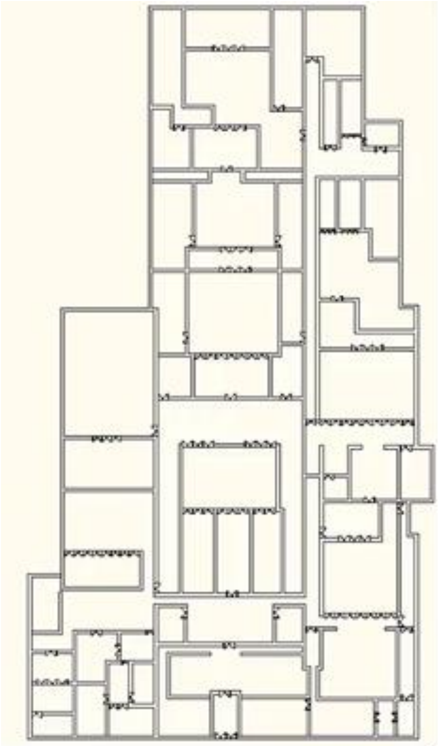
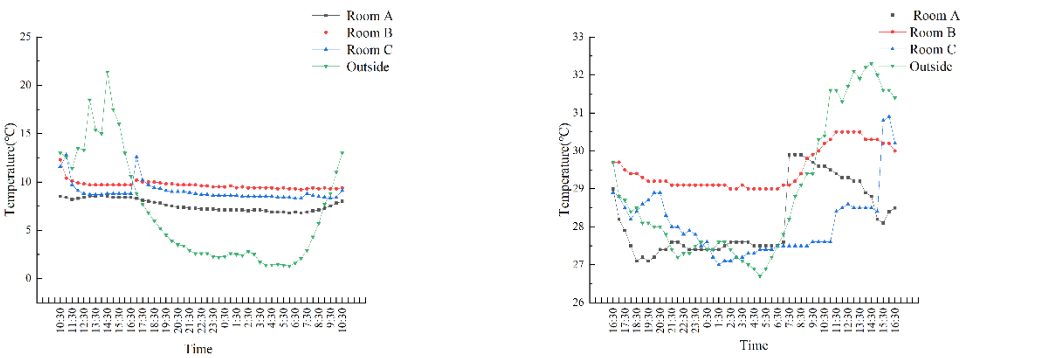


Figure 1 Floor plan of the residence

1.2 Indoor thermal environment

Suzhou is located in the hot summer and cold winter area, with sultry summer, cold winter and heavy rainfall all the year round. In order to understand the indoor thermal environment of residential houses, the typical days in winter and summer were selected to measure the indoor temperature of residential houses continuously for 24 hours. The measuring points are set in the bedroom, living room, kitchen and outdoor, named A, B, C and D. Winter is from 10: 30 on January 29th, 2021 to 10: 30 on January 30th, 2021, and summer is from 16: 30 on August 1st, 2021 to 16: 30 on August 2nd, 2021. The test results are shown in Figure 2.



(a) Indoor and outdoor temperature in winter (b) Indoor and outdoor temperature in summer

Figure 2 Indoor and outdoor temperature of residential buildings in winter and summer

ISSN: 0010-8189

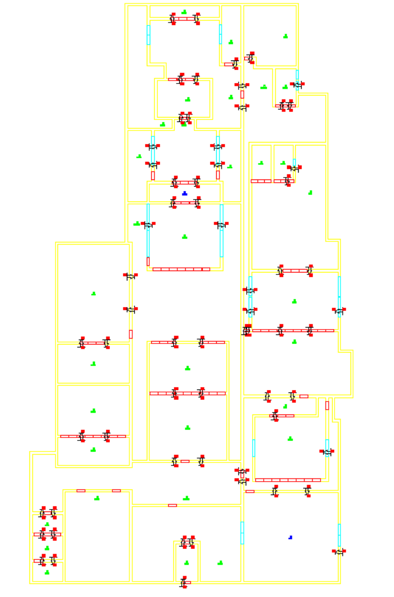
There is no heating or air conditioning in the houses. In winter, the indoor temperature is stable and the outdoor temperature fluctuates greatly. The average indoor temperature is 8.9℃ and the average outdoor temperature is 6.9℃. The indoor temperature does not meet the minimum human comfort of 12℃. The outdoor humidity fluctuates greatly, contrary to the temperature trend, the highest humidity is 81.9%, and the indoor humidity is relatively stable at night, with an average humidity of 64%, which makes the indoor air more bitter and cold in winter, and the overall comfort is not good.

In summer, there is little difference between indoor temperature and outdoor temperature, which is less influenced by outdoor. The average indoor temperature is 28.6℃, the average outdoor temperature is 29℃, and the indoor temperature is 26℃ higher than the human comfort temperature. The trend of indoor humidity is the same as that of outdoor humidity, and the overall humidity is higher than that in winter, with the average indoor humidity of 75.2%, the highest outdoor humidity of 90.5% and the average humidity of 82.7%, which makes the room more sultry.

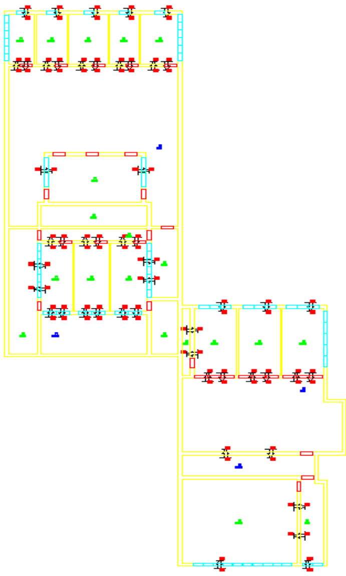
2 Modeling and parameter setting

2.1 Model building

There are two floors in the residential building, and the dest-h software is used to model the residential building. For simple calculation, the model is simplified, as shown in Figure 3.



(a) Plane level 1



(b) Plane level 2

Figure 3 Floor plan of residential model

2.2 Parameter setting

2.2.1 Enclosure structure

The whole residential building adopts beam-column system, with wooden columns, stakes and beams as load-bearing. In order to avoid the influence of ground moisture on stability, stone piers are added at the lower ends of wooden columns. The external wall is an empty bucket wall, with blue bricks as the main material, and the masonry method is one sleep and one bucket, with air interlayer in the middle, without insulation layer, and the partition wall is set as a wooden partition wall. The roof is a sloping roof with a slope of 15 degrees, and the structure from bottom to top is rafters, looking bricks, flying rafters, looking bricks, bottom tiles and cover tiles [11]. The doors are traditional wooden doors, and the windows are single-layer glass with wooden window frames. See Table 1 for the specific structure and heat transfer coefficient of enclosure structure.

ISSN: 0010-8189

Table 1 Heat transfer coefficient of original materials of residential houses

Component part	Material composition	Heat transfer coefficient/ (W/m²·K)
External wall	Lime mortar 20mm+blue brick 190mm+air 20mm+lime mortar 20mm	0.741
Partition	Pine board 120mm + lime mortar 15mm	1.071
Roofing	Pine purlin 50mm+pine rafter 50mm+view brick 100mm+lime mortar 20mm+base tile 20mm+cover tile 20mm	1.516
Door	Wooden door 25mm	4.5
Window	Wooden window frame+5mm single glass	5.7

2.2.2 Indoor environment parameter setting

According to the daily living and usage of the residence, the indoor lighting heat disturbance, equipment heat disturbance and personnel heat disturbance are set. The per capita heat generation of the bedroom and living room is 53W, and the per capita moisture production is 0.061kg/Hr. The per capita calorific value of toilets and kitchens is 60W, and the per capita moisture production is 0.102kg/Hr. The lighting power is 6W/m2, the bedroom equipment power is 12.7W/m2, the living room equipment power is 9.3W/m2, and the bathroom equipment power is 48.2W/m2. The staff in each room is set to a maximum of 3 people and a minimum of 0 people.

The heating period is set from November 15th to March 15th of the following year, the air-conditioning period is set from June 1st to August 31st, the daily air change frequency is set to once /h, and the maximum tolerable temperature of air-conditioning in summer is set to 28℃.

3 Building energy consumption simulation

3.1 Residents begin to consume

After the parameters are set, the initial energy consumption of traditional dwellings in Suzhou water town is simulated, and the cooling and heating load of air conditioning is shown in Figure 4. Before energy-saving renovation, the energy consumption of residential buildings was 30221.13kw·h, and the heat load was generally higher than the cold load. The hollow wall has a certain heat insulation performance, so the indoor temperature is comfortable in summer and the cooling load is small.

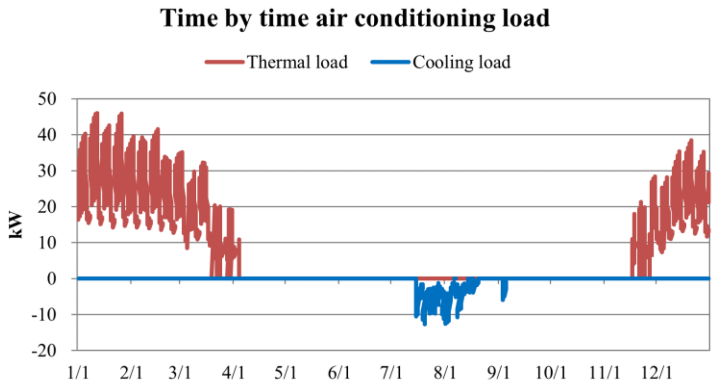


Figure 4 Hourly cooling and heating load of air-conditioning throughout the year

3.2 Energy saving transformation strategy

3.2.1 External wall

Envelope has a great influence on building energy consumption, while external walls account for a large proportion in envelope, and the thermal insulation performance of external walls has a great influence on reducing energy consumption of residential houses [12,13]. The exterior wall of Suzhou traditional dwellings is a blue brick hollow wall with 20mm air interlayer between bricks, which has good heat insulation performance, but it is still lacking. Commonly used thermal insulation materials include EPS, XPS, phenolic foam, expanded perlite, polyurethane foam, etc. The thickness of the material is 80mm, and the heat transfer coefficient and simulated accumulated heat load throughout the year are shown in Figure 5.

It can be seen from the figure that the energy-saving effect of the material is consistent with the trend of the heat transfer coefficient, and the energy consumption decreases with the decrease of the heat transfer coefficient. Phenolic foam board has the lowest energy consumption, followed by XPS. However, in view of the high price of this material, EPS insulation board with economic and better effect is selected. Keep other materials unchanged and change the thickness of EPS insulation layer. See Figure 6 for energy consumption and energy saving rate. It can be seen from the figure that the energy-saving rate increases with the increase of insulation layer thickness, and the energy-saving rate in the early stage increases rapidly. With the gradual increase of insulation layer thickness, the gradient of energy saving rate increases slowly, and the cost increases with the increase of insulation layer thickness, which does not meet the economic requirements.

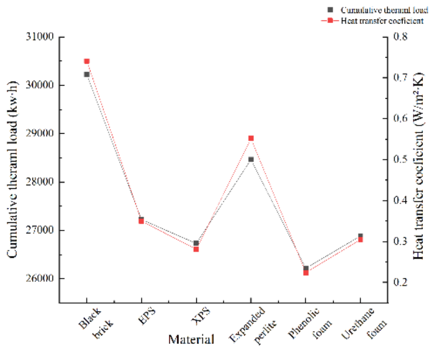


Figure 5 Heat transfer coefficient and energy consumption of different materials on the exterior wall

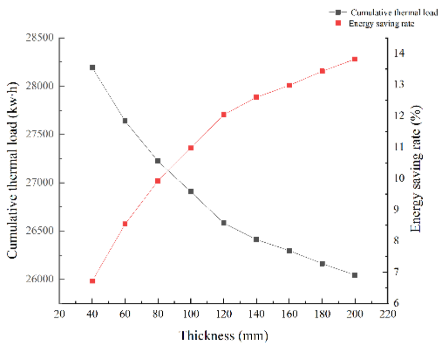


Figure 6 The influence of different thickness of EPS insulation board on energy consumption

3.2.2 Roofing

Different from modern new buildings, the roof of Suzhou traditional dwellings is a traditional sloping roof with colorful finches on both ends of the roof. The bottom rafters and the looking bricks are stacked in a staggered manner, the layers are connected by mortar, and the upper part is overlapped by two bottom tiles and a cover tile, which can prevent the rain from dripping indoors through the gap between the bricks and the rafters and affect the living feeling. Due to the long construction time of residential houses, no insulation layer or waterproof layer is made on the roof, which makes the indoor temperature low in winter, difficult to dissipate in summer, and poor indoor comfort.

Same as the exterior wall, keep the material thickness consistent. See Figure 7 for heat transfer coefficient and energy consumption of different materials. It can be seen from the figure that the heat transfer coefficient and energy consumption of materials show the same trend, and the smaller the heat transfer coefficient, the lower the energy consumption. Phenolic foam has the advantages of small heat transfer coefficient, low energy consumption, low density, innocuity, long service life and good thermal insulation performance. When choosing roofing insulation materials, consider using phenolic foam board. Due to the small heat transfer coefficient, the thickness can be appropriately reduced and the cost can be reduced. Although the EPS insulation board has a slightly higher heat transfer coefficient, it is cheap and light. You can also choose roof insulation materials to increase a certain thickness to achieve the same insulation effect.

ISSN: 0010-8189

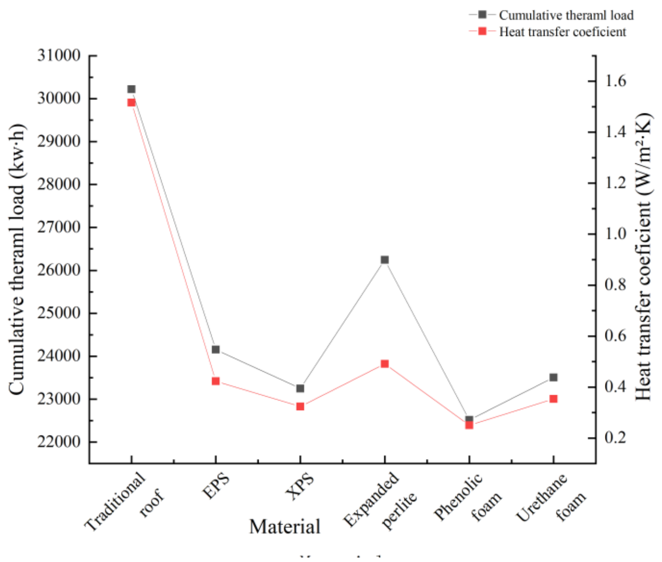


Figure 7 Heat transfer coefficient and energy consumption of different roofing materials

3.2.3 Doors and windows

Aluminum alloy doors and windows were commonly used at the beginning of the 21st century, and most residents of Suzhou did not replace the doors and windows, maintaining the original structure of the residential buildings. The door of the residential house is a traditional wooden door, and the window is a wooden window frame with 5mm single-layer glass. There are gaps between the existing door and the window frame, and the winter wind can easily enter through the gap to reduce the indoor temperature. Some of the windows in the residential buildings are leaky windows, there is no glass in the middle, and the whole is a wooden carved pattern. They are usually installed on the wall between the atrium and the corridor, which can effectively help ventilation and lighting. The leaking window is a decorative window type, which can reflect the characteristics of residential buildings, and no energy-saving renovation design is made for this type of window. The heat transfer coefficient of wood is 0.02W/m²·K, the thermal conductivity is small, and indoor heat is easily lost. Aluminum alloy doors and windows can effectively improve air tightness and reduce heat loss. However, considering the preservation of the original style of the traditional houses, only the gaps between the doors and window frames were repaired, and the original single-layer glass was replaced to reduce the heat transfer coefficient. Commonly used window glass heat transfer coefficient and simulated annual cumulative heat load are shown in Table 2.

Table 2 Window glass types and heat transfer coefficient

Number	Material composition	Heat transfer coefficient/（W/m²·K）	Accumulated annual heat load/（kw·h）
1	Low-e film coated hollow (high permeability type) 6(Low-e)+9+6	2.4	30208.65
2	Filled with inert gas + Low-e film plating hollow 6(Low-e)+9(Argon)+6	2.0	30160.01
3	Ordinary insulating glass 6+9A+6	3.1	29974.89
4	Ordinary insulating glass 6+12A+6	2.9	29952.78
5	Vacuum + Low-e coated glass 3Low-e+0.1+3	2.2	30006.91

3.3 Energy saving transformation scheme and result analysis

3.3.1 Orthogonal experiment

If all materials and thicknesses of exterior walls, roofs and windows are arranged and combined to simulate energy consumption one by one, the workload is heavy and it takes a long time. It is troublesome to consider the repeated factors when analyzing the results, so orthogonal experiment is chosen. Orthogonal experiment [14] is a mathematical statistical method, in which representative experimental conditions are selected from various factors, and the experimental schemes are arranged by orthogonal table. In this process, choose the best or better scheme.

There are three influencing factors for residential energy consumption: external wall, roof and external window, because the external window retains the original window frame. Therefore, only the type of glass is used as the selection factor of external window. See Tables 3 and 4 for the selection of external wall, roof and window factors.

Table 3 Parameters of exterior walls and roofing factors

Member	Material thickness/mm	Heat transfer coefficient/W/m²· K	Thermal resistanceR/m²· K/W	Thermal inertia parameterD
Exterior wall insulation layer	EPS60	0.381	2.418	4.133
	EPS80	0.350	2.893	4.426
	EPS100	0.305	3.319	4.718
	EPS120	0.270	3.744	5.010
Roof insulation layer	EPS80	0.423	2.204	5.070
	EPS100	0.359	2.630	5.362
	XPS50	0.46	2.017	4.436
	Phenolic foam 40	0.43	2.169	4.278

Table 4 Parameters of external window material factors

Number	Outer window material	Heat transfer coefficient/W/m²· K	Solar heat gain coefficient
1	Low-e film coated hollow (high permeability type)6(Low-e)+9+6	2.4	0.487
2	Filled with inert gas + Low-e film plating hollow 6(Low-e)+9(Argon)+6	2.0	0.487
3	Ordinary insulating glass 6+9A+6	3.1	0.722
4	Vacuum + Low-e coated glass 3Low-e+0.1+3	2.2	0.609

3.3.2 Scheme design and energy consumption simulation results

In order to have more combination transformation schemes, select as many levels as possible in the list, so as to achieve the effect of no omission or repetition. The level setting of factors is shown in Table 5, and the orthogonal experiment table based on three factors and four levels is shown in Table 6. There are 16 schemes, and the energy consumption of each scheme is simulated by the software Dest-h, and the energy consumption of scheme 14 is the lowest. That is, when the outer wall insulation layer is 120mm thick, the roof is 100mm thick EPS insulation board, and the outer window is 9mm ordinary insulating glass, the energy-saving effect is the best. Although this scheme has the lowest energy consumption, it does not necessarily meet the economic requirements, and the obtained energy-saving transformation scheme is not the best scheme, so in order to get the best transformation scheme. Economic analysis of 16 schemes.

ISSN: 0010-8189

Table 5 Orthogonal experiment factor level setting

Level	Factor		
	Exterior wall insulation layer	Roof insulation layer	Outer window material
1	EPS60（X1）	EPS80（Y1）	Low-e film coated hollow (high permeability type)6(Low-e)+9+6（Z1）
2	EPS80（X2）	EPS100（Y2）	Filled with inert gas + Low-e film plating hollow 6(Low-e)+9(Argon)+6（Z2）
3	EPS100（X3）	XPS50（Y3）	Ordinary insulating glass 6+9A+6（Z3）
4	EPS120（X4）	Phenolic foam 40（Y4）	Vacuum + Low-e coated glass 3Low-e+0.1+3（Z4）

Table 6 Orthogonal experiment design table of energy-saving transformation scheme

Number of experiments	Exterior wall insulation layer	Roof insulation layer	Outer window material	Accumulated annual heat load/kW·h
1	X1	Y1	Z1	20205.66
2	X1	Y2	Z2	19354.86
3	X1	Y3	Z3	20235.80
4	X1	Y4	Z4	19912.41
5	X2	Y1	Z2	19402.84
6	X2	Y2	Z1	18826.66
7	X2	Y3	Z4	19399.74
8	X2	Y4	Z3	19107.58
9	X3	Y1	Z3	18555.24
10	X3	Y2	Z4	17733.16
11	X3	Y3	Z1	19414.16
12	X3	Y4	Z2	18783.34
13	X4	Y1	Z4	17981.52
14	X4	Y2	Z3	17436.95
15	X4	Y3	Z2	18711.24
16	X4	Y4	Z1	18526.78

3.4 Economic analysis

In order to select economical and effective transformation schemes, 16 kinds of test schemes were analyzed economically. In the analysis, the net present value and static investment payback period are selected to judge the economics and feasibility of the plan. According to market research, the prices of EPS, XPS, and phenolic foam boards are respectively 350, 600, 560 yuan/m3, Low-e film plating hollow (high permeability type), Filled with inert gas + Low-e film plating hollow, 9mm Ordinary insulating The prices of glass and Vacuum + Low-e coated glass are 210, 230, 120, and 220 yuan/m2 respectively. The electricity bill in Suzhou is 0.8 yuan/(kW·h), the discount rate is 8%, and the service life is 25 years.

NPV calculation formula:

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

Where: NPV—net present value

CI—Annual cost savings, yuan

CO—Initial investment, yuan

i—Discount rate,%

t—Service life, years

Calculation formula of static payback period:

ISSN: 0010-8189

$$P = \frac{\text{Initial investment cost}}{\text{Net advanced flow per year}} \quad (2)$$

The energy saving rate and economic analysis of all schemes are shown in Table 7, and the comparison chart between net present value and payback period is shown in Figure 8. According to the table, the trend of net present value and payback period is that the net present value of schemes 4, 8, 9 and 12 is larger, the payback period is shorter, and the energy saving rate of schemes 10, 13, 14 and 16 is higher. 由It can be seen from the figure that the trend of NPV is opposite to that of static investment payback period. The greater the NPV, the shorter the investment payback period, and the more wonderful the surface economic effect. According to the comprehensive evaluation of the three, scheme 9 is selected as the best scheme.

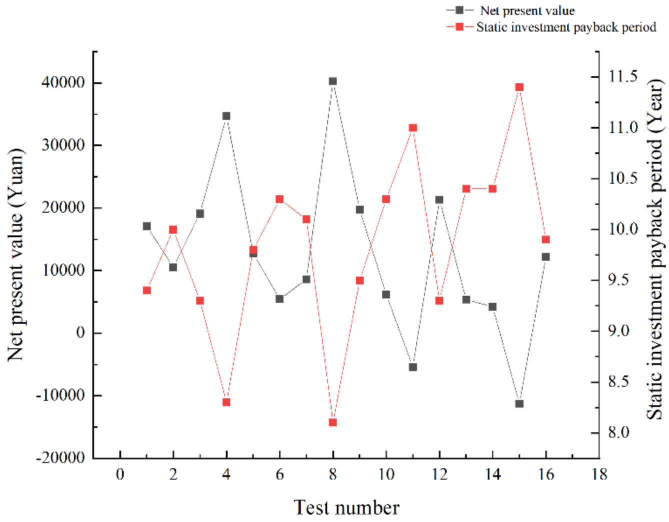


Figure 8 Comparison of energy saving rate and investment payback period of various schemes

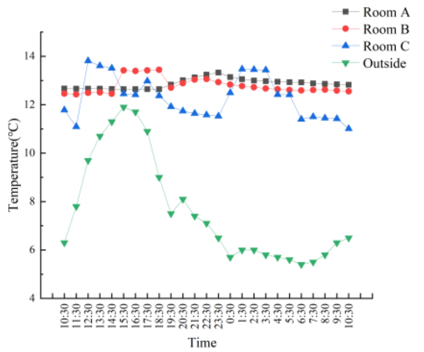
Table 7 Energy-saving rate and economic analysis table of the scheme

Experimental scheme	Energy saving rate/%	Net present value/yuan	Static payback period/year
1	33.14	17127.67	9.4
2	35.96	10558.85	10.0
3	33.04	19109.72	9.3
4	34.11	34693.04	8.3
5	35.8	12748.21	9.8
6	37.7	5413.41	10.3
7	35.81	8611.97	10.1
8	36.77	40240.09	8.1
9	38.6	19775.72	9.5
10	41.32	6169.98	10.3
11	35.76	-5404.78	11.0
12	37.85	21327.67	9.3
13	40.5	5388.5	10.4
14	42.3	4196.1	10.4
15	38.09	-11265.37	11.4
16	38.7	12154.88	9.9

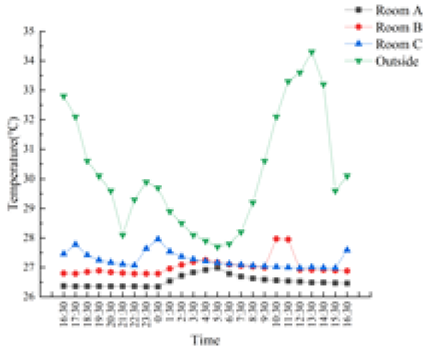
3.5 Energy saving effect analysis

To verify whether the renovation scheme is effective and feasible for Suzhou traditional dwellings, it is necessary to compare the indoor thermal environment before and after the renovation. However, as the renovation scheme cannot be implemented in practice now, the indoor and outdoor temperature is simulated by DeST software, and the simulation results in winter and summer are shown in Figure 9. After renovation, the average indoor temperature in winter is 12.87℃, which is 3.9℃ higher than that before renovation. The average indoor temperature in summer is 26.5℃, which is 2.1℃ lower than that before renovation, which meets the specification requirements [15]. See

Figure 10 for hourly air conditioning load after renovation. It can be seen from the figure that the hourly heat load of the air conditioner is obviously reduced, and the cooling load is 0. Because the maximum tolerable temperature of the air conditioner in summer is set at 28℃, the average indoor temperature after renovation is less than 28℃. After the renovation, the indoor thermal environment has been improved to some extent, which shows that the renovation scheme is effective and feasible.



(a) Simulate indoor and outdoor temperature in winter after renovation



(b) Simulate indoor and outdoor temperature in summer after renovation

Figure 9 Simulated indoor and outdoor temperature in winter and summer after reconstruction

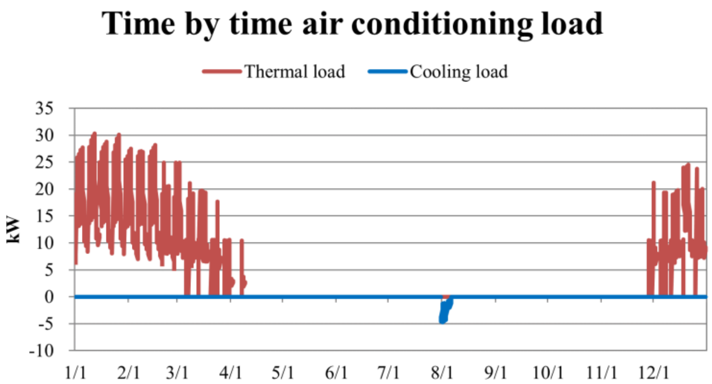


Figure 10 Hourly air-conditioning load throughout the year after renovation

4 Conclusions

In this paper, through indoor thermal environment test and energy consumption simulation of traditional dwellings in Suzhou water town, through economic and feasibility evaluation, the best scheme of energy-saving renovation of dwellings is obtained, and the results are as follows:

Through energy consumption simulation and economic analysis of 16 reconstruction schemes obtained from orthogonal experiment, comprehensive evaluation scheme 9 is the best scheme. That is, the exterior wall is 100mm thick EPS insulation board, the roof is 80mm thick EPS insulation board, and the window is 9mm ordinary insulating glass.

After the renovation, the annual accumulated heat load of the residential building is reduced by 11665.89kW·h, the energy saving rate is 38.6%, and the converted standard coal is about 143t.

Suzhou traditional folk houses were built early, and the indoor thermal environment was poor. Through the design simulation of energy-saving renovation of enclosure structure, the average indoor temperature increased by 3.9℃ in winter and decreased by 2.1℃ in summer, and the indoor thermal environment was improved.

References

1. Zhou Yuzhou, Gong Qian. Research on energy-saving renovation of cold tile roofs of traditional villages in Zunyi area[J]. Urban Architecture, 2021, 18(17): 68-71.
2. Wu Huilai, Tan Hongwei, Deng Feng. Research on the practical research of near-zero energy consumption technology for low-density residential buildings in hot summer and cold winter areas based on measured data[J]. Building Science, 2019, 35(06): 1-8+17 .
3. Liu Xiaozhe, Mo Hongzhi, Rui Ruyi, Wang Haisong. Research on the energy-saving characteristics of traditional residential roofs in Shanghai-Taking Fengxian area as an example [J]. Building Energy, 2020, 48(08): 76-78.
4. Shu Chang. Research on Energy-saving Design of Natural Light Environment in Residential Buildings: Taking Ancient Residential Buildings in Gusu District, Suzhou as an Example [J]. Bulletin of Science and Technology, 2020, 36(09): 66-70.
5. Yang Weiju, Gao Qing, Xu Bin, Yin Shusheng. Inheritance and transformation of low-energy-consumption technology for traditional waterfront residential buildings in Jiangnan water towns[J]. Architecture Journal, 2015(02): 66-69.
6. Cai Ruonan, Sun Zhigao, Yu Hang, Meng Erlin, Wang Junqi, Dai Mengling. Review on optimization of phase change parameters in phase change material building envelopes[J]. Journal of Building Engineering, 2021, 35.
7. May Zune and Lucelia Rodrigues and Mark Gillott. Vernacular passive design in Myanmar housing for thermal comfort[J]. Sustainable Cities and Society, 2020, 54.
8. Phil Symonds, Jonathon Taylor, Anna Mavrogianni, Mike Davies, Clive Shrubsole, Ian Hamilton, Zaid Chalabi. Overheating in English dwellings: comparing modelled and monitored large-scale datasets[J]. Building Research & Information, 2017, 45(1-2).
9. Li Xinyi, Tingley Danielle Densley. Solid wall insulation of the Victorian house stock in England: A whole life carbon perspective[J]. Building and Environment, 2021(prepu blish).
10. Omar Bourass and Aziz Et-Tahir and Kamal Kettani. The Impact of Exterior Walls Materials on Energy Consumption in a Domestic House in Desert Climate[J]. International Journal of Innovative Technology and Exploring Engineering (IJITEE), 2019, 9(2): 4990-4998.
11. Jiang Shuang. Research on architectural skills in the adaptive reuse of traditional houses[D]. Southeast University, 2017.
12. Yuan Liting, Yu Jia, Kang Yanming, Zhong Ke. Sensitivity analysis of the thermal environment of natural ventilated buildings on the external wall and external window thermal insulation performance[J]. Journal of Donghua University (Natural Science Edition), 2020, 46(01) :128-133+155.
13. Zhang Yao, Niu Jiangang. Research on the relationship between the optimization of building exterior wall insulation thickness and design parameterization[J]. Building Science, 2019, 35(12):113-125.
14. Lakhwinder Singh and R. A. Khan and M. L. Aggarwal. Empirical modeling of shot peening parameters for welded austenitic stainless steel using grey relational analysis[J]. Journal of Mechanical Science and Technology, 2012, 26(6): 1731-1739.
15. Jiangsu Academy of Building Research Co., Ltd. Design Standard for Thermal Environment and Energy Conservation of Residential Buildings in Jiangsu Province: DGJ32/J71-2014. [S]. Jiangsu: Phoenix Science and Technology Press, 2014.

ISSN: 0010-8189