An exploration about the Solar Energy Utilization and the Enclosure System Renovation for Rural Residential Buildings in Cold Areas of Northern China——Taking the rural residential renovation design in Zhujialin Village, Linyi as an example

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Abstract. Rural areas in the cold regions of northern China generally suffer from excessive energy consumption, poor thermal comfort, and low thermal efficiency of heating equipment. In order to improve the comfort of rural residential buildings, renovation design has become an indispensable part of the current beautiful rural construction. This paper comprehensively analyzes the current situation of rural residential buildings in cold regions by taking the transformation of a farmhouse in Zhujialin of Linyi City as an example. Moreover, the methods of energy-saving renovation of rural houses are explored from two aspects of solar energy utilization and enclosing system renovation. The research provides a feasible reference for energy-saving renovation of other rural areas in the cold regions of northern China.

1 Survey of rural housing status

Shandong Province has a large population, and the proportion of energy consumption is relatively high. The author conducted a survey on the application status of a variety of farms in different regions and found the following problems.

1.1 Enclosure system

By investigating the current situation of the enclosure system, it is found that the majority of the earlier rural exterior walls are made of ordinary clay bricks, and a few still use the local traditional materials like stones or adobe. With the development of new countryside and the gradual advancement of wall reform, a lot of lightweight materials have been used to build walls, such as ordinary concrete blocks and aerated concrete blocks. However, few insulation measures are taken in the walls. A window is the weakest component of the thermal insulation performance of the outer protective structure of a building. It is found that aluminum alloy windows are popular in the rural areas of Shandong province, and wooden frame windows and steel windows are still used in some buildings. The roof is mostly in the form of a sloping roof or a flat slope. The flat roof is generally directly smeared on the concrete roof slab with cement mortar without a thermal insulation layer. The sloping roof is made of grass mud as the bonding layer and the insulation layer, and the tile is attached thereto.

The heat transfer coefficient of walls in the enclosure system of the cold residential area in the north is between 1.6 and 1.9, the heat transfer coefficient of outer windows is between 5.5 and 6.8, and the heat transfer coefficient of roofs ranges from 1.2 to 1.8. These coefficients are far greater than the limit specified in GBT 50824—2013 Energy Conservation Standard for Rural Residential Buildings, which cannot meet the requirements of relevant energy-saving standards in Shandong Province, resulting in greater energy consumption of buildings.

1.2 Solar energy utilization

From the perspective of passive solar energy utilization, direct benefit and additional sunlight intermittent solar energy have been widely used in rural areas. For active solar energy utilization technology, solar water heating system is a relatively mature and widely used solar energy utilization device. The solar water heating systems used in some rural houses are likely to be affected by the external cold environment in winter and fail to make full use of solar water heaters throughout the year. Due to the limitations of the rural economy, few residents use solar panels. In addition, the form of solar modules is relatively simple, and the integrated design with the farmhouse is poor.

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1.3 Spatial layout

According to the current layout of rural houses, the majority of rural houses in Shandong are independent courtyards, following the traditional courtyards in the north, the courtyards, the walls on either side of the wing, or the three walls. Most houses have one or two floors. As for the functional layout, the courtyard is generally centered, the halls are in the north direction, and the bedrooms are on both sides of the hall. The courtyard is usually in the east-west direction and used as a storage room. In addition, the kitchen and the toilet are often arranged independently on one side of the courtyard, which not only causes inconvenience in use, but also destroys the integrity of the courtyard. Moreover, such layout is not conducive to flexible greening in the courtyard to improve the micro-environment of the farmhouse.

2 Overview of Zhujialin typical rural residence

2.1 Analysis of climatic conditions

The reconstruction object is located in Zhujialin Village, Linyi City, Shandong Province. Linyi is in cold regions. The average temperature is $-11\sim 0^{\circ}\text{C}$ in January and $18^{\circ}\text{C}\sim 28^{\circ}\text{C}$ in July. The meteorological data of neighboring Juxian County are selected for analysis. Through the visualization of meteorological data, it can be found that Linyi is colder in winter and hot in summer, and the temperature is relatively low in winter (Fig. 1). The uncomfortable situation in winter and summer is more serious. The relative humidity is over 60% in most of the year. It is windy in about 80% of a year (Fig. 2), and the wind speed does not exceed 9m/s. Natural ventilation measures are taken in summer to avoid extremely high indoor temperatures. The area is rich in sunshine. Solar radiation comes from all directions, and the highest intensity exceeds $1027.18\text{KW}\cdot\text{h}/\text{m}^2$ (Fig. 3).

Fig. 1. Analysis chart of dry bulb temperature.

Fig. 2. Wind-rose analysis.

Fig. 3. Analysis chart of total radiation.

2.2 Analysis of the current situation of the building

This is a simple courtyard house, with 5 rooms in the square, a kitchen on the west side, a small storage room on the east side, and a toilet in the corner of the courtyard (Fig. 4). The residential house site has an area of 325 square meters and a building area of 134 square meters. The house is made of stone and wood, and the main load is a stone wall 440 mm thick. The U-value of the wall is as high as $2.01\text{W}/(\text{m}^2\cdot\text{K})$. The sloping roof is a wooden beam structure. The roof envelope structure material is concrete rafter, raft insulation layer and red tile from the inside to the outside. The U-value of the roof is $0.96\text{W}/(\text{m}^2\cdot\text{K})$. The wooden doors and windows have been deformed, and the windows are made of single-layer ordinary glass with a heat transfer coefficient of $4.7\text{W}/(\text{m}^2\cdot\text{K})$. Since the farmhouse had no insulation measures and failed to meet the requirements of Energy Conservation Standards for Rural Residential Buildings regarding the heat transfer coefficient limits of rural residential buildings, it is necessary to carry out design research on energy-saving renovation.

Fig. 4. Plan of residential building.

3 Study on energy-saving renovation strategy of rural housing system

The research and analysis results demonstrate that the rural house envelope structure is the most important part of energy conservation, and it is necessary to use energy-efficient building materials with superior performance. The goal of the farmhouse transformation is to transform it into a rural demonstration that combines residence and energy-saving display. Therefore, the space layout was optimized before the renovation of the enclosure system, the storage room on the east side was removed, and an exhibition space and an indoor toilet were added (**Fig. 5**).

Fig. 5. Plan of renovated residential building.

3.1 Improve the insulation performance of the external wall

The exterior walls of Zhujialin's farmhouse are made of stone, which has the characteristics of local architecture. Therefore, the external appearance of the building was preserved during the renovation, and the internal insulation was adopted. An extruded polystyrene board with a thickness of 80 mm and a size of 1200*600 mm was attached to the inner side of the original wall. The outer side of the insulation board was covered with a calcium silicate board 20 mm thick. The U-value of the wall is $0.35\text{W}/(\text{m}^2\cdot\text{K})$. This will greatly enhance the interior comfort of the building.

3.2 Improve the insulation performance of the roof

For the sloping roof, the built-in insulation of the ceiling and the insulation of the sloping roof can be adopted. In the scheme, in order to preserve the structural characteristics of the wooden beam of the roof and the comfort level of the living room, an insulation layer is added inside the slope roof. The insulation layer is made of an expanded polystyrene board with a thickness of 100mm, and the outer side is covered with a calcium silicate board with a thickness of 20 mm. With simple construction and good heat preservation effect, the method can greatly reduce the heat transfer coefficient of the roof. After calculation, the U-value of the roof is $0.24\text{W}/(\text{m}^2\cdot\text{K})$, which meets the requirements of energy-saving design standards.

3.3Improve the insulation of doors and windows

In the scheme, Energy-saving insulated door and hollow glass plastic windows which have the advantages of high energy-saving efficiency and environmental protection are used. At the same time, the energy consumption for producing PVC profiles is much less than that of aluminum profiles, and PVC materials can be reused. After calculation, the U-value of the retrofitted windows drops to $2.40\text{W}/(\text{m}^2\cdot\text{K})$.

4 Study on Solar Energy Utilization Strategy

Passive solar houses are applied in several forms, such as heat collection and regeneration, direct benefit, and additional sunlight. The walls of solar house with heat collection walls are painted with dark color, the overall appearance of the building is affected. Therefore, the scheme uses two types of passive solar houses, namely, direct benefit and additional sunlight.

4.1 Passive solar technology application

In the south bedroom, solar cells that directly benefit are used. During the daytime, the sun shines directly through the south window. At night, when the room temperature decreases, the heat stored in the heat storage material is slowly released, and the heat is exchanged to maintain the indoor temperature. On the south side of the living room, a double-glass plastic window is installed to add sunlight, and the depth is 1.5 meters. The shape of the slope roof is conducive to drainage and increasing the heated area. There are inlet and exhaust vents on the upper and lower sides of the glass to control the ventilation. Heat storage materials are used in the floor to keep the indoor temperature relatively constant. In winter, the sun room becomes an indoor space with comfortable temperature. Shandong province is cold in winter and hot in summer. In order to reduce the influence of solar radiation on indoor temperature in summer, bamboo curtains are adopted as a means of shading (**Fig. 6**).

Fig. 6. Sun space schematic diagram.

4.2 Active solar technology application

In order to further utilize solar energy resources and alleviate the energy pressure of rural domestic hot water and electricity consumption, the integrated design method of solar energy components and rural housing is also discussed in the scheme (**Fig. 7**). Since the roof structure of the original building cannot carry the weight of the solar component, a flat solar collector is provided in combination with the sloping roof shape of the sunlight room and the added part. In addition, a row of trees on the south side of the yard is reserved, and a steel sunshade frame is set up. The PV modules are used as a sun visor for the gallery. The renewable energy of solar energy is fully utilized, and a small courtyard is added. Additional liveliness, vitality, and the specific technical solutions are shown in the figure. The renovation scheme not only retains the traditional style of the northern farmhouse, but also adds simplicity and clarity to modern architecture.

Fig. 7. Solar technology utilization analysis chart.

5 Conclusion

The construction of rural houses has shown a continuous development trend in the past few years, accompanied by the rapid growth of energy consumption in rural houses. Using some feasible strategies in rural areas for energy-saving renovation of integrated enclosure systems and promoting the solar energy technology have become the focus and trend of rural construction. While

inheriting the local fine traditions, we should proceed from reality to improve the comfort of rural houses and create a healthy, comfortable and energy-saving new living environment for farmers.

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