Research on the Design Strategy of Assembled Low-energy Housing for Post-disaster Reconstruction in Beijing Rural Areas Based on the Characteristics of *Sansheng Space*

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Abstract. For the urgent need of rural housing reconstruction in Beijing after the devastation caused by heavy rainfall and flooding, based on an analysis of the area's basic climatic conditions and considering the spatial characteristics of production, living, and ecological spaces, known as the *Sansheng spaces*, a comprehensive investigation of residents' needs has been conducted. To meet the requirements of rapid reconstruction, measures such as respecting the natural environment, scientific planning, reflecting local characteristics, demand orientation, and low-energy design and construction are proposed. In the post-disaster reconstruction process, the use of prefabricated buildings is emphasized due to their modular nature, fast construction, and strong adaptability, which makes them suitable as the primary building structure. The paper concludes by highlighting the achievement of dual goals in rural housing reconstruction: rapid reconstruction and energy saving and consumption reduction through reasonable planning, site selection, functional module design, module standardization, menu module combination, and organic integration of production, living, and ecological spaces.

Keywords: Prefabricated housing, post-disaster reconstruction, rural housing, Low-energy consumption, *Sansheng Space.*

1 Introduction

In the summer 2023, a rare flood disaster occurred in Beijing, causing serious damage. Especially in rural self-built houses in low-lying areas and flood discharge areas, which leads to structural damage, wall cracking, roof leakage and other problems, especially serious damage. The flood mainly damaged the low-rise masonry structure and the bottom of multi-storey buildings. Seriously damaged houses need to be rebuilt. However, the traditional reconstruction method has long cycle, high energy

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consumption and great pressure on the environment. Therefore, it is urgent to find a fast, environmentally friendly and low-energy reconstruction method.

At present, low-carbon economy and low-carbon buildings have become the focus of global attention. Under the background that China is actively fulfilling its international environmental responsibility and promoting the construction industry to achieve the goal of *Double Carbon*, it is of great significance to reduce carbon emissions from the construction industry to slow down global climate change. Rebuilding low-energy residential buildings after the disaster is a key measure to achieve the goal. This kind of residence can reduce energy consumption and greenhouse gas emissions, and promote the application of renewable energy. By means of factory production of prefabricated parts and on-site assembly, the construction period can be greatly shortened, the building quality can be improved, and the impact on the environment can be reduced, which perfectly meets the urgent needs of post-disaster reconstruction.[1] In addition, the combination of low-energy residential buildings and renewable energy will lay a solid foundation for the sustainable development of rural areas, such as achieving energy self-sufficiency by installing solar photovoltaic systems and wind power generation systems. This application not only helps to accelerate the post-disaster reconstruction process, but also provides strong support for the future sustainable development of rural areas.[2]

2 Rural residential disaster situation and analysis

2.1 Analysis of the impact of floods on rural self-built houses

Through the investigation of the damaged houses in Xiacun Village, Shilou Town, Fangshan District, it is found that the seriously damaged buildings are mainly located in the low-lying areas in the flood discharge area and protruding in the corner of the flood discharge passage, which shows the importance of base site selection (Figure 1). Affected by the flood, the damaged buildings show problems such as damaged structural safety, decreased performance of building materials, deterioration of internal facilities and environment. At the same time, due to the contradiction between courtyard size limitation and indoor functional space and the restriction of economic factors, the sunshine condition and ventilation control effect of the original residential building are not good.

Fig. 1. Damaged residential area and current situation in Xia village, Shilou town

2.2 Basic climatic conditions in Xiacun, Shilou Town

Shilou Town is located in the southwest of Beijing and belongs to Fangshan District. Xiacun is located between Fangshan District and Doudian Town, at the intersection of Fangliang Road and Shixia Road. It is about 2 kilometers away from Doudian and 3.5 kilometers away from Fangshan City, with Dashi River on the east side of the village. The area under the jurisdiction of the village is partly within the blue line of the river and partly within the flood discharge area, which requires that the residential construction site selection should fully consider avoiding the relevant areas and reasonably set the elevation of the building floor. Through the analysis of the basic climatic conditions in this area, it can be known that the rational use of natural resources and technical means to create a comfortable and healthy indoor environment can effectively reduce energy consumption and reduce the burden on the environment.

2.2.1. Temperature conditions. The temperature of dry and wet bulb in this area varies from -10℃ to 30℃ throughout the year. From -5℃ to 5℃, with the increase of temperature, the humidity gradually decreases. When the temperature exceeds 5℃, the humidity always remains at a relatively high level(Figure 2). When the temperature is suitable and the humidity is low, making full use of natural ventilation can effectively reduce the dependence on mechanical ventilation and air conditioning and reduce building energy consumption. Rational allocation of green vegetation around the building can adjust outdoor temperature and humidity and reduce the impact of outdoor climate conditions on the indoor environment of the building.

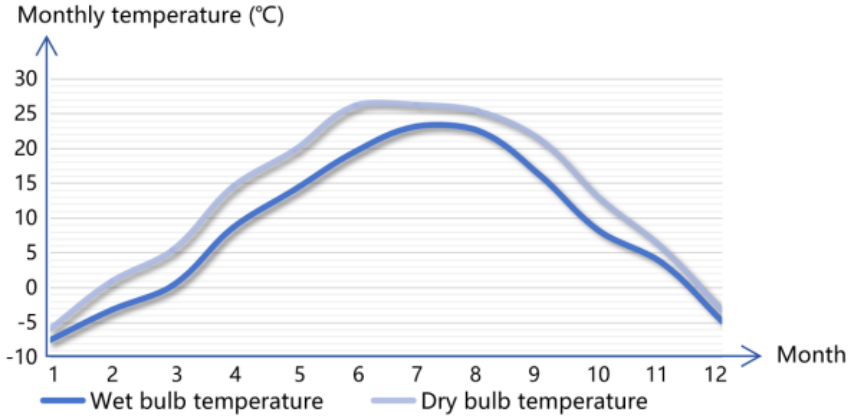

Fig. 2. Monthly dry and wet bulb temperature

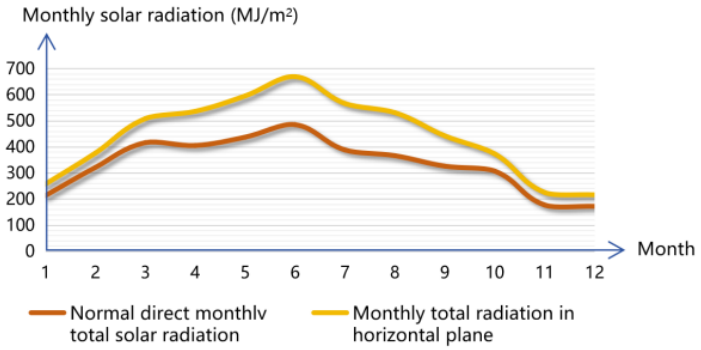

Fig. 3. Monthly total solar radiation

2.2.2. Solar radiation conditions. Through the analysis of the monthly total solar radiation in the region, the region is rich in solar energy resources and has good solar energy utilization potential. Solar radiation changes seasonally, and it is more suitable to make full use of solar energy resources in summer. By comparing the data of the total solar normal direct radiation and the total horizontal radiation, the direct radiation is higher, while the radiation under oblique radiation cannot be ignored(Figure 3) . In the design of building energy efficiency, it is necessary to comprehensively consider the impact of radiation, and reasonably design the orientation and shading facilities. Through the analysis of the distribution of solar radiation in different directions, the solar radiation in all directions throughout the day changes significantly with time, especially in the south direction, the solar radiation is the largest at noon, which is conducive to the role of solar energy facilities (Figure 4).

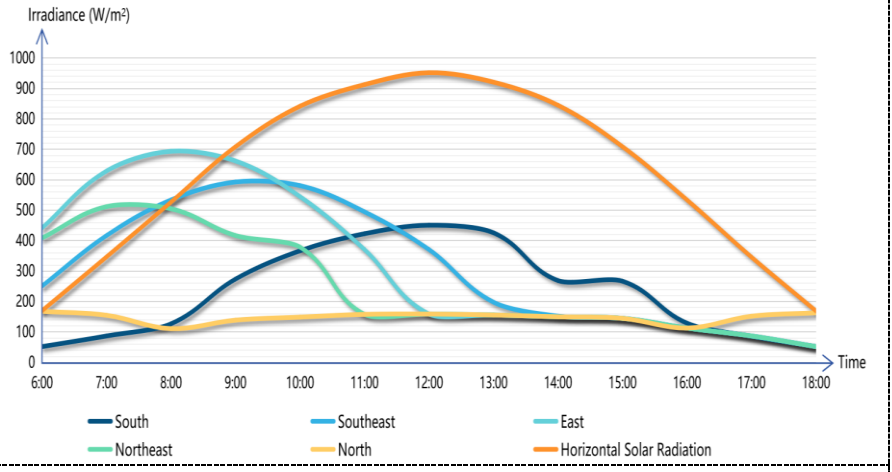

Fig. 4. Hourly solar radiation illuminance

2.2.3. Wind conditions. Through the statistical analysis of monthly wind speed in this area, it is found that this area is rich in wind energy resources. There are obvious differences in wind speed throughout the year, in which March and November are the highest and lowest monthly average wind speeds respectively(Figure 5). According to the seasonal variation of wind speed, reasonable planning of building layout and effective organization of natural ventilation inside buildings can effectively reduce the application of mechanical ventilation equipment.

2.2.4. Thermodynamic characteristics. Through the statistical analysis of monthly enthalpy, the four seasons in this area are distinct and the temperature difference is large. The highest and lowest monthly average temperatures appear in July and January(Figure 6). Based on the obvious temperature difference change, it is considered to set an adjustable sunshade device in combination with climate change in architectural design, and adopt thermal insulation materials with good thermal resistance. In warm season, natural ventilation and sunshade design can reduce the use of air conditioning, while in cold season, heat preservation and heating system can reduce heating energy consumption. Combined with the hourly outdoor enthalpy change in summer, there are obvious fluctuations in a day and the gap between peak and valley is large, which is closely related to the large temperature difference between morning and evening and the frequent rainfall in summer (Figure 7). In the architectural design, good thermal insulation performed materials and construction practices are selected for exterior walls, windows and roofs in combination with the temperature and humidity changes, so as to reduce the impact of the external environment on the indoor environment.

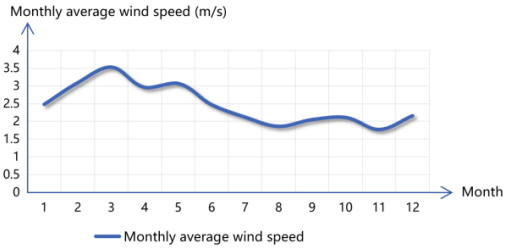

Fig. 5. Monthly average wind speed

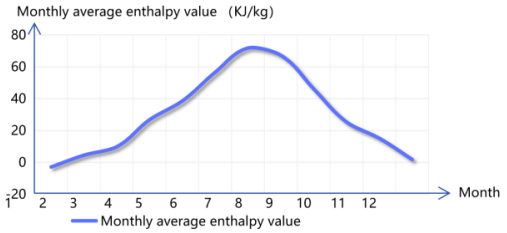

Fig. 6. Monthly average enthalpy value

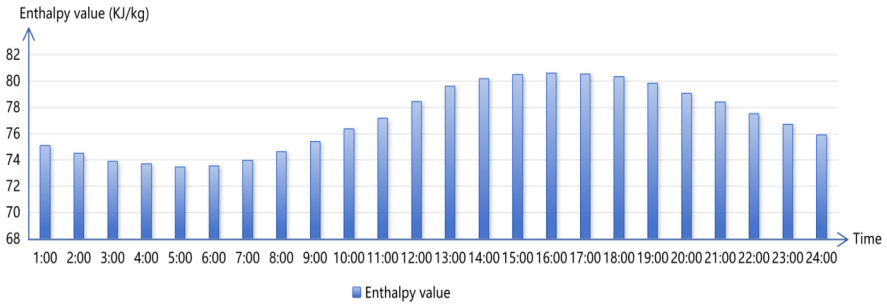

Fig. 7. Hourly enthalpy of outdoor air conditioning in summer

3 Post-disaster rural residential design practice

In the reconstruction design of farmers' self-built houses in Xiacun, Shilou Town, Fangshan District, living space is the main place for residents' daily life, and its design strategy is very important. Combined with the characteristics of *Sansheng Space*, life, ecology and production space are organically integrated, and the integration of life and ecological space, the coordination of production and ecological space, and the interaction between life and production space are explored. In order to meet the rapid reconstruction of livable, comfortable and functional rural houses, the main design strategies adopted include the following measures.[3]

3.1 Building design concept

Sansheng spatial characteristics refer to the synthesis of three characteristics: production, life and ecology. The space used for agriculture, industry and other economic activities. Living space is the top priority of post-disaster reconstruction, including the space for residents to live, relax and socialize. The restoration and protection of ecological space can effectively prevent soil erosion and improve rural ecological functions.[4]

3.1.1. Scientific planning & site selection. This post-disaster reconstruction first ensures scientific planning, including accurate planning of village construction land and agricultural land protection, and combining with the history of village population change, scientifically judging the trend of village population flow, and predicting the scale and composition of village permanent population, registered population and floating population according to the classification of village functions. So as to effectively avoid idle or inefficient use of village construction land and prevent excessive hardening of village land.

The site selection for the rebuilt houses, trys to stay away from the concave bank of the planned flood channel and the area where the soil is seriously washed by running water. Keep a safe distance from the flood channel as much as possible to reduce the impact of possible flood discharge in the future. Pay attention to the land texture and

geomorphological characteristics in the site selection of the rebuilt, provide a good natural environment and landscape, and be beneficial to the lighting and ventilation organization of the building. When choosing land, keep the original natural environment as much as possible to avoid damage to the natural environment. At the same time, buildings should be integrated with surrounding buildings to maintain overall balance and harmony.

As part of Xiacun Village is the actual situation of the planned flood discharge area, this area is vulnerable to the threat of flood, especially in the flood season or when the rainfall is large, low houses are easy to be flooded. Raising the building height can reduce the flood invasion and improve the flood control capacity of the building. Therefore, in the reconstruction design, combined with the height of the submerged water level in this disaster, measures are proposed to determine the elevation for each household, improve the ground elevation of the first floor, and protect the surrounding site. That is to measure the difference between the flood waterline and the elevation of the first floor of the current building with the help of professional measuring tools. After confirming that the gap is 1.5m, the elevation of the first floor of the building is 1.5m, increasing the floor height by filling or frame support, embankments, retaining walls and other measures should be taken around the site to ensure the ground is safe and stable and can effectively resist floods(Figure 8).

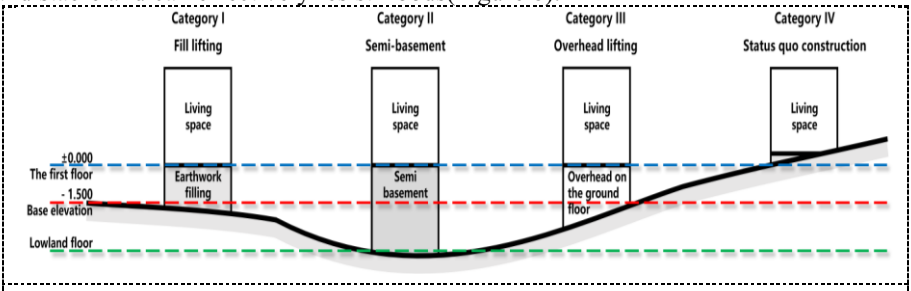

Fig. 8. Adjust the floor elevation of the first floor of the house according to the site situation

3.1.2. Prefabricated housing & functional modules. The progress of prefabricated housing is about 30% faster than that of the traditional one. Considering the urgent needs of basic post-disaster reconstruction, combined with the development trend of national construction industry, prefabricated housing is chosen as the main type of reconstruction. Prefabricated assembly components in the factory can improve some common quality problems such as cracking and leakage of building walls to the greatest extent, so as to improve the overall safety level and durability of the house.[5]

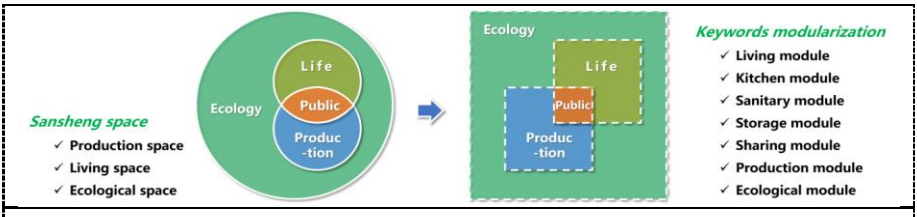

Fig. 9. Corresponding schematic diagram of "Sansheng" space and modular residential design

The plane function design combines the needs of production space, living space and ecological space in rural areas to ensure that the ecological space has ecological protection function, the living space meets the living space and entertainment space used in daily life activities, and the production space meets the specific functions of production activities and the storage space for agricultural tools and agricultural products processing and storage. The design emphasizes people-oriented, attaches importance to the protection of ecological environment and the improvement of people's quality of life. By refining the "three-life" space configuration inside the house and sequencing the functional module design of the house, it lays a solid foundation for the modular design of the assembled house.

Within the post-disaster rural residential design, by refining the Sansheng Space configuration inside the house and sequencing the functional module design of the house, it lays a solid foundation for the modular design of the assembled house (Figure 9).

3.1.3. Selection of structural system & standard design of modules. In prefabricated buildings, the light steel structure system is constructed by cold-formed thin-walled steel profiles and connectors, which has the advantages of light weight, high strength and fast construction. The contradiction between the long service life of the residential building itself and the rapid change of the use function with the user's demand needs to be solved through the effective configuration between the external "support" and the internal "filling" of the residential building itself. The structural system of prefabricated buildings can provide "light steel box" as external support for the buildings, while the internal combination of carefully designed prefabricated functional modules can ensure the functionality and sustainability.

In order to better realize the modular design of living space, living space, kitchen space, auxiliary space and other specific use functions, the main parameters of each space need to be clearly defined in the plane function design. These include the height of functional space, indoor clear height, plane modulus, functional module scale and so on. By orderly organizing the use of function and space modules, a functional module space with special attributes that can be commonly used is formed, including various existing ports such as building functions, interior decoration, structural components, equipment pipelines, etc., so that after batch prefabrication in the factory, it can be assembled according to the drawings of customized modules on the spot, and high-quality and efficient residential building assembly construction can be realized.

Assembled modules use renewable green materials and choose environment-friendly decorative materials, to reduce indoor air pollution and ensure a healthy living environment.

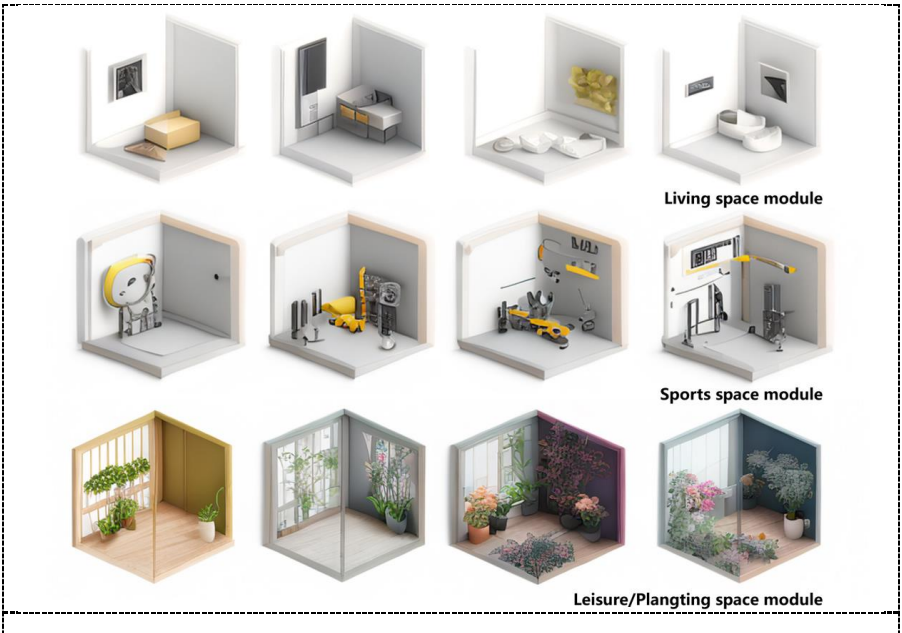

Fig. 10. Modular design for prefabricated Low-Energy consumption residential buildings

In order to better realize the modular design of specific use functions such as living space, living space, public space, kitchen space and auxiliary space, it is necessary to define the main parameters of each space in the architectural plane function design (Figure 10). These include the height of functional space, indoor clear height, plane modulus, functional module scale and so on. By orderly organizing the use of function and space modules, a functional module space with special properties that can be commonly used is formed, including various existing ports such as building functions, interior decoration, structural components, equipment pipelines, etc., so that after batch prefabrication in the factory, it can be assembled according to the drawings of personalized modules on the spot, and high-quality and efficient residential building construction can be realized.

3.1.4. Ecological Space Design & Menu-type add-on module. *While Ecological Space Design, through* careful analysis of natural elements such as topography, hydrology and vegetation, it is ensured that the design scheme can conform to nature and blend into the environment. Adopt the concept of green infrastructure design and the utilization of renewable energy to reduce the interference of artificial environment on natural ecology. Local materials, environmentally friendly and recyclable materials and high-performance thermal insulation materials are preferred as building materials

to improve the energy-saving performance of buildings and reduce energy consumption.[6]

In order to meet farmers' production activities, in the design of production space, indoor storage space and small processing space should be rationally planned. For the improvement of the efficiency of space utilization, multi-layer storage facilities or vertical planting systems are designed to reduce invalid space occupation and enrich the space function of residential courtyards. Based on the concept of the characteristics of Sansheng Space, the design pays attention to the integrated design and realization of production space, ecology and living space.[7] Combine agricultural production with ecological landscape, create a small planting space with ornamental value and provide leisure and entertainment places for residents.

According to the owner's demand, the required modules are selected, and the plane combination configuration is reasonable according to the basic situation of the building construction base(Figure 11). On the premise of meeting the needs of the owner, realize the flexibility of function combination. At the same time, it reflects the advantages of timeliness, unification and quality of prefabricated buildings in post-disaster reconstruction. In the Sansheng Space integration of menu module selection, great attention should be paid to the streamline design across spaces to realize the orderly organization and spatial circulation of all spaces in residential areas.

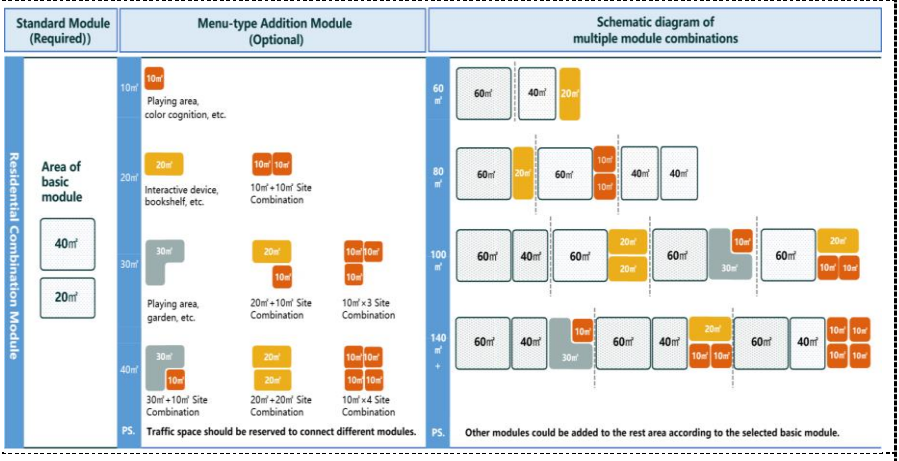

Fig. 11. Schematic diagram of functional design combination of menu-type addition module

3.1.5. Precision Design & efficient energy utilization. *Envelope structure*. Effective thermal insulation design of enclosing structures reduces heating energy consumption. In the design process of assembled module, high-performance thermal insulation materials are used for roof thermal insulation to reduce the amplitude of heat transfer and temperature fluctuation. The multiple problems of thermal insulation, space separation and partial load-bearing can be solved by increasing the thickness of the wall, selecting lightweight materials with high porosity, and using a variety of materials to

form a thermal insulation structure system.[8] Adopt broken bridge aluminum alloy window frames and door frames to avoid "hot bridge". In order to prevent condensation water from appearing on the external wall, a steam barrier is set at the side with higher temperature to prevent water vapor from entering the wall, meanwhile, the blocked water vapor is discharged to the outside of the enclosure structure. Materials such as coiled material, waterproof coating or vapor permeable membrane are commonly used in vapor barrier.[9] In addition, the necessary heat protection design is considered through the modular design of movable sunshade components on the outer surface.[10]

In the overall layout of residential buildings, attention should be paid to the orientation selection, and the main windows should face south or south by east to ensure good lighting effect. Avoid facing west to reduce the impact of excessive solar radiation. The functional space layout arranges the living room, bedroom and other main living spaces on the south side to make full use of sunshine. The kitchen, bathroom and other auxiliary spaces are located in the north to avoid too much sunlight. At the same time, according to the actual needs of each functional space, add reflective panels indoors to introduce natural light into the interior, or LED lights and other auxiliary light sources to ensure the indoor lighting effect.

In order to make full use of natural conditions to organize ventilation, in terms of building layout, multiple rows of houses are arranged side by side under the premise of the base conditions, and passages are left in the middle to improve the ventilation of adjacent houses. At the beginning of architectural design, it is necessary to understand the local climate and wind direction and make rational use of natural wind to promote indoor ventilation. In cold season, in order to prevent the cold wind from blowing into the room, a sloping roof facing south or set a high wall on the north side of the house could be set to block. In addition, the indoor layout of building functional modules should meet the basic functional requirements, and furniture and partition layout should be fully considered to avoid airflow obstruction or vortex formation. At the same time, ventilation ceiling or ground ventilation system can be set up to enhance indoor air distribution.

4 Conclusion and prospect

4.1 Features and Conclusions

The concept based on the characteristics of *Sansheng Space* is of great significance in the design of assembled low-energy residential buildings for post-disaster reconstruction in rural areas of Beijing. This concept highlights the close relationship and interaction between life, ecology and production space, and provides a comprehensive perspective for rural housing design. Assembled low-energy residential buildings, with the efficient construction speed, excellent quality control and environmental protection characteristics, show the advantages suitable for rural post-disaster reconstruction. By integrating the design strategy of *Sansheng* spatial characteristics, the quality of life improvement, rural houses' ecological environment and production efficiency, livable living environment creation, realization of the harmonious symbio-

sis between man and nature, and the promotion of the sustainable development of rural economy, could be achieved. This design introduces the concept of the characteristics into the residential design of rural post-disaster reconstruction, constructs an all-round design strategy framework, effectively integrates the needs of life, ecology and production space, and opens up new ideas and methods for rural residential design. In the design, the assembled low-energy residential building is advocated as an ideal architectural form for rural post-disaster reconstruction, and combined with the design strategy of the characteristics, a forward-looking rural residential design scheme is put forward, which highlights the characteristics of high efficiency, environmental protection and sustainability, aiming at providing solid support for rural post-disaster reconstruction.

4.2 Prospects and suggestions

This design study takes Xiacun Village, Shilou Town, Fangshan District as the research object. Post-disaster reconstruction is complex and time-limited. At present, there is no relevant index to quantitatively evaluate the characteristics of *Sansheng Space*. Future research will continue to expand empirical cases, deepen data collection and analysis, establish a quantitative evaluation system of the the characteristics, and strengthen interdisciplinary cooperation research to guide rural post-disaster reconstruction more scientifically and effectively, and enhance the universality and applicability of research. In summary, this study provides a design reference for creating a livable and sustainable environment for rural areas, promoting all-round development, and building assembled low-energy rural houses in Beijing and even wider areas.

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