Research on the Sustainable Development of Rural Energy-saving Housing in Hebei Region

Tao Yang ¹,a*, Shan Yao²,b

¹School of Design Art, Shenyang Jianzhu University, Shenyang City, Liaoning Province, China
²School of Design Art, Shenyang Jianzhu University, Shenyang City, Liaoning Province, China

*aemail: ysxy@sjzu.edu.cn
bemail: 1346781963@qq.com

Abstract: Rural housing construction has become a key target of reconstruction for the current ecological civilization construction for its lacking scientific and reasonable construction guidance, causing serious environmental pollution and waste of resources. The research object in this paper is the rural area of Hebei. The author proposes appropriate design strategies based on the local climate, environment, economic and technical conditions, and provides a reference for the sustainable development of rural energy-saving housing in Hebei.

1. Introduction
With the rapid development of human modernization, the shortage of arable land and the shortage of energy and resources constitute acute contradictions. According to the Annual report on China building energy efficiency 2020 released by the Tsinghua University Building Energy Saving Research Center, building construction and operation energy consumption accounted for 37% of the total energy consumption of the whole society in recent years, and related carbon dioxide emissions accounted for 42% of the total CO2 emissions of our society [1]. Moreover, China is a large agricultural country with a large proportion of the rural population and extensive rural housing construction. However, lacking scientific and reasonable construction guidance and backward construction technology result in serious waste of residential energy and resources. Therefore, the sustainable development of rural residential buildings is a necessary condition to ensure the sustained, coordinated and healthy development of society and economy, and the balance of ecological environment.

2. The status quo of rural housing construction in Hebei
Hebei Province is located between 113°27′~119°50′ east longitude and 36°05′~42°40′ north latitude. It is located in the North China Plain, with a temperate continental monsoon climate, covering cold region A, cold region B and a few severe cold region C cities. The four seasons are distinct in most areas of Hebei Province. The average temperature in January is above -4°C and the average temperature in July is between 24°C and 32°C (Figure 1). The heating period in winter is generally from the beginning of November to mid-March of the following year, which lasts for five and a half months.
Although from 2017 to 2020, the urbanization rate of the registered population in Hebei Province has increased to about 45%, the rural economy has developed rapidly in recent years. Many young people have begun to devote themselves to rural economic construction, and the number of housing construction in rural areas has increased sharply. However, due to the lack of planning and design for construction, rural houses are basically under spontaneous construction. Due to the limitations of technical conditions and construction methods and insufficient understanding, scientific construction methods cannot be used in the construction process, and environmental factors such as climate, orientation, and ventilation cannot be fully considered. A large part of the residences is still using traditional heating and thermal insulation methods. The exterior walls, roofs, doors and windows of the residences are still being built by conventional methods, and the heat transfer coefficient greatly exceeds the limit of the building energy-saving design standards, resulting in huge energy waste. In the process of Beijing-Tianjin-Hebei integration, the Party Central Committee and the State Council have attached great importance to the construction of ecological civilization, and successively issued a series of major decision-making arrangements to promote the construction of ecological civilization. Rural housing in Hebei has become the focus of ecological reconstruction.

This article will be based on self-built houses in rural areas of Hebei, starting from the status quo of rural houses, combining with new rural development planning, considering local climate and economic conditions, using appropriate energy complementary technologies, and striving to achieve the effect of energy saving and emission reduction, in order to be conducive to the sustainable development of residential buildings in northern rural areas.

3. Building layout and shape coefficient

First, considering the architectural layout, there are roughly three forms of rural housing in Hebei (Figure 2-4). Type 1 is a relatively traditional form (Figure 2). Three or five rooms facing south are the living room and bedrooms. The east and west rooms are generally used as a kitchen or dining room, and the other is used as a storage room or a spare guest bedroom. They are usually placed in the corners due to odor and hygiene considerations. However, in such a layout, the room is highly independent, the movement line is not very reasonable, and the heat loss is large during the heating process. Type 2 is arranged in the direction of the sun with a corridor connecting the rooms to form a small sunny room, which is conducive to absorbing solar radiation in winter and increasing the solar heat gain coefficient. However, it will also increase the indoor temperature in summer. Type 3 is a relatively new self-built house layout. Due to the upgrade of bathroom and kitchen facilities, the problems of smell, hygiene and oil fume can be solved well. It can be centrally arranged in functional rooms such as the living room and bedrooms, which can optimize the movement line, and avoid having to pass outdoors in the cold winter to reach other functional rooms (Figure 4).
Type 3 also has great advantages in energy saving. First, the functional rooms are arranged in a centralized manner to make the shape coefficient of the building smaller. The shape coefficient is the ratio of the external surface area of the building in contact with air and the volume of the building. The calculation formula is \( S = \frac{F}{V} \), where \( S \) is the shape coefficient, \( F \) is the surface area of the building in contact with air, and \( V \) is the volume of the building. The research by Gao Feng and Zhu Neng showed that in buildings with regular architectural shapes such as rectangles and squares, the increase in shape coefficient caused by the simple decrease in the number of layers or the decrease in the aspect ratio will cause a significant increase in the annual cumulative heating load per unit area [3]. When the shape coefficient is increased by 0.01 on the basis of 0.3, the energy consumption will increase by 2.4%–2.8%. We can see that the bigger the shape coefficient, the larger the heat loss area shared by the unit building, which means more energy consumption. Therefore, when designing energy-saving buildings, it is necessary to reduce the figure coefficient as much as possible, reduce the contact area between the outer surface and the outdoor air, and reduce the heat dissipation. Refer to Design Standard for Energy Efficiency of Residential Buildings in Severe Cold and Cold Areas JGJ 26-2018 and Design standard for energy efficiency of residential buildings of Hebei Province (Energy saving 75%) (DB13 (J) 185-2020), the shape coefficient of buildings less than or equal to 3 stories in cold areas shall not exceed 0.57 [4-5]. According to the comparative analysis of type 1 and type 3, when the building area is maintained at 114 m², the height is 3m, and the residence is flat-topped, the surface area of type 1 is \((12+6)2*3+(8+3)2*3+(6+3)2*3+12*6+8*3+6*3=342\) m², the shape coefficient is approximately equal to 1; the surface area of the type 2 is \((12+9.5)2*3+12*9.5=243\) m², the shape coefficient is approximately equal to 0.71. The layout of type 3 is compact and concentrated, which reduces the unevenness of the building and reduces the area of the exterior wall of the building. It can be seen that the shape coefficient of the building can be reduced to a certain extent by changing the layout. However, by analyzing the data of type 1 and type 3, it is found that the shape coefficient of single-story flat-roofed rural houses is still far from that of energy-saving houses. Therefore, in order to reduce the shape coefficient, on the one hand, the layout of the building can be adjusted, and on the other hand, the design optimization can be carried out by increasing the number of building floors and changing the form of the roof[6]. For example, when the number of floors of apartment type three is increased to two, the shape coefficient is approximately equal to 0.57, which can basically reach the standard of energy-saving housing. However, considering that not all residents have the need to build two-story houses, it is not economical to increase the number of residential floors in order to reduce the shape coefficient. Therefore, such residents can achieve energy-saving effects by modifying the roof shape. For example, if it is made into a round arch or triangle, the volume of the building can be increased, but the increase in its surface area is not much. In this way, the shape coefficient of the building can be kept within the energy-saving limit. In addition, the arched or triangular roof can increase the distance between the interior space and the roof, achieving the effect of heat preservation in winter and heat insulation in summer, and also saving energy to a certain extent. In terms of practical effects, it can facilitate the
removal of snow in winter and rain in summer, and is suitable for areas with snowy winter and rainy summer in Hebei area.

4. Natural ventilation and lighting
Hebei is located in the North China Plain. It belongs to the temperate continental monsoon climate, which is affected by the monsoon and has plenty of sunshine throughout the year. The dominant wind direction in Hebei is northwest wind in winter, and southeast wind in summer. Therefore, it is best to make the building on the basis of the traditional determinant arrangement of sit north and face south, and deviate the arrangement direction of the houses from due south by a certain angle (0° ~ 15°), so that not only can better sunshine conditions be obtained, but also obtain better ventilation conditions and improve the indoor living environment. And the opening of the north and south windows should be located in the middle of the room as much as possible, so as to form a draught indoors in summer and strengthen indoor air flow. In winter, the wind direction turns to northwest wind, and no windows or small windows are opened in the north direction (sealed in winter) to prevent cold air. The wind enters the room through the south-facing doors and windows. Due to the short opening distance, the ventilation effect is general, but it is conducive to indoor heat preservation (Figure 5). When the room on the gable wall is not in the prevailing wind direction in winter, windows can be opened to facilitate lighting and ventilation. In winter, the openings are in the negative pressure area, which is difficult to form natural ventilation, which is beneficial to indoor heat preservation. In summer, better natural ventilation can be formed (Figure 6).

In addition to the architectural layout, rural houses in Hebei have their own small courtyards. Planting certain plants in the courtyards can not only play a role in greening, but also contribute to building energy conservation. Planting evergreen plants on the north side of the house can reduce wind speed and heat loss in winter, and planting tall deciduous trees on the south or southeast side of the building can provide shade in summer and have less resistance to the wind. The influence of the sun's heat gain is also small (Figure 7-9).
5. Thermal insulation measures for building envelope

The building envelope occupies a large part of the energy loss. Therefore, in addition to reducing the area of the building envelope, it is also very important to ensure the thermal insulation performance of the building envelope. The energy-saving standards for residential buildings in Hebei province give limits for external thermal performance parameters for different cold regions in Hebei Province. For example, Baoding is in the cold region B, and the maximum heat transfer coefficient of external walls should not be greater than 0.3. When the external window-to-wall ratio is less than or equal to 0.3, the maximum heat transfer coefficient of the external window shall not be greater than 1.8. When the external window-to-wall ratio is greater than 0.3 and less than or equal to 0.5, the maximum heat transfer coefficient of the external window shall not be greater than 1.5 (Table 1).

| Envelope structure | heat transfer coefficient $K$ [W/m²·K] (building≤3) |
|--------------------|-----------------------------------------------|
|                    | Cold region A | Cold region B | Severe cold region C |
| House roof         | 0.25          | 0.30          | 0.20                  |
| Exterior wall       | 0.35          | 0.30          |
| External window     |               |               |
| area ratio of window to wall≤0.30 | 1.8          | 1.6          |
| 0.30＜area ratio of window to wall≤0.5 | 1.5          | 1.4          |

In terms of building thermal insulation materials, the combination of self-insulating walls and external thermal insulation is more suitable for Hebei, which is cold in winter and hot in summer. At present, the most widely used self-insulating wall materials in China are: autoclaved aerated concrete block, sintered shale porous brick, foam concrete, and ceramic self-insulation block etc.

Autoclaved aerated concrete block is divided into six levels of B03-B08 according to the dry density, and is often used as a self-insulating exterior wall material for energy-saving buildings in cold areas. When it is used as a bearing wall, a product with a strength level of not less than A5.0 should be selected, not less than A3.5 for external walls, and no less than A2.5 for internal walls. In addition, due to the consideration of material performance during construction, matching mortar should be used to reduce the impact on thermal insulation performance [8]. The second choice is ceramic foam concrete block. The compatibility of ceramic and foam concrete is better than that of ordinary concrete. The advantages of both complement each other and significantly improve the physical and mechanical properties of foam concrete materials [9]. Sintered shale porous brick is a new type of thermal insulation and energy-saving material, with relatively poor thermal insulation effect, high porosity in its structure, and good crack resistance and resistance to stress, which is usually used in the construction of civil buildings or non-load-bearing wall structures of industrial buildings [10]. Foamed concrete block material has many internal voids, high water absorption rate, and poor compression resistance, so it is not suitable to be used as a single enclosure building material, but is mostly used as a building filling material or used in conjunction with other building materials. Moreover, the construction process of it is difficult, and it is not easy for the rural independent construction team to control the quality.

The selection of maintenance structure materials for rural energy-saving houses, as well as the comprehensive comparative analysis of their relative material performance, construction difficulty and economic cost input, are shown in Table 2. After comprehensive consideration, the most cost-effective and the most ideal choice is autoclaved aerated concrete block and ceramic foam concrete block. However, no matter what kind of material is used alone, it cannot achieve the ideal insulation effect while maintaining a thin wall thickness. Therefore, we need to combine the building's external insulation to achieve a better insulation effect.
Table 2: Common insulation wall materials

| Material name       | Autoclaved aerated concrete block | Sintered shale porous brick | Foam concrete | Ceramic self-insulation block |
|---------------------|----------------------------------|----------------------------|--------------|-----------------------------|
| Pictures            | [Image]                          | [Image]                    | [Image]      | [Image]                     |
| Material specifications | 500/600*240*240/200 and many other models, buy by the cube | 290/190*240/190/90 *190/90 and other models, buy by the number of pieces | Powder in bag, pouring on site | 600*100/120/18 0/240/300*200/250/300 and many other models, buy by the cube |
| Material costs      | 200~300 RMB/cube                 | 150~300 RMB/cube           | 180~280 RMB/cube | 150~320 RMB/cube            |
| Thermal insulation performance (thermal conductivity) | B05 autoclaved aerated concrete block When the total thickness of the exterior wall is 260mm, the thermal conductivity is about 0.75 W/m²·K | When the total thickness of the exterior wall is 260mm, the thermal conductivity is about 1.23 W/m²·K | When the total thickness of the exterior wall is 260mm, the thermal conductivity is about 0.53 W/m²·K | When the total thickness of the exterior wall is 260mm, the thermal conductivity is about 0.81 W/m²·K |
| Compressive strength (map) | 1, 2, 2.5, 3.5, 5, 7, 10 | 2.5-10 | 1-7.5 | 3.5, 5, 7.5 |

It is a feasible design method to use relatively stable thermal insulation materials on the outer building envelope. The main thermal insulation materials include molded polystyrene plates, Graphite molded polystyrene plates, and extruded sheet, polyurethane composite plates, rock wool board, rock wool tape and vacuum insulation panel. The performance of these types of materials can meet the requirements of the current national or industry standards for thin plastering system. In addition, the properties of these materials are relatively stable and can be used in energy-saving building insulation system. According to the experimental research data of Deng Qin, Jiang Wei, Zhao Chu, Yang Yuzhong, and Song Bo, when the thickness of the insulation layer is constant, the theoretically better insulation effect is the vacuum insulation panel system (Table 3). In terms of compression shear, rock wool board and rock wool belt perform slightly worse. In terms of weather resistance, SEPS system > EPS system > PU system > rock wool tape system > plastic benzoic board system > Rock wool panel (RWP) system > Vacuum insulation panel (VIP) system. In terms of flame retardant rating, rock wool and vacuum insulation panel are grade A, the processed extruded sheet and molded polystyrene panel can reach B1 grade, and the rest are B2 flame retardant grade. From a comprehensive comparison, although the vacuum insulation panel has the best thermal insulation effect, it is difficult to construct. Once damaged, the thermal insulation effect drops sharply, and the weather resistance of the polyurethane composite panel is poor, which is not suitable for Hebei’s cold winter and hot summer climate. Extruded sheet and graphite molded polystyrene panel have excellent performance in terms of thermal insulation effect and weather resistance, and the price is relatively economical, and the
construction is relatively easy. Therefore, it is recommended to use these two thermal insulation materials.

| sheet                        | thermal conductivity of the exterior wall | The theoretical thickness value that meets the requirements /mm | Construction method               |
|------------------------------|------------------------------------------|--------------------------------------------------------------|----------------------------------|
| Vacuum insulation panel (VIP)| ≤0.2w/ (m²·K)                           | ≥30                                                          | Single layer insulation board    |
| polyurethane composite panel (PU) |                                          | ≥120                                                         | Cannot be produced at one time (Need to paste) |
| extruded sheet (XPS)         | ≥150                                     |                                                             | Cannot be produced at one time (Need to paste) |
| (SEPS)                       | ≥160                                     |                                                             | Bulk foaming technology          |
| (EPS)                        | ≥180                                     |                                                             | Bulk foaming technology          |
| rock wool board (RWP)        | ≥200                                     |                                                             | Single layer insulation board    |
| rock wool tape               | ≥240                                     |                                                             | Cannot be produced at one time (Need to paste) |

In addition to building walls, the window-to-wall ratio is also very important. Design Standard for Energy Efficiency of Residential Buildings in Severe Cold and Cold Areas JGJ 26-2018 and Design standard for energy efficiency of residential buildings of Hebei Province (Energy saving 75%) (DB13 (J) 185-2020) also give the limit of door-window ratio (Table 4), and the number of limit is also the same.

| references                                                                 | regions                  | North | East, West | South |
|---------------------------------------------------------------------------|--------------------------|-------|------------|-------|
| Design standard for energy efficiency of residential buildings of Hebei Province (Energy saving 75%) (DB13 (J) 185-2020) | Cold region A, B         | 0.30  | 0.35       | 0.5   |
|                                                                            | Severe cold region C     | 0.25  | 0.30       | 0.45  |

Changes in the window-to-wall ratio have varying degrees of impact on energy consumption in winter and summer. For example, in winter, an increase in the south-facing window-to-wall ratio can increase the solar heat gain coefficient when there is enough sunlight, but also increase the functional energy consumption due to poor heat preservation in the absence of sunlight. In summer, high energy consumption of the air conditioner will be caused when there is too much sunlight, but it is also conducive to ventilation and heat dissipation. Windows with different orientations also have different effects on building insulation. From the following (Figure 10), it can be seen that the total energy consumption of building heating decreases with the increase of the south-facing window-to-wall ratio, and the decreasing trend gradually slows down; The total energy consumption increases with the increase of the north, east, and west window-to-wall ratios, and basically shows a linear increase trend; the increase in the north-facing window-to-wall ratio causes the largest increase in total energy consumption, followed by the west, and The increase in the total heating energy consumption caused by the increase in the eastward window-to-wall ratio is the smallest [12].
Figure 10 The effect of window-to-wall ratios in different orientations on the total energy consumption of the building

Source: Research on Energy-saving System and Indoor Thermal Comfort of Rural Residential Buildings in Chongli District, Hebei Province

In addition to the above-mentioned window-to-wall ratio problem, we should also pay attention to the heat preservation effect and opening method. External window profiles should be made of materials with good thermal insulation performance and structural design. At present, common new energy-saving windows include Cavity-Glass Energy Saving Window, Plastic aluminum window, and FRP energy-saving window, open vacuum glass plastic aluminum frame insulation window etc. Coated glass is recommended for its wonderful insulation performance, but the price is also higher. In consideration of costs and heat preservation, it is recommended to use Cavity-Glass Energy Saving Window [13]. At the same time, the window opening method should adopt the form of internal flat opening or inverting, which is more conducive to keeping warm in winter and ventilation in summer.

6. Conclusion

From the perspective of "suitability design", considering that most of the houses in rural areas are self-built houses and have certain initiative, with relatively backward technology, author feels pity that many advanced energy-saving technologies cannot be properly applied and promoted. Therefore, in combination with the climate and environmental conditions in Hebei, the following suggestions are given from the layout of the building and the choice of building materials:

In terms of the layout of the building, the convex surface of the building can be reduced by combining, thereby reducing the building surface area. According to the needs of different residents, the number of building floors or the change of the roof shape can be adopted in order to reduce shape coefficient. Considering the impact on the total energy consumption caused by the different building orientation and the window-to-wall ratio, the green plants in the courtyard should be planted for the purpose of preventing wind in winter and shading the house in summer. In the choice of building materials, combine suitable energy-saving building materials and external insulation materials can achieve better energy-saving effects.

Scientific and reasonable architectural design can not only achieve the effect of energy saving and environmental protection, but also provide residents with more economical and comfortable houses
from a long-term perspective. And scientific rationality is not only the optimal consideration from the technical level, but also the analysis of the actual situation to obtain the "suitability design". It is hoped that the data in this paper can provide a certain reference basis for the construction of energy-saving houses in rural areas in Hebei.

References
[1]. Tsinghua University Building Energy Saving Research Center, Annual report on China building energy efficiency 2020: Special Topics on Rural Housing[M]. China Building Industry Press, 2020-06-01.
[2]. Qiu Ju, Teng Jiajia. Research on passive energy-saving design of public buildings in severe cold areas[J]. China Housing Facilities, 2020(01): 43-44+32.
[3]. Gao Feng, Zhu Neng. The influence of building shape on the sensitivity of building load and its influencing parameters[J]. Journal of Western Human Settlements and Environment, 2020, 35(04): 67-73.
[4]. Design Standard for Energy Efficiency of Residential Buildings in Severe Cold and Cold Areas JGJ 26-2018[S]. Published by China Construction Industry Press
[5]. Residential Building Energy Efficiency Design Standard of Hebei Province (75% energy saving) (DB13 (J) 185-2020) [S]. Published by China Building Industry Press
[6]. Li Jun. Discussion on energy-saving measures of construction engineering [J]. Engineering Construction, 2020, 52(07): 79-82.
[7]. Sun Bo, Ji Xiang, Gu Xianguang. Application of indoor natural ventilation simulation in residential space layout[J]. Huazhong Architecture, 2018, 36(05): 39-43.
[8]. Gong Yufa, Wang Hongyi. Energy-saving calculation of the integrated system of embedded thermal insulation and masonry[J]. Building Energy Conservation, 2018, 46(12): 58-61.
[9]. Chen Zhichun, Li Yingquan, Hu Shikai, Wang Xiaofan, Chen Jiayu. Development status of ceramsite foam concrete in my country[J]. Wall material innovation and building energy saving, 2017(10): 33-35.
[10]. Zhou Shuhong, Ye Long, Zhang Wenwen, Xiao Bowen. Discussion on the construction technology of external wall self-insulation system[J]. Urban Housing, 2019, 26(11):181-182.
[11]. Deng Qinquin, Jiang Wei, Zhao Chu, Yang Yuzhong, Song Bo. Research on performance testing of exterior wall insulation system for near zero energy consumption buildings[J]. Building Energy Conservation, 2018, 46(08): 13-18.
[12]. Sun Linwei. Research on the energy-saving system and indoor thermal comfort of rural houses in Chongli, Hebei[D]. Tianjin University, 2017.
[13]. Chen Yu, Qiang Shaohua. Research on energy-saving technology of residential building envelope structure in hot summer and cold winter area[J]. Wall Material Innovation and Building Energy Efficiency, 2015(08): 65-68.