Application and Economic Analysis of Energy-Saving Wall Materials in Low-Income Rural Areas of China

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Abstract. China's rural buildings are large in scale. Most of them are not energy efficient. New wall materials play a significant role in energy-saving building. However, the slow promotion in low-income rural areas has affected the energy conservation and emission reduction of rural buildings. Based on the survey data, the economic evaluation method of energy saving wall materials in rural buildings is proposed, and a static recovery period model is established. The cost and benefit of the sample are calculated. The research results will help solve the problem of popularizing technologies in low-income rural areas.

1. Introduction

Existing buildings in China are 43 billion m². Rural buildings account for 60% of total building area, about 1 billion m², and more than 95% of them are non-energy-efficient buildings. The total demand for building wall materials in China amounts to 1 trillion bricks (standard bricks). 80% of clay solid bricks are used in rural areas [1]. Most of the brick-making factories are township enterprises located in rural area. In 2004, in order to promote the production of new wall materials for energy saving, the Ministry of Agriculture undertook the responsibility for the reform of the national wall materials [2]. This program has achieved remarkable results during last decade. Through the brick industry, it has stimulated the local economy and promoted the energy saving of rural buildings. But there are still some problems in low-income rural area [3]. The increased cost of energy-efficient wall materials has affected their application. Studying the relationship between the cost and benefit of energy-efficient wall materials provides a direction for solving the above problems.

2. Literature review

2.1. The development and application of energy-saving wall materials in rural areas in foreign countries

Foreign countries have conducted a lot of research and application of rural energy-saving buildings and their application technologies. Especially in North America, Europe and other countries, based on the requirements of energy conservation, environmental protection, and economy, large research funds have been invested in rural energy-saving buildings and many new technologies have been developed.
New energy-saving building wall materials play a greater role in energy-saving buildings. New energy-saving building wall materials play a greater role in energy-saving buildings. Therefore, it is the focus of research and development. Due to the small population, the urban suburbs and countryside buildings in developed countries are one or two-story buildings (figure 1). Because of the high industrialization of the villages and towns, envelope is mainly based on assembly standard wall panels and decorative materials. Figure 2 is a structure integrated with thermal insulation and exterior decoration layer. In figure 3, it is a concrete block filled with wood chips of waste recycling. Wooden structure is used mostly in Canada and American (figure 4). Other types of wall are the straw bale wall and light steel structure wall.
2.2. Development and application status of domestic rural energy-saving wall materials

2.2.1. Rural building structure systems. China's rural construction is mainly a brick-concrete structure. China's rural buildings are mainly one-story detached buildings, which are brick-concrete structures. In the rural areas with good economic conditions in the south, there are more houses of one floor to four floors, which are concrete frame structures. With the development of energy-saving projects in rural buildings, some areas have begun to apply light-weight steel wall insulation panels. Light insulation panels include ASA panels, cement composite panels, and wood wool composite panels. This system is an energy-saving system for assembling walls. It has the features of light structure, light wall material, light roof plate, light floor, and good wind-resistant and shock-resistant performance (figure 5 and figure 6).

![Fig.5. Cross sections of ASA panel](image1)

![Fig. 6. Connection detail of ASA panel and steel column](image2)

2.2.2. Application status of rural building materials. In the past, rural construction uses a lot of clay solid bricks. Heat transfer coefficient of clay brick wall is large, difficult to meet the energy-saving requirements. The producing clay bricks consumes a lot of energy, polluting the environment, destroying farmland, and affecting the ecological environment of rural areas. After the clay solid bricks using prohibited, the wall material of rural buildings changed Clay solid bricks replaced with energy-saving wall materials, such as non-clay porous bricks or hollow bricks, concrete hollow blocks and aerated concrete hollow block. Because of price and other reasons, block and hollow bricks is less than 40% of the total amount of wall materials in China (figure 7). The use in rural areas is less than 10% [4]. In low-income rural areas, materials for wall are mainly clay bricks. The total output is 500 billion, accounting for 60% of the total wall material, and the energy consumption is over 50 million tons of standard coal.

![Fig. 7. The proportion of different materials of rural buildings in low-income areas of China](image3)
3. Method

Cost-benefit analysis is a method of assessing the value of a project by comparing the full costs and benefits of the project \(^5\). It can be calculated directly at market prices or measured by different economic measures. Incremental cost can also be used as a cost-benefit analysis method for comparing different technical means to assess the impact of additional benefits generated by different technologies. Due to the large number of factors involved in the overall cost of building statistics, the cost-benefit analysis method of this project is aimed at incremental cost-benefit analysis methods. Incremental cost refers to the additional cost incurred by the construction entity when it adopts a new technology, new material, or new product under the premise of meeting the building function, compared to the conventional construction practice of the building in the local energy-saving building.

3.1. Incremental costs of rural energy-efficient brick buildings

3.1.1. Incremental cost.

The material cost increment is the energy cost of energy-saving buildings using energy-efficient bricks, comparing with local ordinary bricks. The increase in construction cost is compared with the construction of ordinary bricks, increasing cost caused by the construction load and complexity of energy-efficient bricks.

3.1.2. The overall benefits of energy-efficient bricks. Reducing energy consumption costs: Compared to conventional buildings, rural energy-saving buildings have lower energy consumption costs. For example, the energy-saving building will use less electricity of air-conditioning, and coal consumption for heating will decrease in winter. Reducing environmental improvement costs: As the consumption of electricity or coal is reduced, the amount of carbon emissions of the rural buildings will be brought down. It is the environmental value of carbon emission reduction in rural society. It is estimated that in the future, the price of emission reduction during the period 2020-2030 can reach to 30-40 dollars per ton. The equivalent of RMB is about 198-264 yuan/t.

3.2. Evaluation of the overall benefits obtained under incremental costs

To evaluate the overall benefits obtained under incremental costs, investment payback periods can be used to describe. The payback period refers to the number of years that the investment is recovered through the return flow of funds, divided into the dynamic investment payback period and the static investment payback period. The static investment payback period is the time required to recover all of its investment based on the net income of the project without considering the time value of money, which can intuitively reflect the return period of the original total investment. The disadvantage is that it does not consider the time value of money and the cash flow that occurs after the payback period expires.

The dynamic investment payback period is to convert the net cash flow of each year of the investment project into the present value according to the benchmark rate of return, and then calculate the payback period. The dynamic investment payback period is the year when the present value of the accumulated net cash flow is equal to zero. The cost-benefit analysis of rural energy-saving wall materials can be limited to the initial investment stage. Thus, the static payback period is appropriate for evaluation. Energy-efficient wall materials in rural areas produce similar benefits each year.

The static payback period can be described as follows:

\[
P_j = \frac{\Delta B}{\Delta C}
\]

\[
\Delta B = \Delta A \times C + \Delta A \times f \times C_c
\]

\[
\Delta C = C_n - C_0
\]

In the formulas:
$P_i$: Static investment payback period, (year);
$\Delta B$: The overall benefits of technology, (yuan);
$\Delta C$: Increase in cost, (yuan);
$\Delta A$: The amount of standard coal equivalent (ton) or power consumption (degree) saved after the implementation of new technologies each year;
$C$: Local raw coal price or electricity price. The price of raw coal in different regions of China is about 800~1200 yuan/ton (average value 1000 yuan/ton). Electricity price is 0.5~0.6 yuan/degree (average value 0.55 yuan/degree). 1 ton raw coal converts to 0.7143 t standard coal. 1° electricity converts to 0.404 t standard coal.
$f$: Raw coal emission factor GHG 0.7559 kg(C)/kg (standard coal) (IPCC National Greenhouse Gas Emission Inventory Guide). Emission factor GHG for purchasing electricity 0.623kg/kW·h.
$C_c$: Price of carbon sequestration, 230.7 yuan/t.
$C_n$: Construction cost of energy efficient building in rural areas after application of new technology, (yuan).
$C_0$: Construction costs of conventional rural construction practices, (yuan).

4. Results

External insulation is a common practice in rural energy-saving buildings at present. The wall materials are mainly porous brick or non-clay brick. In table 1, W1 and W2 are benchmarks for comparing the cost of new energy-saving wall materials. The cost in table 1 is only calculated for the main part of the wall, accounting for each wall. It needs to be converted and then compared under the same condition. The sample is 10 buildings in two districts, with new wall materials. The research sample is 10 buildings in two districts with new wall materials. The contents of table 3 are obtained by statistics. Data of table 4 is calculated based on it of table 1, table 2 and table 3. Table 4 shows that there is a certain difference between incremental cost and energy saving cost in different climatic zones, so the static investment payback periods are not equal, within an average of 10 years.

**Table 1. Construction cost list of external insulation wall in rural buildings**

| NO. | Type of wall | Wall construction | Thermal design climate zone | Material cost (yuan/m²) | Labour and equipment cost (yuan/m²) | Total cost (yuan/m²) |
|-----|--------------|--------------------|-----------------------------|-------------------------|-------------------------------------|----------------------|
| W1s | Porous brick + EPS | Mixed mortar + perforated brick + cement mortar +EPS + adhesive + glass fibre mesh cloth + polymer mortar | Severe cold region | 4.65+77.49+8.03+27.3+0.56+1.67+2.44=122.14 | 53.53+31.73 =85.26 | 207.4 |
| W1c | Cold region | 4.65+77.49+8.03+18.9+0.56+1.67+2.44=113.74 | 53.53+31.73 =85.26 | 199.0 |

| W2s | Non-clay solid brick + EPS | Mixed mortar + non-clay solid brick + cement mortar +EPS + adhesive + glass fibre mesh cloth + polymer mortar | Severe cold region | 4.65+63.71+8.03+29.4+0.56+1.67+2.44=113.46 | 61.20+31.73 =92.93 | 203.39 |
| W2c | Cold region | 4.65+63.71+8.03+21+0.56+1.67+2.44=102.06 | 61.20+31.73 =92.93 | 194.99 |

**Table 2. Conventional construction cost of energy saving buildings in rural areas**

| Type of wall | Severe cold region (yuan/m²) | Cold region (yuan/m²) |
|--------------|-------------------------------|-----------------------|
| Porous brick + EPS | 802.2 | 836.7 |
| Non-clay solid brick + EPS | 790.1 | 823.4 |
| Average value | 796.2 | 830.1 |
Table 3. New energy saving wall material cost

| Thermal design climate zone | Type of energy-saving brick | Average of total cost (yuan) |
|-----------------------------|-----------------------------|-----------------------------|
| Severe cold region          | Gangue porous brick, shale sintering energy-saving thermal insulation block | 1360 |
| Cold region                 | Porous shale brick          | 1000 |

Table 4. Benefits and static investment recovery period of new energy saving wall materials

| Thermal design climate zone | Coal saving equivalent (kg/m². Year) | Cost saving (yuan/m²) | Static investment recovery period (year) | Cumulative construction area (million m²) | Total energy conservation (ton coal) | Carbon reduction (ton carbon) |
|-----------------------------|-------------------------------------|-----------------------|----------------------------------------|------------------------------------------|-------------------------------------|-------------------------------|
| Severe cold region          | 20.7                                | 24.1                  | 11.2                                   | 0.3874                                   | 8019.18                             | 6061.7                        |
| Cold region                 | 13.2                                | 15.4                  | 7.3                                    | 0.5288                                   | 6980.16                             | 5276.3                        |

5. Conclusion
Based on the fact that the energy saving wall materials in low income rural areas are difficult to popularize, the economics of these materials are analyzed in this paper. Through field investigation, data collection and theoretical analysis and comparison, the method of the cost benefit of project promotion project is given as the evaluation index of the static investment recovery period, and calculation method of the static investment recovery period in the rural energy saving building is also proposed. In future studies, investment recovery period evaluation reference should be refined in smaller areas and with local features to make the model more accurate.

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