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Analysis of Energy Saving Status of Rural Residential Buildings in Northern China

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Abstract. Based on the characteristics of rural architecture in China and the living habits of farmers, this paper investigates the research status of domestic passive energy-saving technologies and active-passive combined energy-saving technologies and their application effects in rural residential buildings, and draws guiding conclusions for rural residential design and renovation in northern areas.

1. Preface

With the rapid development of China's social economy and the continuous acceleration of urbanization process, energy consumption has increased dramatically. China's rural areas are wide-ranging, and the improvement of farmers' living environment and the improvement of living standards will inevitably lead to a significant increase in energy consumption in rural residential buildings. According to the "Annual Report on China Building Energy Efficiency (2016-2018)", The energy consumption of rural residential construction commodities increased from 193 million tce in 2006 to 223 million tce in 2016, accounting for 25% of the total building energy consumption in the country. According to the research data of Tsinghua University on the energy consumption of rural buildings in China, the energy consumption of rural heating in northern China accounts for about 53.6% of the total energy consumption of rural life, it is equivalent to the energy consumption of buildings that use coal-fired boilers for direct heating in northern towns.

Under the new era, buildings carry people's needs for a healthier and more comfortable living space. With the implementation of the rural revitalization strategy, speeding up the resolution of the contradiction between residential comfort and increased energy consumption in rural areas, carrying out energy-saving design and transformation of rural residential buildings and improving their energy efficiency are in line with the important issue of "Accelerate the reform of the ecological civilization system and build a beautiful China" in The 19th National Congress of the Communist Party of China, It is also an important part in the implementation of the strategy of rural revitalization and the construction of beautiful villages.

2. The status quo of rural residential building in the north

2.1 Basic situation of the building



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The technical conditions and construction means of rural areas of China are relatively backward and farmers' understanding of building energy conservation is insufficient. In the process of building construction, most of them are designed and constructed according to the local residential style and according to their owner's wishes. According to the survey of Ruijun Sun et al. [1], the shape coefficient of rural residential buildings in northeast China is more than 0.7, which is twice times that of urban residential buildings. The greater the body size coefficient of the building means the greater the heat dissipation surface per unit area. The research by Harbin Institute of Technology, Meng Zhen et al. [2] found that the body shape coefficient decreased by 0.1 and the heating energy consumption decreased by 15.57%. Their choice of building materials is also based on the principle of economics at the time of construction, and the selection of relatively backward traditional building materials. There is little involvement in the orientation of the building, the spatial layout, and the insulation of the enclosure. According to a survey conducted by Bo Song et al. [3] of China Academy of Building Research on 883 rural houses in northern China, 80% of the external walls of rural houses have no insulation layer, and the walls are mostly 370mm or 240mm solid clay bricks, generally there is no insulation measures. Farmhouses tend to have large window walls, 87% use single glass or aluminum alloy windows, poor sealing and large heat transfer coefficient; 85% of the roof has no insulation layer, and the floor has no insulation. The thermal insulation performance of the house is poor, which cannot meet the energy-saving requirements, and cannot meet the people's requirements for indoor thermal comfort.

2.2 Residential heating situation

In the northern rural areas, the heating means is mainly by stove or heated brick bed, 74% use coal as heating source, 21% is fuelwood, and other heating methods only account for 6%. But the average thermal efficiency of furnace heating is only 15%-25%, resulting in a serious waste of energy [1]. The most common heated brick bed is ground-based, and its thermal efficiency is around 45% [4-6]. As a supplementary heating method, rural heating radiator is characterized by a continuous heat source. In the rural areas, coal-fired furnaces are used as heat sources. The cost is large, the comfort is poor, the pollution is serious and its thermal efficiency is only 40% [1, 7].

3. Passive energy-saving technology in rural residential buildings

3.1 Introduction to Passive Energy Saving Technology

Passive energy-saving technology refers to the basic non-installation of additional equipment, through the building orientation and the surrounding environment of the rational arrangement, the internal space structure and external form of the ingenious treatment, as well as the maintenance of the structure and reasonable selection of building materials to achieve the purpose of improving the indoor air environment, saving building energy consumption. Passive architecture does not mean not consuming energy, but enabling it to use renewable energy to the greatest potential, reducing the use of conventional energy.

3.2 Passive energy-saving design in rural residential buildings

3.2.1 Energy-saving Measures for Insulation and Insulation of Envelope Structure

According to Ruijun Sun et al. [1] calculation and analysis heat consumption of a typical rural residence in Changchun City, Jilin Province, it is concluded that the residence's external wall of this farm is 490mm solid clay brick, its roof is prefabricated hollow floor slab, its exterior window is double-decker wooden window, and its enclosures heat consumption accounts for about 87.3% of the total heat consumption, energy-saving space is huge, energy-saving design and transformation of the enclosure structure can greatly improve energy utilization rate and reduce the energy consumption of rural buildings. At present, there are many researches on the insulation structure of the envelope structure in China: Jiaping Liu et al. [8] Xi'an University of Architecture and Technology based on the

steady-state heat transfer theory, using DOE-2 simulation software to construct the building envelope in the severe cold area. The heat transfer coefficient of exterior wall and exterior window shows a good linear relationship with the heating energy consumption per unit area, and the heat transfer coefficient of exterior wall increases $0.1 \text{ W}/(\text{m}^2 \cdot \text{K})$, the heating energy consumption per unit area increased by about 3 W , and the heat transfer coefficient of the exterior window increased by $0.1 \text{ W}/(\text{m}^2 \cdot \text{K})$, the energy consumption per unit area heating increased by about 1.2 W . Hong Jin et al. [9, 10] from Harbin Institute of Technology applied grass-sand sandwich insulation to a wall in Daqing City, Heilongjiang Province, and analyzed energy consumption in an experimental farmhouse with a composite insulation of grass and rice husk. The thermal resistance of the maintenance structure is more than twice that of the traditional brick wall, and the energy saving rate is over 65%. Baozhu Cao et al. [11] of Jilin Institute of Architecture and Engineering proposed a light steel structure as the force skeleton for the rural residential area in Northeast China. The 200-400mm straw grass brick was used as the envelope structure, and the grass mud and cement mortar were used as the wall decoration. This new load-bearing and retaining system, not only the unit cost is 150 yuan cheaper than the traditional red brick masonry building, but also the energy-saving effect has reached the North region building energy saving 50% or even 65% requirements.

3.2.2 Other Passive Energy Saving Measures

In addition to the research and exploration of envelope materials, some domestic groups have explored other passive energy-saving means, such as collecting heat storage walls, passive sunlight, direct benefit windows, Dengjia Wang et al. [12] Xi'an University of Architecture and Technology, Experimental tests were carried out on the Trombe wall solar house in the Qinghai-Tibet Plateau. Through the analysis of the radiation intensity of the sun, the temperature and heat flux density of each point of the wall, it is clear that the heat collecting wall has good heat collecting and heat storage performance, and the solar room with heat storage wall can get 52.6 MJ of heat in the whole day compared with the ordinary building, so that the average indoor temperature is 17.6°C higher than the outdoor; the energy saving rate is up to 72.8%. Jianfei Chen et al. [13] from Harbin Institute of Technology used Ecotect to analyze the energy-saving effects of passive sunlight in a rural farmhouse in Northeast China, and simulated the building models between the sun and the sun. Analysis of the monthly energy consumption shows that the total energy consumption can be saved by about 10.4% in the setting of sunlight. Shiwei Yang et al. [14] of North China University of Technology used fluent Airpak software to carry on the steady-state numerical simulation of the heat storage wall, it is concluded that most of the heat of the heat storage wall is concentrated near the vents, and if the hot air can be evenly distributed in the room through other disturbances, the energy saving rate will be higher.

4. Research status and application of active-passive combined energy-saving technology

In order to realize the popularization of low-energy buildings in rural areas, it is necessary to consider the optimization of passive technology and active technology while applying passive energy-saving measures in buildings. According to our research team using DeST-h simulation software to analyze the impact of the insulation performance of the maintenance structure on the energy consumption of building heating, it is found that we cannot blindly improve the energy saving ratio of the building by increasing the insulation performance such as the enclosure structure, and other auxiliary energy-saving measures should be adopted if necessary [15]. Dengjia Wang et al. [16] of Xi'an University of Architecture and Technology carried out a comprehensive test on a set of 100 demonstration buildings in the Qinghai-Tibet area. The results showed that passive solar technology had a significant improvement on the hot and humid environment in the building, which could basically meet the requirements of comfort in the heating transition period, but the comfort of the coldest months was difficult to meet, and active heating technology should be added. Therefore, in order to fully reduce the energy consumption of buildings and ensure the indoor thermal comfort of extreme weather and the stability of room temperature throughout the day, the active and passive

energy-saving measures will be combined to establish the main passive combination of low-energy house. China's existing active-passive combined low-energy housing is mainly active-passive combined solar heating technology, which combines active solar heating with passive solar heating technology to make full use of solar heating to reduce building heating energy consumption.

According to our research team and Wensheng Ma et al. [14, 17] from China Academy of Building Research, conducted a solar energy active heating system in a rural nursing home in Huzhu County, Haidong City, Qinghai Province in 2017, and the coupling of the solar passive heating system with the heat storage wall and the direct benefit window. The results show that in the Solar Kang full-day operation and heat storage wall daytime operation of the coupling mode, it can save 2.725kg of standard coal by solar heating, reduce emissions of carbon dioxide 6.732kg, sulfur dioxide 0.055kg, dust 0.027kg, save 8.37 yuan in electricity, solar room energy saving rate reached 64.2%; In 2018, the experimental test of the active-passive combined heating system was carried out on a newly built self-occupied farm house had been applied a passive and additional sunlight, passive direct benefit window and active direct expansion solar-air source heat pump the end of floor radiant heating in Guide County, Qinghai Province, the results show that the annual energy saving rate of this heating system is 30.3%, and it also achieves good energy-saving effect.

5. Summary and prospect of energy-saving design of rural residential buildings

5.1 Analysis of passive energy-saving measures in rural residential buildings

The application and research of passive energy-saving technologies must be directed to the local geographical environment, climate characteristics, people's living habits and cultural background. It is necessary to adapt to local conditions and cannot simply copy and apply existing research results or technologies. If the use of urban construction technology and construction methods in rural areas will be difficult to control the rapid growth of rural building energy consumption.

Most rural houses are self-constructed, so economics is an important factor restricting the popularization of building energy-saving technologies. Low-tech, low-cost passive energy-saving design can be more suitable for the promotion in rural areas. Good thermal insulation performance can effectively improve the energy saving ratio of buildings; the application of direct benefit window can further enhance the comfort of the interior; the application of Trombe wall can obviously improve the energy saving effect, if the hot air concentrated in the air supply opening can be evenly dispersed to achieve indoor circulation, it will achieve better energy saving effect.

5.2 Application analysis of active and passive combined energy saving measures in rural residential buildings

According to the distribution map of solar energy resources in China, the northern regions of China are located in the solar zone I and II resource areas. The annual sunshine hours are 3000-3300h, and the total amount of solar radiation received in one year per square meter is 5860- 8370MJ, equivalent to the heat generated by the burning of 200-285kg standard coal [18], China's solar energy resources are abundant; most of the rural houses in China are one- or two-story single-family buildings, according to Huaiyun Guo et al. [19] on the northwest of the rural residential survey to obtain the Northwest rural flat roof ratio is more than 70%, for the solar photothermal heating system to provide adequate layout space.

5.3 Prospects for rural low-energy buildings

Facing the complex geographical environment of the countryside and the economic conditions that lag behind the city, it is not realistic to rely on auxiliary equipment to reduce the conventional energy consumption of the active energy-saving measures, even if the energy-saving effect is remarkable. Since the investment of energy-saving equipment for rural residents, it is necessary to rely on the government's strong support and financial subsidies, and the active energy-saving technologies can be widely used in rural buildings. Compared with the active energy-saving measures passive

energy-saving technology is relatively cheap, more suitable for rural residential buildings energy-saving design status quo, but in extreme weather conditions, simply rely on passive energy-saving technology for heating, cannot meet the requirements of people's comfort. According to the analysis of the economics of active and passive solar heating systems by Min Wang et al. [20], the active-passive combined solar heating system is more economical and more cost-effective. In addition, the density of rural buildings is small, and when designing and constructing rural houses, it can provide sufficient creative space for active and passive combined energy-saving design. Therefore, the combination of passive energy-saving design and active solar heating system will be an important way to realize low-energy consumption building in rural areas.

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