Performance evaluation and comparison between rural new and traditional house in severe cold regions of China

T Shao¹ and H Jin²

¹ Assistant Professor, School of Mechanics, Civil Engineering and Architecture, Northwestern Polytechnical University, Xi’an, China
² Professor, School of Architecture, Harbin Institute of Technology, Harbin, China
* shaoteng1989@qq.com

Abstract. With the development of urban-rural integration, the number of newly built houses is increasing. Due to the influence of climatic characteristics, traditional technology, economy etc, the phenomenon of large heating energy consumption and low indoor thermal comfort in winter is common in rural houses. In order to explore the energy-saving design methods for rural houses in severe cold regions and create a low-carbon and comfortable indoor thermal environment in winter, this paper selects the new house and traditional house of Zhalantun, Inner Mongolia as research objects, applying the methods of testing and calculation to comprehensive comparison of the differences between two types of housing from the aspects of building energy consumption, indoor thermal environment and thermal performance of building envelop. Results show that through the reasonable thermal environment zoning, performance optimization of building envelop and improvement of heating mode etc., the indoor thermal environment can be effectively improved, so as to achieve the purpose of comfort and energy saving.

1. Introduction
The areas of severe cold region cover a quarter of China, with villages taking up far more land than cities. Rural houses are small in size and dispersed in layout. Meanwhile, restricted by the characteristics of severe cold climate, rural traditional technology, economic level etc., it is common to have large heating energy consumption, low indoor thermal comfort in winter, and appear condensation phenomenon on the inner surface of building envelop[1]. In the year of 2015, rural buildings consumed 197 million tons of standard coal in China, accounting for 22.9% of the total energy consumption of civil buildings[2]. Chinese scholars have gradually focused on the design and construction of rural houses. According to the different regions and building types, some studies on reducing building energy consumption and improving indoor thermal environment have been carried out by using the methods of questionnaire survey, field test, numerical simulation etc[3-7]. However, there are great differences in climate, economy & technology level, living habits and natural resources among regions, the current studies have obvious regional and lack of attention to the performance difference analysis and evaluation for new house and traditional house in severe cold regions of China.

During the period of 2013-2016 years, the research group carried out the practice of rural energy-saving houses in Zhalantun, Inner Mongolia. In order to verify the effectiveness of energy-saving measures, the monitoring of building performance parameters for new and traditional houses were conducted three months in winter. From the aspects of energy consumption, indoor thermal environment and thermal performance of building envelop, the implementation effect of energy-saving measures on new house were analysed, so as to explore the regional adaptability energy-saving design method.
2. Methods

2.1. Research object
Zhalantun is located in the east of Inner Mongolia, having the climate characteristic of long and cold in winter. The average temperature of the coldest month is -17.0°C, and the extreme cold temperature is -39.5°C. The bad weather conditions result in this region’s houses having the characteristic of high energy consumption and low comfort in winter. As shown in Fig.1 and Fig.2, a new house and a traditional house are selected as testing objects.

Compared with rural traditional house, the new house has been optimized as follows: Optimizing the building form and reducing the shape coefficient. The building shape is optimized to be close to square shape, and the shape coefficient of new house is 0.74 m⁻¹, which is 20% lower than that of traditional house. Improving the plane layout and forming reasonable thermal partition. As shown in Fig.5, according to the temperature requirements of different rooms, the double-depth layout pattern was applied in the new house, which the heating source is located in the center, the living room and bedrooms are located in the south to make full use of solar radiation, and the auxiliary spaces such as storeroom, toilet are arranged in the north, so as to form a temperature buffer zone to effectively prevent the indoor temperature of main functional areas from being affected by cold air infiltration. Optimizing the building envelop and improving insulation performance. The specific information is shown in Tab.1. Improving the heating mode. The traditional heating equipment is fire Kang (Fig.3), which mainly use the heat of smoke flow, but it’s easy to cause uneven indoor temperature distribution, and the temperature is lower away from the fire Kang. As shown in Fig.4, break through the traditional way of solely relying on fire Kang, and adopt the comprehensive mode of combining fire Kang with ground radiation heating to improve the uniformity and stability of indoor thermal environment.

| Parts          | New house                      | U-values | Traditional house | U-values |
|----------------|--------------------------------|----------|------------------|----------|
| Exterior wall  | 240mm brick wall + 100mm XPS board + 120mm brick wall | 0.38     | 370mm brick wall | 1.55     |
| Roof           | Tiled roof + wooden roof truss + 150mm XPS board + wooden frame + ceiling | 0.35     | Tiled roof + wooden roof truss + 150mm plant ash + wooden frame + ceiling | 0.93     |
| Window         | Double layer single-frame double-glass PVC plastic steel window | 1.46     | Double wooden window | 2.30     |
| Door           | Metal insulated door           | 1.70     | Double wooden door | 2.33     |
| Ground         | 100mm XPS board + concrete cushion | —        | Cement mortar + concrete cushion | —        |
2.2. Field testing method

The testing time is from December 2014 to February 2015, which is the colder month in winter of severe cold region. The testing parameters include air temperature, relative humidity and black globe temperature etc., which were continuous monitored by BES-02 temperature and humidity recorder and BES-01 black globe temperature recorder. Indoor measuring points were uniformly arranged at the geometric center of each room, with a height of 1.6m. A group of data was recorded every 15 min. BES-A field test instrument was used to measure the thermal performance of building envelop, and the sampling time was also recorded every 15 min. Before selecting the measuring point, FLIR infrared thermal imager was used to judge the thermal bridge’s position of building envelop, so as to avoid interference to the test result and ensure the validity of test data.

![Figure 5](image)

**Figure 5.** The plane and measuring point layout of new house (left) and traditional house

3. Results and discussions

In accordance with the monthly temperature change rule of Zalantun, January is the coldest month. The five day testing results from January 14 to 18 were selected to detailed analysis, which the outdoor maximum temperature is -10.2 °C, and the minimum temperature is -27.9°C, can reflect the winter climate characteristics of severe cold region.

3.1. Contrast of indoor thermal environment

During the testing period, the fuel consumption of two houses was simultaneously recorded, as shown in Tab.2. The results show that the energy saving rate of new house is 64.1%. Since the fuel consumption of two houses was different, it mainly from the perspective of space type to analysis the indoor temperature fluctuation amplitude and distribution uniformity.

| Type           | Area (㎡) | Fuel consumption (kg/d·m²·℃) |
|----------------|-----------|------------------------------|
|                |           | Coal | Straw | Standard coal |
| New house      | 122.48    | 13.8 | 35.0  | 0.014         |
| Traditional house | 86.14    | 28.7 | 0.0   | 0.039         |

According to the thermal environment zoning of rural house in northeast severe cold region, the interior space can be divided into the main space (living room, bedroom, dining room etc., as shown in the yellow area of Fig.5), auxiliary space (storage room, toilet, entrance space etc., as shown in the blue area of Fig.5) and heating space (kitchen, as shown in the red area of Fig.5).

Heating space includes the kitchen and other space for cooking activities and heating equipment operation. The kitchen of new house is located in the centre. On the north side, the auxiliary space (storage room and entrance space) forms the temperature buffer area, which can reduce the influence of outdoor temperature change on heat sources and form the spatial pattern of "kitchen-buffer area-outdoor". However, the kitchen of traditional house is located in the north side, forming the spatial pattern of "kitchen-outdoor", which is directly affected by the outdoor environment, and due to the poor insulation performance of building envelop, resulting in more heat loss. As shown in Fig.6, the variance of temperature data is 2.63 of new house’s kitchen, indicating that the temperature change
range is small. The variance of temperature data is 6.96 of traditional house’s kitchen, with large
temperature fluctuation and varies widely from day to night. The temperature fluctuation of heating
space has direct influence on the thermal environment of adjacent space.

![Figure 6. The temperature variation curve of outdoor, heating space and auxiliary space](image)

The main space includes living room, bedroom and dining room. According to the rural resident’s living
habit, the bedroom and living room are normally combined together to satisfy the double function of daily
life and sleeping. Both the new house and traditional house have the spatial pattern of "living + sleeping ". According to the space’s position in the building, two groups of A and B are selected for comparison. As shown in Fig.7, two spaces in group A are located in different positions in the building, while two spaces in group B are in the same position. The temperature statistics values of testing points are shown in Tab.3 and taking group A for example, the temperature change curves is shown in Fig.8.

![Figure 7. Two contrast groups of the main space](image)

| Table 3. The temperature statistics values of testing points |
| --- | --- | --- | --- | --- |
| Group | Position | Minimum value(℃) | Maximum value(℃) | Difference (℃) | Variance |
| --- | --- | --- | --- | --- | --- |
| A | Traditional house | bedroom | 21.77 | 6.91 | 14.86 | 14.22 |
| | above the Kang | 6.21 | 12.75 | 6.54 | 2.65 |
| | New house | living room | 10.96 | 16.86 | 5.90 | 1.82 |
| | above the Kang | 10.52 | 16.15 | 5.63 | 1.65 |
| B | Traditional house | bedroom | 21.77 | 6.91 | 14.86 | 14.22 |
| | above the Kang | 6.21 | 12.75 | 6.54 | 2.65 |
| | New house | living room | 11.30 | 16.42 | 5.12 | 1.31 |
| | above the Kang | 11.10 | 16.14 | 5.03 | 1.32 |

For group A, the temperature fluctuations of new house is small, which the variance of temperature
data is 1.82 in living room, and the maximum temperature difference is 5.90℃; the variance of temperature data is 1.65 in above the fire Kang and the maximum temperature difference is 5.63℃. The temperature change of traditional house shows a trend of dualization. The temperature fluctuation of bedroom is large, the variance is 14.22, with the maximum temperature difference 14.86℃; the temperature fluctuation of above the fire Kang is small, the variance is 2.65, with the maximum
temperature difference 6.54℃, but all of them are higher than the temperature fluctuation of new house. Analysis of its causes: 1) In the new house, the north side of the space is adjacent to other rooms and does not directly contact with the outdoor space, thus reducing the impact of outdoor temperature fluctuations on the indoor thermal environment. 2) The building envelop of new house adopts effective thermal insulation measures to reduce the heat loss. 3) The heating mode of "fire Kang+ floor radiation" is adopted in new house, making the indoor temperature distribution even. However, the heating mode of "fire Kang" is usually used in traditional house, resulting in uneven indoor temperature distribution. For group B, it’s basically the same as group A. The temperature fluctuation in bedroom and above the fire Kang of new house is small, while that of the traditional house shows a trend of dualization. Since the two spaces are in the same position of the building, it is mainly due to the enhance of thermal performance of building envelop and the improvement of heating mode.

With the improvement of people's living standard, the evenness of indoor thermal environment is becoming more and more important. Survey results show that the traditional life pattern is gradually changing, and most people prefer indoor activities at home in winter with skimpy clothing. This requires indoor thermal environment to have good evenness, avoiding large temperature difference among different space to cause human uncomfortable. The temperature values at three moments, respectively are 9:00, 12:00 and 18:00, were selected for the comparative analysis of indoor temperature uniformity. As shown in Fig.9 (a), the temperature fluctuations of each room in new house is small, and the variances of temperature data at three moments were 1.12, 1.00 and 2.96 respectively. The average difference value is 3.96℃ between the maximum and minimum temperatures at the same time. As shown in Fig.9 (b), the temperature fluctuations of each room in traditional house is large, and the variances of temperature data at three moments were 6.66, 8.92 and 24.08 respectively. The average difference value is 8.97℃ between the maximum and minimum temperatures at the same time. This also confirms the survey results. Though the interview, it is found that users of new house generally reflect that the indoor thermal environment is relatively stable and comfortable, while in traditional house only the bedroom and living room have high temperature, and the overall thermal environment quality is poor.

**Figure 8.** The temperature change curves of group A

**Figure 9.** Temperature distribution of each room in new house and traditional house
3.2. Surface temperature of building envelop

Due to the poor insulation performance of traditional house’s envelop, the inner surface temperature is usually lower than the air dew point temperature, so that the inner surface and corner often appear moldy, peeling and condensation phenomenon. The infrared thermal imaging of inner surface is shown in Fig.10. The thermal performance of new house’s envelop is significantly improved after the adoption of thermal insulation measures. As shown in Fig.11, The inner surface temperature of wall and roof was higher than the dew point temperature, very close to the indoor air temperature. There was no condensation on the inner surface of wall and roof in winter. The surface temperature of external window was also higher than the dew point temperature.

![Figure 10. Inner surface of building envelop](image)

![Figure 11. Inner surface temperature of new house](image)

4. Conclusions

Through the analysis of indoor thermal environment, thermal performance of building envelop and thermal comfort of new and traditional house, the following conclusions can be drawn. ① According to the functional requirement of different rooms, forming a reasonable thermal zoning, which can create a comfortable thermal environment for main space. For example, setting auxiliary space on the north side to forming the "temperature buffer", which can improve the indoor temperature and reduce temperature fluctuation. ② Relying solely on the heating mode of fire Kang and fire wall will lead to great difference of indoor temperature distribution. The heating mode of "fire Kang + floor radiation" in new house can improve the uniformity and comfort of indoor temperature. ③ Adopting effective insulation measures for external walls, roofs and windows can enhance the thermal performance of building envelop, avoid condensation on inner surface and reduce indoor temperature fluctuations in winter.

References

[1] Teng Shao, Hong Jin, Lihua Zhao. 2017. Current Situation and Improving Strategies for Northeast China’s Rural Housings. Open House International, 42(4): 70-77
[2] Energy consumption statistics committee of China building energy conservation association. 2018. China building energy consumption research report (2017)
[3] Sun H, Leng M. 2015. Analysis on building energy performance of Tibetan traditional dwelling in cold rural area of Gannan. Energy and Buildings, 96:251-260
[4] Yang Weijiu, Gao Qing, Xu Bin, et al. 2015. Inheriting and Updating the Technology of Low Energy Consumption Used in Waterside Vernacular Dwellings in the Lower Yangtze Basin. Architectural Journal, 1(2):66-69
[5] Yang Liu, Liu Jiaping.2003. Improvements of Thermal Environment of Traditional Yaodong Dwellings with Solar Energy. ACTA ENERGIAE SOLARIS SINICA, 24(5):605-610
[6] Hao S M, Song Y H, Li J J, et al. 2014. Field Study on Indoor Thermal and Luminous Environment in Winter of Vernacular Houses in Northern Hebei Province of China. Journal of Harbin Institute of Technology, 21(4):77-83
[7] Teng Shao, Hong Jin, Lihua Zhao. 2015. The Economic Benefits Analysis on Rural Energy-Saving Housing of Northern China. International Journal of Civil Engineering and Construction Science, 2(4): 24-29
[8] Jin Hong, Chen Kai, Shao Teng, et al. 2015. Designing Rural Houses of Low Energy Consumption and High Comfort in Response to the Extremely Cold Climate. Architectural Journal, (2):74-77