

Article

Design of Green Assembled Rural Houses in Xuzhou

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Abstract: Based on understanding the current situation of rural houses, we propose a new way of building rural houses which are environment friendly and correspond to modernization and urbanization. The prefabricated house with the functions of renewable energy use, effective energy use, and sustainability can be a solution to problems that the existing rural houses have had in China. For reducing construction waste, the prefabricated house can use recycled materials from construction sites. For using renewable energy, the solar water heater is proposed to be included in the design of the houses. For large temperature variations in seasons, appropriate design of façade, planting on buildings, and sunshades need to be installed with the harmonization of the house design. The development of modern technologies needs to be reflected in the design of new rural houses in various design elements as the proposed prefabricated house. The new design helps farmers improve their quality of living, recognize environmental problems, and finally adopt new measures for saving energy and environmental protection. The new design of rural houses is expected to promote the sustainable development of the rural community.

Keywords: Green energy saving, Fabricated building, Farmhouse

1. Introduction

Xuzhou has a vast rural area. With the increasing industrialization, the rural ecological environment is deteriorating day by day. The dirty, messy, and poor environment has become common in several rural areas of Xuzhou, which has seriously affected the quality of life of rural residents. In recent years, rural buildings have increased rapidly every year, and the energy consumption of rural buildings in Xuzhou is also increasing. Xuzhou has a typical climate of hot summer and cold winter. The rural building in this area is small and relatively scattered. Most of them are single-story buildings, which need cooling in summer and heating in winter, so the energy consumption is huge. Due to the energy waste and the rapid deterioration of the rural ecological environment, it is urgent to study new ecological energy-saving rural houses suitable for Xuzhou, China [1].

2. Current Situation of Rural Housing in Xuzhou

Jiangsu is located in the Yangtze River basin with a harsh climate. Xuzhou, Jiangsu Province is located in the east of China and the middle of the Huaihai region, between 116°22'–118°40'E and 33°43'–34°58'N. It is located at the junction of Jiangsu, Shandong and Henan, and Anhui provinces. The number of days with a temperature of less than 5 °C which is an annual average is 97 days. The average temperature in spring and fall is 16 °C. The number of days in summer with a temperature of higher than 26 °C which is the daily average temperature is 49 days, with a long duration. The sum of winter and summer is 146 days, accounting for 40% of the number of days in the whole year [2].

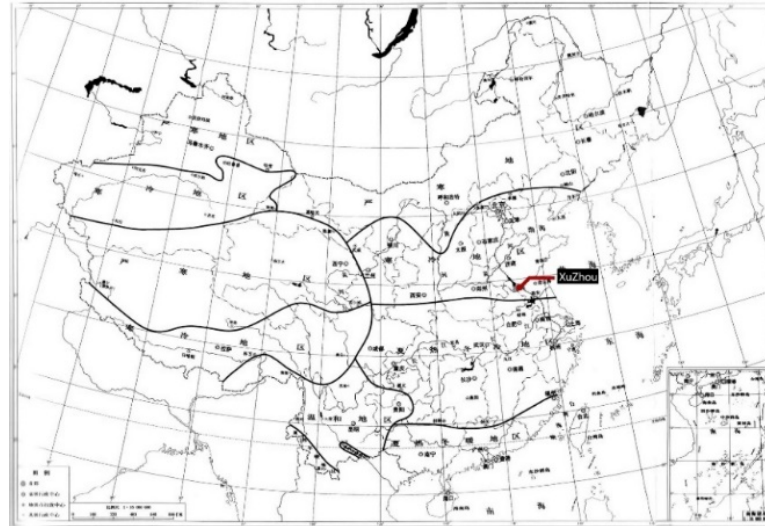


Fig. 1. Location of Xuzhou building thermal design zoning.

Xuzhou is a representative city in the cold area of Northern Jiangsu. Its climate is characterized by dry and cold winter and relatively less hot, humid, and extreme weather in summer [3].

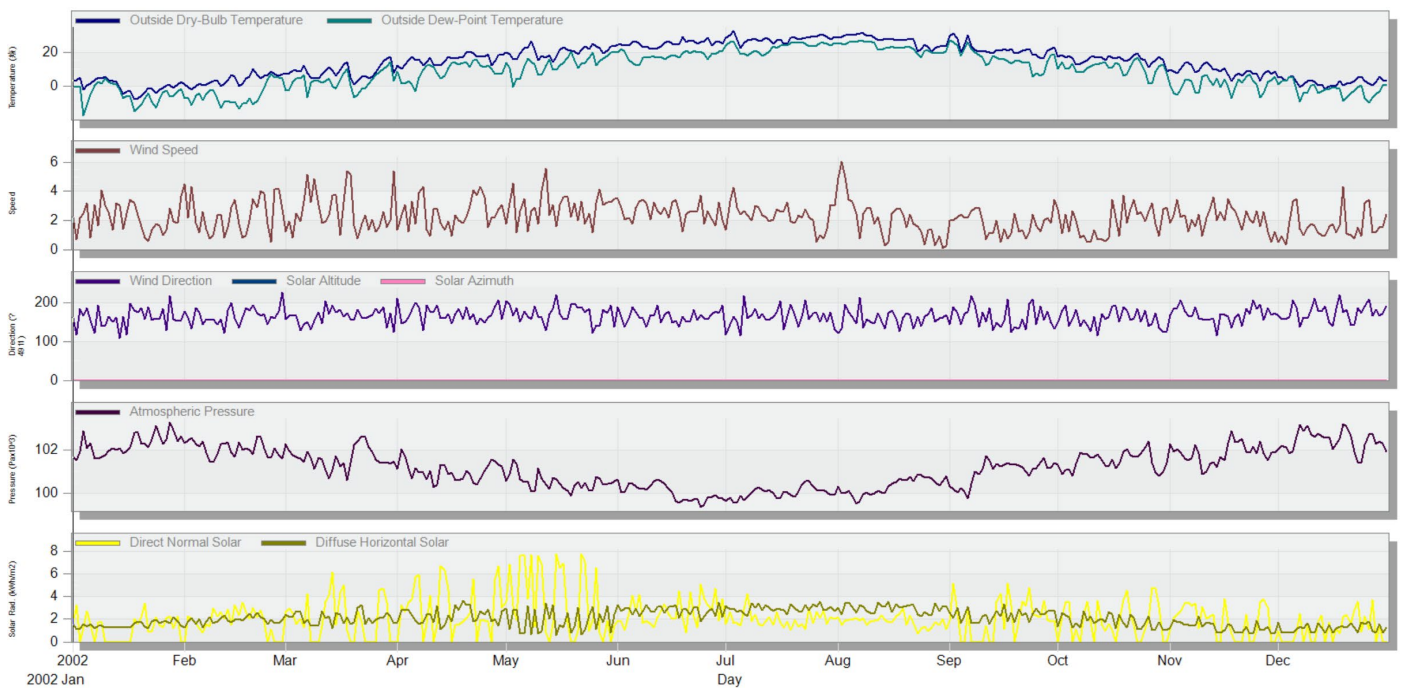


Fig. 2. Xuzhou meteorological data.

3. Problems of Prefabricated Agricultural Houses

3.1. Large Energy Consumption of Buildings in Xuzhou

Materials for buildings are usually for insulation. Thus, it is important to find appropriate materials that have excellent insulation properties. In terms of materials and structure, the traditional rural houses in Xuzhou are categorized into the following types: brick and concrete houses, frame houses, and earth wall houses. According to the different local economic development, the structure, materials, style, and quality of rural houses are various. In economically developed rural areas, rural houses have modern frame structures with materials of good quality and style. In areas with general or relatively under-development, most rural houses are made of bricks and concrete, even mud walls.

The construction of rural houses requires a large number of bricks, and low-cost clay bricks are used as the main masonry materials, resulting in great damage to land resources. In addition, many traditional building materials are not good for insulation and consume a significant amount of energy during winter for heating. Therefore, it is urgent to promote the use of green building materials in rural areas. For example, changing the traditional masonry material from clay bricks to concrete blocks can save one-third of the energy consumption in the production process of building materials. Industrial waste residue can also be used as raw materials for bricks to reduce production costs and protect the environment. At the same time, it also has light weights and is earthquake-proof, and is easy to contract with.

Due to the historical legacy and traditional ideas of the Xuzhou rural areas, there are many problems in the living situation in Xuzhou rural areas. The randomness of rural self-built houses is an obstacle to the implementation of unified planning and layout for rural houses. Rural housing construction in Xuzhou results in the waste of human, material and financial resources as well as land resources.



Fig. 3. Common forms of rural houses in Xuzhou.

3.2. Energy Consumption of Rural Houses

Energy consumption is required for manufacturing materials for construction, constructing buildings, and using buildings. 80–90% of the energy consumption related to buildings is for heating and air-conditioning buildings [4]. Thus, reducing energy consumption is enabled by the development of green buildings. Due to the lack of construction technology for self-built rural houses, the thermal insulation of its materials is not enough. The material, its use, and shapes are far from saving energy. Besides, poor ventilation and daylighting also increase the use of energy by increasing heating and air-conditioning and using home appliances. The use of various energy sources such as liquefied petroleum gas intensifies the energy consumption of buildings. Especially in the rural areas of northern China, the energy consumption for heating contributes to 60% of total rural energy consumption. At present, in China's rural areas, the use of renewable energy is not common. People still use coal, firewood, straws, and wood for cooking. While their energy efficiency is low, it also brings air and environmental pollution.

In the 21st century, China's economy has made great progress, which has also led to the increase in the population of migrant workers in rural areas, and the economic income of farmers is also increasing. Rural areas have become prosperous, and rural houses are being transformed from single-story brick houses to two to three-story buildings. Due to the traditional concept of rural areas in China, farmers tend to have large houses with more floors, larger areas, and more rooms, without considering the rationality of design. Such self-built houses also have poor energy efficiency as they lack the functions such as thermal insulation and sunshade. The unnecessary areas and floors cause a waste of property and increase the use of energy. The disposable income of rural residents in Xuzhou is high. When building rural houses, residents blindly build them just considering profit and comparison, which results in serious illegal construction and unreasonable design. The planning and layout of "box-type buildings" are common in the economically developed rural areas of Xuzhou. Typical characteristics of "box-type buildings" are high density, high floor height, small spacing, and lack of proper design. To make full use of the homestead, residents blindly increase the construction area and floors. Rural areas in suburbs of cities have many houses for rent to increase family income. The high interest leads to the intensification of private construction of rural houses. The crowded layout affects the lighting and ventilation between houses, which seriously reduces the living comfort and greatly increases the building energy consumption, especially in summer. To solve the problem of unauthorized construction in the rural areas of Xuzhou and reduce energy consumption, the development of new rural construction and green buildings in southern China is required.

3.3. Other Problems of Rural Housing in Xuzhou

In terms of the design of rural houses in Xuzhou, more than 90% of them are constructed without drawings. Instead, the design is copied without considering the differences in geotechnical conditions of the house site and other factors, resulting in great randomness of construction. For economic reasons, private farmhouses are built with minimum costs with the ignorance of the

quality of labor, raw materials, and finished buildings. Non-professional construction teams who have not received appropriate education and training are building houses with wasted bricks, steel bars, and other materials which are obtained from demolished construction sites. Most farmers do not supervise the construction, which results in frequent illegal operations on the construction site. Due to the problems of building materials, construction technology, and construction quality, a considerable number of rural self-built houses have structural safety problems. The low quality, incomplete function and low durability of houses are the important reasons for continuous renovation and reconstruction.

The lack of supervision of safety often causes the potential hazards of rural houses. The current safety management is only applied to farmers' homesteads. There are no relevant regulations for the structure of self-built houses. The quality, safety, and durability are not considered. Self-built houses are built just with a planning permit. However, quality inspection, security inspection, and construction supervision are not found in the construction process. Therefore, there is a huge potential safety hazard for illegal constructions and the unauthorized addition of floors.

The frequent construction of rural houses produces a large amount of waste. Due to the imperfect infrastructure in rural areas, many villages have not set up unified landfill sites. Farmers reuse steel bars, wires, and accessories for construction. However, a significant amount of construction waste is dumped everywhere without being recycled. Incinerating combustible construction waste in rural areas produces toxic and carcinogenic substances. The decomposition of organic substances such as paint and asphalt also produces harmful gases. The landfill leachate also pollutes surface water and groundwater, affects soil quality and structure, and endangers the quality of crops and human health.

With the accelerating process of rural construction and urbanization, the living standards and environment of farmers are improving. The appearance of rural areas in Xuzhou has undergone dramatic changes, and the gap between urban and rural areas is decreasing. In this urbanization, many self-built houses have appeared since the 1990s in Xuzhou rural areas. Most of them have identical designs of box-type buildings which look like European mansions. China has a vast territory, with different regional climates and cultures, and the types and styles of traditional houses are diverse. In the construction of villages and towns, regional characteristics and weather conditions need to be considered. The inheritance of local architectural culture must be considered for designing rural houses and green energy conservation.

4. Design of Rural Houses in Xuzhou based on Green Concept

The prefabricated buildings in factories have standardized and modularized production of components and parts for building. The prefabricated residential buildings show a major innovation in the construction industry. Xuzhou's rural houses need to implement the construction policy of "applicability, economy, green and beauty" established by the state to realize energy conservation, emission reduction, and sustainable and healthy development.

4.1. Principle of Assembly System

(1) Economic condition: Economic conditions are the decisive factor in the construction and development of housing in the rural areas of Xuzhou. It is difficult for rural residents to accept the conservative idea of building new houses, and they are unwilling to spend too much money on building new houses. In terms of the prefabricated houses in China, the occupancy rate of prefabricated houses in rural areas is significantly lower than that in urban areas as the economic income is the key to limiting its introduction. To ensure the popularization of prefabricated rural houses in Xuzhou, it is necessary to reasonably control the cost, which is in line with the psychological expectations and economic affordability. Therefore, the economy of structure and materials should be prioritized.

(2) Security: Residential safety is an important factor in construction. For safety, fire and earthquake must be considered. Materials must be tested for fire and earthquake-proof.

(3) Green ecology: Due to the lack of infrastructure for environmental protection, the pollution of construction waste in rural areas of Xuzhou is serious. In terms of materials, we need to pay attention to the environmental protection and recyclability of building materials.

(4) Degree of industrialization: The popularity of prefabricated house construction depends on the proportion and degree of assembly components. The utilization rate of prefabricated components of various structural systems is necessary for the selection of structures and materials. At the same time, the proportion of on-site dry and wet operations need to be considered.

4.2. Rural House Design

According to the living habits and characteristics of residents in rural areas of Xuzhou, the residential space is divided into three parts.

- (1) Living space: rural houses are mainly for eating, sleeping, and receiving guests. The corresponding building functional spaces are restaurants, bedrooms, and living rooms. Due to the characteristics of rural life, storage rooms and granaries are needed where farm tools and grain are stored. As the quality of life in rural areas has improved, people need indoor toilets, and the kitchen needs a separate space from the living room. All of these need to be considered for designing prefabricated rural houses.
- (2) Key designs: In the rural environment of Xuzhou, different environments require different needs for living space. Thus, prefabricated rural houses can be supplied for three-generation and two-generation families with single or two-story buildings. At the same time, the prefabricated rural houses need to solve the construction cost problem.
- (3) Function requirements: The prefabricated rural houses need to satisfy the living habits of rural residents. The development of rural areas also needs to be reflected by introducing urban building layouts to better expand the specific functions of rural buildings.

4.3. Combination Design of Rural House Rooms

The standardized design, component processing, and construction of prefabricated buildings are related to the modularization of construction. Because the components in prefabricated rural houses are produced in the factory, in the design stage of rural houses, the modular design is required for the functions of the building according to the basic requirements and the easiness of construction and further modernization.

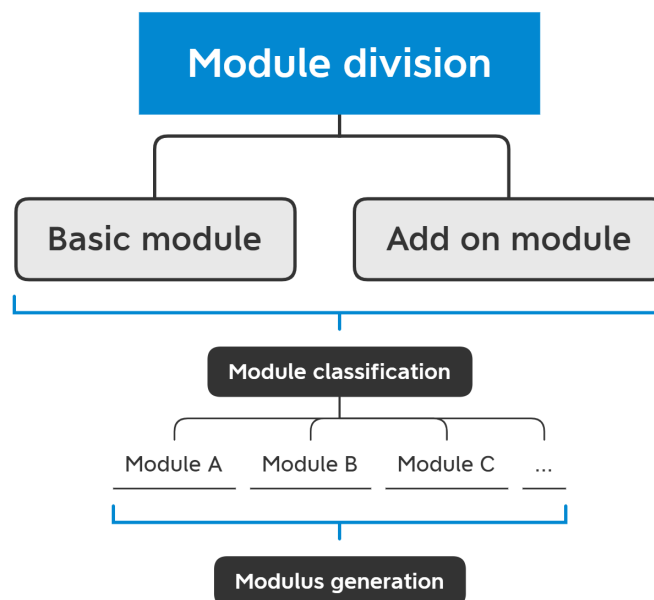


Fig. 4. Basic design process of prefabricated farmhouse.

In the design of the prefabricated farmhouse, the basic specifications and standard requirements need to be ensured with the surrounding environment and industrial resources. In the actual design, the prefabricated farmhouse must have a reduced number of parts and components to increase the recycling rate. The modular combination of building components and parts must be related to the basic design principles of standardization. Connectors and accessories also need to be manufactured according to the principle. Modularization is for cost reduction and quality assurance as well as for energy saving. Therefore, the construction technology and construction process are necessary to consider for modularization.

4.4. Facade Design of Rural Houses

Xuzhou is hot in summer and cold in winter. Buildings are required to open in summer for ventilation and close in winter for thermal insulation. There are contradictions in design due to different seasons. Therefore, a better shape design is necessary to meet the environmental changes in winter and summer and to save energy. According to the design standard for energy efficiency of rural residential buildings (GBT20824-2013), the shape of rural residential buildings in cold areas is standardized not to have convex or

concave parts on the plane and facade [5]. Many concaves and convexes lead to the increase of exposed areas, which increase the heat transfer surface and increase the building energy consumption. According to the design standard for residential buildings for energy efficiency in cold areas (JGJ26-2010), residential buildings must have a body shape coefficient greater than 0.52, and less than three floors [6]. Therefore, the shape coefficient of agricultural houses in Xuzhou must not be greater than 0.52. Under the same residential volume, the larger the shape coefficient of the residence, the larger the outer surface area of the building, resulting in more heat transfer, which is not conducive to the thermal insulation of the building.

Facade design is to create a natural and harmonious rural village landscape. The key factors of the facade of rural residential buildings are determined by the functionality of housing and the standardization and regionality of structure. Diverse designs of the facade of prefabricated rural houses in Xuzhou need to conform to nature and the traditional historical features. At the same time, it needs to be unique and identifiable.

4.5. Green Technology Design Strategy

The solar water heater uses solar radiation energy for heating water [7]. In recent years, the state has attached great importance to the construction of new countryside rural houses with solar water heaters. Solar water heaters are grouped into two types: flat plate solar water heaters and vacuum tube water heaters [8]. The flat plate water heater makes the internal water circulate naturally through the thermal siphon principle. Water is heated on the heat collecting plate and flows around a water tank. In the water tank, the heat is transferred to the water in the tank through the heat exchanger. The vacuum tube water heater uses solar energy to irradiate the vacuum tube which transmits the solar energy to the heat exchanger to heat water flowing in the heat exchanger. With the continuous storage of hot water in the water tank and the continuous replenishment of low-temperature water, the water in the tank will eventually rise to a certain temperature for residents to use. Vacuum tube solar water heater is widely used in agricultural houses in the Zhangjiakou area. The water heater is installed on the roof of the building and placed in the north-south direction. The vacuum tube solar water heater is easy to install and cheap. People give priority to installing the water heater. The integration of solar energy is to integrate technology into rural housing design as an effort of environment-friendly construction. Thus, the solar water heater needs to be included in the design and construction of prefabricated residential buildings.

Although Xuzhou is a cold area, it is hot in summer with an average temperature of 27 °C. Therefore, residential buildings in Xuzhou must have sunshades to reduce building energy consumption and improve indoor living comfort. However, most rural houses in Xuzhou have no sunshades. Baffle, cornical, and fabric sunshades have been used by houses with curtains indoors. In the sunshade design of rural houses in the Xuzhou area, the external sunshade with indoor sunshade (such as curtain, shutter, and roller blinds) must be included in the design and construction. The sun shading design of rural houses in Xuzhou can be in combination with the characteristics of different types of sun shading forms such as horizontal, vertical, comprehensive and louver sunshades.



Fig. 5. Application of facade shading.

Based on the needs of farmers, planting can be considered including flowers, vegetables, fruits and crops in courtyards and on roofs, walls, windowsills, balconies, and corridors. Planting is for improving the living environment and saving energy as the species of plants change in seasons. Thus, plants provide different characteristics to the facade of houses. Especially in summer, plants help to cool and insulate buildings while in winter, it helps to keep warm.

5. Conclusions

The rapid development of modern technologies has affected rural areas for design concepts and construction methods of rural buildings [9]. Nowadays, buildings need to reflect the concept of reducing waste, recycling resources, and saving energy. At the same time, comfort and stability also are required. Rural houses in the Xuzhou area, China are experiencing great changes owing to

rapid development. However, traditional building methods and the lack of understanding of environmental protection, constructing self-built houses does not reflect recycling resources and saving energy as well as safety. Thus, we propose prefabricated houses for rural houses by considering easiness and comfort of construction, the use of renewable energy, effective prevention of unnecessary heat transfer using shades and planting, and efficient design with façade using convexes and concaves. The proposed method of rural house construction provides good stability and safety, and modernization, which meets the various living needs of farmers. At the same time, it also effectively reduce energy consumption and promote the sustainable development of rural housing in Xuzhou.

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