Study on indoor thermal environment in winter for rural residences in Yulin region

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Abstract. Yulin region is located in the northern part of Shaanxi Province, China. The winter here is very cold and it has a long duration. In this paper, a rural residence which was located in Yulin region was taken as a study object. Indoor thermal environment of the rural residence were tested, including indoor air temperature and air relative humidity. Then, test data were analyzed. It was summarized that indoor thermal environment of test room can not fully meet human thermal comfort needs, and some tactics of regulation building thermal environment were proposed. This research contributes to improvement of indoor thermal environment for local rural residences and it provides reference for rural residences in other cold regions.

1. Introduction
In northern China, the winter here is very cold and it has a long duration. Under harsh climatic conditions, heating and thermal comfort of local buildings is an important issue. Meanwhile, energy consumption of local buildings also aroused great concern of scholars. In 2015, heating energy consumption of northern cities and towns was 191 million tce, accounting for 22% of the building's total energy consumption, and primary energy consumption of rural residences was 213 million tce, accounting for 25% of the building's total energy consumption [1]. In the primary energy consumption of rural residences, 206 billion kWh of electricity consumption was included, and besides these energy consumption, 100 million tce of biomass such as straw and firewood were consumed by rural residences [1]. Because people's demand for thermal comfort is convergence, so it is obvious that heating energy consumption of rural residences in northern China is huge. For rural residences, poor thermal performance and sealing performance of building envelope also caused a huge waste of heating energy consumption. So there is a great potential in heating energy efficiency of rural residences. Prof. Long's research conclusion included the following: (1) Building energy efficiency was not an accumulation of single technology, but the comprehensive utilization of various technologies reasonably, and appropriate technology was the best one. (2) There should be fully inclusive in selection and evaluation of technology [2]. Some scholars [3] [4] had studied indoor thermal environment in winter for rural residences in particular areas. But Yulin region have a unique climatic conditions, resource conditions and natural environment. So the indoor thermal environment in winter for rural residences in Yulin region was studied in this paper.

2. Overview of Yulin region
Yulin is located at 36° 57′-39° 35′N and 107° 28′-111° 15′E, which is located in the northern part of Shaanxi Province, China. In the east, Yulin region and Shanxi Province are separated by the Yellow
River. It is bordered by the Gansu province and Ningxia Hui autonomous region in the west, meanwhile it is adjoined the Inner Mongolia autonomous region in the north. Yulin is located in the southern edge of Mu Us desert and it is the transitional zone between the Loess Plateau and Inner Mongolia Plateau.

Yulin region has a typical semi-arid continental monsoon climate. There is less precipitation and higher evaporation, and there are more wind and sandstorm in local. There are large temperature difference between day and night. It’s cold and dry in winter, and there are abundant solar energy resources. Table 1 shows basic meteorological parameters of Yulin region.

| Outdoor calculation temperature in winter (℃) | Outdoor calculation temperature in summer (℃) | Heating period days (d) | Sunshine percentage in winter (%) | Sunshine hours (h) | Rainfall (mm) |
|---------------------------------------------|---------------------------------------------|------------------------|-----------------------------------|-------------------|--------------|
| -14.9                                       | 28.0                                        | 151                    | 67                                | 2900.5            | 451.0        |

3. Overview of a typical rural residence

3.1. Description of residence

A typical rural residence, which was located at Xiaoji Khan village, Xiaoji Khan town of Yuyang District, was chosen as object of study. Residential courtyard faced towards west. Residential rooms was built at north of the courtyard, while kitchen and other auxiliary rooms were built at east of the courtyard. Residential building block and auxiliary building block were not connected together, and they were independent each other. Both building blocks were built up within a decade. Figure 1 shows house plane and layout of test points. Table 2 shows building envelope information of the typical residence.

3.2. Usage pattern of the house

It can be seen from Figure 1 that residential building block was divided into two parts. House owner couple lived in right part of the building block, meanwhile their son, daughter-in-law and granddaughter lived in left rooms. Two families shared the kitchen, boiler room and other ancillary rooms. Heating method of the house was boiler hot water system. House owner burnt coal to heat the house from November to next March. In fact, the boiler hot water system started at 5 pm and closed at 11 pm every day in heating period. There were hanging thick cotton curtains inside of windows in winter in order to reduce heat loss of the house. As indoor air temperature were not satisfactory, so the
aged often wore coats and jacket in room, but young people only need to wear a sweater in order to meet comfort.

Table 2. Building envelope information of the typical residence.

| Category | Construction practices of building envelope (From indoor to outdoor) | Heat transfer coefficient [W/m²·K] |
|----------|---------------------------------------------------------------|----------------------------------|
| Exterior wall | ① 20mm lime plaster | 1.477 |
| | ② 370mm sintered clay brickwork | |
| | ③ 10mm cement mortar plaster | |
| | ④ 10mm ceramic tile | |
| Interior wall | ① 20mm lime plaster | 1.688 |
| | ② 240mm sintered clay brickwork | |
| | ③ 20mm lime plaster | |
| | ① 10mm lime plaster | |
| | ② 240mm sintered clay brickwork | |
| | ③ 20mm lime plaster | |
| | ① 10mm lime plaster | |
| | ② 100mm reinforced concrete plate | |
| | ③ 50mm aerated concrete | |
| | ④ 20mm cement mortar | |
| | ⑤ 4mm modified bitumen membrane | |
| | ⑥ 5mm hard stone protective layer | |
| Window | Aluminum alloy hollow glass window | 3.600 |
| Door | Anti-theft insulation door | ------ |
| Floor | ① 10mm ceramic tile | 1.488 |
| | ② 10mm cement plaster | |
| | ③ 100mm concrete cushion | |
| | ④ 50mm aerated concrete | |

4. Thermal environment research of the rural residence

4.1. Thermal environment tests of the rural residence

Although building thermal environment was affected by four elements, including air temperature, air relative humidity, air velocity and ambient temperature. But air temperature and air relative humidity were main factors which affected thermal comfort. Meanwhile doors of the rural residence were often closed in order to keep warmth in winter, and there was no wind in rooms. Air temperature and air relative humidity were tested by instrument. Temperature and humidity tester JTR08D was chosen as the instrument, which had measuring range of -40~120°C and 0~100%, and it had accuracy of ±0.1°C and ±0.1%. Solar radiation intensity was tested by JTR05. It can test the spectral range as 0.3~3.2µm and it had accuracy of 7~14mv/kw.m². Among right rooms of the residential building block, Living room, Bedroom A, Bedroom B and Bedroom C were chosen as test room. Figure 1 shows plane layout of test points, and there was a height of 1.5[m] from the test point to ground. Outdoor test point was located in the shade, and it was obscured by tinfoil sleeve.

Air temperature and air relative humidity test time began at 14:00 o'clock on January 18th, 2017, and it ended at 10:30 o'clock on January 20th, 2017. Test data was acquired and recorded once at the interval of 30[min]. Solar radiation intensity test time began at 10:30 o'clock on January 18th, 2017, and it ended at 11:00 o'clock on January 20th, 2017. Test data was acquired and recorded once at the interval of 15[min]. It's sunny during test period.
4.2. Test data analysis of air temperature

Figure 2 shows variation of air temperature in each room and outdoor during test period. It can be seen that air temperature of each room and outdoor varied periodically. Based on living habits of house owner couple, intermittent heating was used during test period. It was learned through research interviews that the boiler hot water system usually started at 5 pm and closed at 11 pm every day in heating period. So it can be seen in Figure 2 that variation of air temperature in test rooms was similar to each other during that specific time. In daytime of the second test day, air temperature of Living room and Bedroom A had a clear rise and fall process. The variation process was consistent with operation of the sun. In fact, during daylight hours, the boiler hot water system was not running and both rooms were mainly heated by solar energy. It can be seen that air temperature of living room had been higher than other rooms’. On the one hand, the living room which located at southern part of the building block can be heated by solar radiation, so its air temperature was higher than two rooms which located at northern part. On the other hand, Living room and Bedroom A were compared and it can be find that although both rooms located at southern part of the building block, but Bedroom A had more external envelope. So under the heating of solar radiation and boiler hot water system, air temperature of living room was higher than Bedroom A’s all the time.

| Room/ Outdoor | The highest value (°C) | Average value (°C) | The lowest value (°C) |
|---------------|------------------------|--------------------|----------------------|
| Living room   | 22.7                   | 19.8               | 16.3                 |
| Bedroom A     | 20.7                   | 16.3               | 12.6                 |
| Bedroom B     | 19.1                   | 15.7               | 12.6                 |
| Bedroom C     | 21.0                   | 16.8               | 12.9                 |
| Outer         | 9.3                    | -12.9              | -24.7                |

Air temperature change of each room and outdoor were analyzed in detail. For Living room, air temperature reached the highest value as 22.7°C at 21: 30 and 22: 00 of the first test day. And air temperature reached the second highest value as 22.6°C at 20: 30, 23:00 and 23: 30 of the second test day.
day. Air temperature reached the lowest value as 16.3°C at 8:00 of the third test day. In the case of not heating, the Living room was heated by solar energy and its air temperature reached 21.8°C at 11:30 and 12:00 of the second test day. For Bedroom A, when the boiler hot water system was not running, it was heated by solar energy and its air temperature reached 20.7°C at 11:30 of the second test day. And its air temperature reached the lowest value as 12.6°C at 8:00 of the third test day. For Bedroom B, air temperature reached the highest value as 19.1°C at 22:00 of the first test day. Its air temperature reached the lowest value as 12.6°C at 16:30 of the second test day. For Bedroom A, when the boiler hot water system was not running, it was heated by solar energy and its air temperature reached 20.7°C at 11:30 of the second test day. For Bedroom B and Bedroom C, the lowest value of air temperature appeared in the afternoon because of two things. On the one hand, the boiler hot water system was not running at that time. On the other hand, both rooms were located at northern part of the building block and it can't get enough solar radiation heat. It can be find that the lowest value of outdoor air temperature was -24.7°C, and this reflected the fact that it was unusually cold in winter in local region.

4.3. Test data analysis of air relative humidity

Figure 3 shows variation of air relative humidity in each room and outdoor during test period. Because it was near the Mu Us desert, so it was well known that local climate was very drought. Especially in winter, evaporation and precipitation was both small, which led to low relative humidity. It can be seen from Figure 3 that all air relative humidity in each room and outdoor were below 30% during test period. At some time of night, the relative humidity of outdoor air even reached zero. Some researchers [7] believe that if air relative humidity remained at 40% -70%, human body can maintain the stability of the evaporation process. Conversely, if air relative humidity was less than 30%, it would not only cause dissatisfaction of human body thermal sensation, but also cause respiratory diseases. So it was apparent that humid environment of these rooms can’t meet human thermal comfort need.

![Figure 3. Variation of air relative humidity in each room and outdoor during test period.](image)

Table 4 shows analysis of air relative humidity in each room and outdoor during test period. It can be seen that average air relative humidity of Living room was 25.7%, average air relative humidity of Bedroom A was 25.3%, average air relative humidity of Bedroom B was 27.4%, average air relative humidity of Bedroom C was 25.3%, average air relative humidity of Outer was 4.7%. Air relative humidity was affected by many factors, including occupants’ behaviours, ventilation, indoor air temperature, and so on. Air relative humidity change of each room and outdoor were analyzed in detail.
It was found that air relative humidity of each room reached the highest value at night of the first test day. For Living room, air relative humidity reached the highest value as 28.7% at 22:00. Bedroom A reached the highest value as 28.5% at 22:30. Bedroom B reached the highest value as 29.8% at 21:30. Bedroom C reached the highest value as 27.7% at 22:00. At night, doors and windows were closed in order to keep warmth, so there was no ventilation. During these times, boiler hot water system was running and air temperature of each room was rising. It was inferred that occupants’ behaviours affected air relative humidity of each room.

| Room/ Outdoor | The highest value | Average value | The lowest value |
|---------------|------------------|---------------|-----------------|
| Living room   | 28.7             | 25.7          | 21.5            |
| Bedroom A     | 28.5             | 25.3          | 22.2            |
| Bedroom B     | 29.8             | 27.4          | 23.9            |
| Bedroom C     | 27.7             | 25.3          | 21.4            |
| Outer         | 13.9             | 4.7           | 0               |

4.4. Test data analysis of solar radiation intensity

Figure 4 shows variation of solar radiation during test period. It’s well known that solar energy resources were abundant in local, and test data proved this. Solar radiation intensity had been zero all the time at night and these test data were cancelled. Figure 4 mainly shows variation of solar radiation intensity in the daytime during test period. Solar radiation intensity during test period was analyzed in detail. Solar radiation intensity reached the highest value as 676W/MM at 13:15 of the second test day.

For solar applications, there was an influencing factor which called solar effective sunlight time. The solar effective sunlight time of Yulin region was nearly 6 hours. So it can be calculated that there was an average value of solar radiation intensity as 477 W/MM during solar effective sunlight time. All these proved that local solar energy resources had a great application potential. In fact, solar energy heats the southern rooms of the building block had already been discussed in the above.

Figure 4. Variation of solar radiation during test period.

5. Results and comments

5.1. Human behaviours determines energy consumption of building
The house was just a building and it was be used by human. View point and attitude of the house’s owner determined the building's appearance, energy consumption and all other features. So people's habits can greatly affect energy consumption of building. More comfortable thermal and humid environment would inevitably come with more energy consumption. Appropriate thermal and humid environment should be determined and human behaviours should be guided in favour of building energy efficiency.

5.2. Building thermal environment should be regulated and controlled by zone division

Building thermal environment should be regulated and controlled in order to meet human needs. But people used different building spaces at different times, and these building space had different thermal comfort standards. So building thermal environment should be regulated and controlled by zone division. In this way, each technology played its own advantage. For example, a building was divided into southern part and northern part, and southern part can make full use of solar energy to satisfy human thermal comfort easily. Meanwhile, northern part can be heated by use of other appropriate technology in winter. In this paper, the whole building was heated by the boiler hot water system. The system was open and close regularly in order to save coal. But thermal environment of the building was general, and it can’t fully meet the needs of people.

5.3. Diverse technologies should be integrated application in heating of rural residences

Comprehensive utilization of various technologies reasonably would gain a great advantage in heating of rural residences. A variety of energy sources, such as electricity, coal, biomass, solar energy, natural gas, etc., can be used for building heating. Similarly, there was a variety of heating technology which matched with energy sources. Solar energy and biomass fuel, which both was clean, ecological and renewable energy sources, but they were unstable. Electric power had advantages of quick response and convenience adjustment in heating of building, but it was expensive. Burning coal in heating of building was not conducive to environment protection, but it was easily accessible and stable. Natural gas was clean energy source, but its energy reserve was small in China. So composite heating of diverse energy sources was the most suitable pattern for rural residences, which maximized the advantages of diverse energy sources and complemented the deficiencies each other.

6. Conclusions

Through test and analysis of indoor thermal environment in a typical rural residence, conclusions were summarized as follow:

1) Thermal environment of test rooms was in general, but humid environment was far below the human health standards. In these rooms, humidity control equipment was needed to adjust the air humidity.

2) The local solar energy resources had huge potential for building applications especially in heating. But solar energy had not been fully used in the test building.

3) The boiler hot water system was not the best heating method of rural residence. It consumed a great deal of energy when it met human thermal comfort.

4) Building thermal environment should be regulated and controlled by zone division, and each area was regulated and controlled by the most appropriate technology, so diverse technologies could be integrated application reasonably.

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