Study on Optimization of Rural Housing Energy-saving Reconstruction Strategy in Severe Cold Area

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Abstract. Unreasonable design of the outer envelope structure of rural houses in severe cold areas leads to high heat consumption index, poor indoor comfort and increased heating cost in winter. In order to solve this problem, this paper takes a rural house in Heilongjiang as an example, establishes a three-dimensional model using BIM technology, calculates the heat consumption of existing maintenance structures, and proposes an energy-saving renovation scheme. The energy-saving percentage is obtained by numerical calculation before and after the energy-saving renovation of the rural houses using building energy consumption simulation software DeST, and the investment cost of the energy-saving renovation scheme is given through economic and technical analysis. The energy consumption of the reconstructed building is reduced, the indoor comfort is improved, and the people's happiness is enhanced.

Keywords: Cold region; Rural housing; Energy-saving renovation; Numerical simulation; Economic analysis.

1. Introduction
For severe cold areas, heating energy consumption in winter is the main component of building energy consumption. How to reduce building energy consumption on the premise of ensuring indoor comfort is an urgent problem to be solved. In severe cold areas, the outdoor climate is cold and dry in winter, and the wind is strong, so the buildings in this area should meet the requirements of anti-freezing, cold protection and heat preservation[1]. As for the farm house, it does not meet the energy-saving standards after construction, which leads to the unsuitable indoor temperature and humidity in winter. However, the way of blindly burning more fuel to improve the indoor temperature can not meet the comfort level, but also cause energy waste and environmental pollution. Therefore, this paper takes a farm house located in a village in Heilongjiang Province as an example, first establishes a three-dimensional model by using revit of BIM technology, understands the existing building conditions, and calculates and gives heating by using static and dynamic methods[2]. According to this building, the energy-saving renovation scheme of optimizing the maintenance structure is put forward. The heating energy consumption before and after energy saving is simulated by DeST simulation software, the energy saving percentage is calculated, and the technical and economic analysis is carried out, which provides reference for improving indoor temperature and humidity environment and energy saving and emission reduction in this area.

2. Overview of the Project
2.1. Introduction of Basic Information of Case Farmhouse
This building is located in Xinhua Village, Harbin City, Heilongjiang Province. It is a single-story
building with herringbone roof and brick-concrete structure. It is 3.3 stories high, 5.7 meters high, 15 meters long and 7.5 meters wide, with a total construction area of 112.5m². It faces north to south, and mainly adopts fire wall, fire resistance and earth heating in winter. It is a typical local farmhouse building. Rooms are divided into three functional rooms: bedroom, kitchen and living room. Figure 1 shows an example of a three-dimensional model and room map established by Revit in BIM technology[3].

Figure 1. Plan and 3D drawing of farm house building.

2.2. Thermal Performance of Case Farmhouse Building
In this case, the rural house was built in 2005, and now the enclosure structure has a good appearance. The exterior wall adopts the structure of coating surface +20mm cement mortar +240mm thick clay brick +10mm mortar plaster +240mm thick brick wall +20mm cement mortar +10mm thick exterior wall facing brick. The overall heat transfer coefficient is 1.27W/m²·K, and the exterior window adopts single-layer aluminum alloy glass window with a heat transfer coefficient of 4.2 W/m²·K. The roof is a herringbone roof, that is, a stuffy roof structure with non-heating space added to the flat roof. The roof structure is made of anti-corrosion sawdust, gypsum, linoleum waterproof layer and tiles, with a total heat transfer coefficient of 0.93W/m²·K, and gravel on the ground. Oolite concrete 1(50.0mm)+ reinforced concrete (250.0mm)+ fine stone concrete (internal reinforcement) (100.0mm)+ compacted clay 1(500.0mm), which belongs to the non-thermal insulation ground with the heat transfer coefficient of 0.47W/m²·K in the first zone and 0.23W/m²·K in the second zone. Heat transfer coefficient is 2.33W/m²·K. If static analysis method of energy consumption calculation based on steady-state heat transfer is adopted, the heat load of east and west exterior walls is 1326W, that of south exterior wall is 1451W, that of north exterior wall is 2281W, and that of total exterior wall is 6384W. The heat transfer load of the south outer window is 670W, the heat transfer of the north outer window is 1053W, the cold air infiltration heat consumption of the outer window is 3353W. The heat consumption of roof is 3974W, the heat load caused by external door is 511W, and the heat load caused by ground is 1868W. The total heat load of the building is 16090W, and the heating heat index is 143W/m². This thermal index is too high, and it does not meet the design standard of 65% energy saving of residential buildings in Heilongjiang Province through calculation[4]. It consumes a lot of heat, has high energy saving potential, and has high necessity of energy saving transformation.

It can be clearly seen that the heat load caused by each maintenance structure can be sorted into external wall, roof, external window, ground and external door according to the heat load, so the maintenance structure with a large proportion of heat load can be given priority in energy-saving renovation. Therefore, in this case, the external walls, windows and roofs which cause more heat load are reformed, so as to achieve the energy saving effect[5].

3. Comparative Analysis of Energy-saving Transformation Strategies and Effects

3.1. Transformation Scheme
In this case, the maintenance structure of the outer wall, outer window and roof is optimized to reduce the heat transfer coefficient and indoor heat dissipation[6], so as to achieve the effect of energy saving and heat preservation. The exterior wall can be added with EPS expanded polystyrene board, XPS...
extruded polystyrene board, EIFS polyurethane insulation board and other insulation materials based on the original exterior wall. In this case, polystyrene board with 100mm thick steel wire mesh frame was added, which reduced the heat transfer coefficient to 42.44%. In the energy-saving renovation of exterior windows, it is necessary to consider the premise of not affecting lighting needs, and minimize the heat transfer caused by exterior window envelope and the cold air infiltration heat consumption caused by gaps. In this case, the original single-layer aluminum alloy glass window was replaced with aluminum alloy hollow glass window with emissivity $\leq 0.25$. LOW-E, and the heat transfer coefficient was reduced by 28.57%. The roof was reconstructed by adding insulation layer, which was made of 50mm polyurethane foam, and the heat transfer coefficient was reduced by 42.15%. The enclosure structure form and heat transfer coefficient after energy-saving transformation in this case are shown in Table 1.

Table 1. Energy saving reconstruction scheme of each enclosure structure.

| Exterior protected construction | Structural form | Heat transfer coefficient ($W/m^2K$) |
|--------------------------------|-----------------|-------------------------------------|
| Exterior wall                  | Add 100mm thick steel wire mesh polystyrene board | 0.539 |
| Outer window                   | Aluminum alloy emissivity $\leq 0.25$. LOW-E hollow glass window | 3.0 |
| Roof                           | Add 50mm polyurethane foam for insulation | 0.538 |

3.2. Comparative Analysis of Energy Consumption before and after Energy-saving Transformation

Dynamic simulation of heat consumption is carried out by using DeST software, and the comparison of accumulated heat load of each functional room in heating season before and after energy-saving renovation is shown in Figure 2.

Figure 2. Cumulative value of heat load heating season before and after transformation.

It can be seen from the above figure that after adopting the energy-saving scheme, the accumulated heat load of each functional room in the heating season shows a decreasing trend, and the decreasing degree is close to that, which indicates that adopting energy-saving measures reduces the heating energy consumption, thus improving the indoor temperature. At the same time, the simulation tool also obtains the annual cumulative heat load index of the original scheme and the optimized scheme. It is 192.18KWh/m$^2$ before optimization and 131.68KWh/m$^2$ after optimization. Through calculation, it can be concluded that the annual cumulative heat load index is reduced by 60.5KWh/m$^2$ and the energy saving percentage is 31.48%.
4. Economic Analysis of Optimization Scheme
For users of rural buildings, comfort and investment cost should be balanced. We can't simply pursue energy-saving potential without considering investment, and we can't only consider cost saving without energy-saving transformation. Therefore, it is more comprehensive and reasonable to evaluate the optimization scheme by integrating energy-saving potential and economic benefits. In this case, every maintenance structure optimization will cause corresponding expenses and costs. The cost includes material cost and construction cost. After consulting data and market research, it is found that the cost of adding polystyrene board with steel wire mesh frame to the exterior wall is 60 yuan /m², the cost of adding 50mm polyurethane foam to the roof is 55 yuan /m², and the investment for replacing aluminum alloy hollow glass windows is 1,200 yuan/group. According to the actual size of each envelope in this case, combined with the unit price information of renovation, the total cost of renovation scheme and the cost of saving energy consumption per unit percentage can be achieved. The energy-saving optimization scheme not only improves the indoor temperature, but also reduces the coal consumption. Through calculation, it can be concluded that saving 1% of energy consumption can reduce 0.061 tons of coal. According to the price of anthracite per ton of 1000 yuan, reducing 1% of energy consumption can save the cost of 61 yuan. The cost unit price and net cost unit price of the optimized scheme are shown in Table 2.

Table 2. Unit price table of net cost for energy saving of 1%.

| Total renovation price (RMB) | Unit price for saving energy by 1% (RMB) | Save the cost of coal consumption (RMB) | Energy saving 1% net unit price (RMB) |
|-----------------------------|---------------------------------|---------------------------------|---------------------------------|
| 18,730.5                    | 594.97                          | 61                              | 533.97                          |

It can be seen from the above table that based on the optimization scheme and the calculation of construction materials and labor costs, the total investment of the reconstruction scheme is 18,730.5 yuan, and the energy saving percentage is 31.48%. Through calculation, the investment cost of saving energy by 1% is 594.97 yuan, and the net unit price when saving energy by 1% is 533.97 yuan RMB.

5. Conclusion
(1) Building a BIM three-dimensional model, based on the original maintenance structure, through the static analysis method, calculating the total heat consumption, it is concluded that the heating heat index is very high, the existing building is in a non-energy-saving situation, and energy-saving optimization is needed. By comparing the heat consumption of each maintenance structure, it is concluded that the heat consumption of exterior wall, exterior window and roof is high, so it is necessary to transform and optimize these three types of envelope structures.
(2) The optimization scheme of energy saving and consumption reduction is put forward. The polystyrene board with 10050mm thick steel wire mesh frame is added to the outer wall surface, the polyurethane foam insulation layer is added to the original roof, and the outer window is replaced by aluminum alloy hollow glass window with emissivity ≤0.25.LOW-E without affecting lighting. By simulating the energy consumption before and after the transformation with simulation software, it is calculated that the transformation optimization scheme can save 31.48% of energy consumption.
(3) Through economic and technical analysis, the total cost of the optimized scheme is 18,730.5 yuan, and the investment cost of saving energy by 1% is calculated to be 594.97 yuan. If the coal price is saved, the net unit price when saving energy by 1% is 533.97 yuan. The energy saving rate and the comprehensive benefit of investment should be considered comprehensively when the rural house is reformed.

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