Study and Analysis on the Thermal Environment Test in Guanzhong Farm Residential in Winter

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Abstract. Rural residences in Guanzhong area have suffered from poor indoor thermal environment and backward energy-saving methods for a long time in winter. In order to study the local thermal environment, improve residents’ thermal comfort in winter and reduce building energy consumption. The research team conducted a typical winter solstice day Conduct thermal environment test and field survey on typical residential buildings in Guanzhong area, and quantify the test data to get the results: 1. Local solar energy resources have a certain potential. 2. The indoor thermal environment is severely humid and cold so that thermal comfort is low. 3. The first floor of residential buildings can basically meet thermal comfort requirements. According to the results of energy consumption calculations, Guanzhong’s farm buildings consume too much energy. In response to the national energy conservation and emission reduction policy, some improvement measures are needed to improve the atmospheric environment. Taking into account the local climate adaptability, residents' living habits and economic conditions, measures are proposed to reduce the area of the north window by a certain percentage, install additional sunshine rooms, and transform the second floor south to a balcony.

Keyword. Guanzhong area, dwellings, indoor thermal environment, improvement measures.

1. Introduction
The Guanzhong Plain of Shaanxi Province is located in the central part of Shaanxi Province, between the Qinling Mountains and the Weishan North Mountains, from Tongguan West to Baoji in the east, and is known as the "Eight Baiji Qinchuan". The basic landform types are river terraces and loess plateaus [1]. It is deep inland and away from the ocean. It belongs to the warm zone and semi-humid continental monsoon climate, and the winter is cold. This area is a cold area in my country's construction thermal zone. Winter insulation is the main problem that this area deals with.

In recent years, the reputation of the "Hometown of Kiwifruit" in Guanzhong has promoted the economic development of Guanzhong, so that people's lifestyles and living standards have been greatly changed and improved. Affected by brand-new value orientation, increasing technological level and foreign culture, people have also put forward higher quality requirements for living conditions. The form of rural housing in Guanzhong, Shaanxi has been transformed from "burrowing" to courtyards to self-built houses [2]. However, rural buildings have always been blindly imitating urban residential buildings, failing to design according to local conditions such as local climatic conditions. In addition, due to the limitations of rural craftsmen's skills, it has led to shortcomings such as unsatisfactory indoor thermal environment in rural buildings. In this context, in order to achieve the desired indoor temperature, most farm houses must use heating measures in winter, which causes a sharp increase in building energy consumption, contrary to the sustainable development of the building and ecological harmony. On December 21, 2016, General Secretary Xi Jinping pointed out at...
the 14th meeting of the Central Finance and Economics Leading Group that we should promote clean heating in the northern region. Therefore, traditional heating methods in rural areas need to be improved.

The field survey in China started in 1999 [3]. So far, a large number of scholars have conducted research on the thermal environment of rural buildings. There are systematic survey reports in Shaanxi [4], Lhasa [5], Quanzhou [6] and other places. The results show that due to the differences between rural residents and urban residents in dressing habits, lifestyle, etc., the construction standards and heating standards for rural buildings cannot be completely copied from urban buildings. Regarding the Guanzhong area of Shaanxi, there has not yet been systematic investigation and testing, nor has it fully quantified the solar radiation intensity and energy consumption test results.

2. Features of Residential
The research team chose a test farm house in Xiaoliu Village, Zhouzhi County, Guanzhong County, Shaanxi Province. Located between 33°42' and 34°14' north latitude, Zhouzhi County is 68 kilometers away from the urban area of Xi'an and has typical Guanzhong’s climate and topographic features. It is cold and dry in winter with little precipitation.

The local dwellings are dominated by brick-concrete structures. The most dwellings are two-story plus attic, as is shown in figure 1. According to the investigation, there are three types of residential buildings in the Guanzhong area: single-family, single-family with front yard and primary and secondary house plus front and back yard. The spatial layout of single-family and main house is mainly three-bay L-shaped, and most of them are north-south. The front yard is mostly a chatting place for residents, and most of them have independent kitchens. The main house is equipped with a bedroom and a living room and the backyard leads to the second house, which has storage rooms, toilets and bathrooms.

![Figure 1. Guanzhong rural typical housing.](image)

3. Test Residential and Test Plan

3.1. Basic Information of Test Object
The test object is a farm house in Xiaoliu Village, whose architectural plan is a typical three-bay L-shaped layout, as is shown in figure 2. The building consists of two floors and a loft. The first floor is mainly for toilets, bedrooms and living rooms, with a height of 3.8 m. The second floor has two bedrooms and a living room, with a height of 3.5 m. The main bedroom on the first floor is equipped with 2.2 m×2.0 m single glass windows in the north-south direction. The main bedroom is heated by a coal stove. There is no insulation layer on the roof, and the outer wall is 240 mm thick solid clay brick wall. The inside and outside are plastered without insulation layer, and the outer door is a metal door with cotton curtain.
a) The first floor of residential buildings. b) The second floor of residential buildings.

**Figure 2.** The architectural plan and measurement points of the residential buildings in Xiaoliu Village.

### 3.2. Physical Information of Test Object

According to survey statistics, 90% of people in the rural areas of Zhouzhi County uses electricity, 35% uses coal, 30% uses firewood, and 1% uses solar energy for winter heating. However, air conditioning is used regularly at night, and other heating tools are used most of the time. Due to economic constraints, the heating mode of local residential is more traditional and polluted. The average daily heating time is relatively short, and most residents have a monthly heating cost of about 150 yuan.

### 3.3. Basic Information of Residents

Due to the low average income of local rural residents, most young people choose to go out to work and live at home for a short period of time, while the elderly and children live at home for a long time. Therefore, chatting has become a daily habit of residents. Different from the living habit of urban residents, the auxiliary rooms such as toilets and kitchens of local rural buildings are usually outside the main house, and the main house is more frequent. Therefore, indoor and outdoor residents wear the same clothing, and the thermal resistance of the clothing in the heating room is greater.

### 3.4. Test Plan and Equipment

On January 10–14, 2020 (around the winter solstice), a 48-hour thermal environment test was carried out in two residential houses. The model of the solar radiation meter is JTDL-4, the measurement accuracy is ±2%, and it is installed horizontally outdoors without obstructions. The model of the temperature and humidity tester is 175-H1, and the accuracy is 0.2℃. The accuracy of the heat transfer coefficient detector of the enclosure structure adopts JTNT-C instrument with accuracy of 0.5℃. The test phase is located one week before the winter solstice, during which weather is sunny. During the test period, the master bedroom adopts the same heating measures as usual. The windows are closed 24 hours a day, and the personnel activities are the same as usual.

### 4. Test and Analysis

#### 4.1. Outdoor Thermal Environment Test

**4.1.1. Solar Radiation Intensity.** The solar radiation intensity of this test is shown in figure 3. The measurement point is located on the balcony on the second floor of the first residential building without any obstructions around it. Therefore, the test data is true and valid. The solar radiation intensity includes the total solar radiation intensity and the scattered solar radiation intensity. The effective duration of solar radiation on the day of the test is 9 hours, from 9:00 to 18:00. It can be seen that the winter solar radiation is mainly scattered and the peak appears around 13:00. The peak value
of total solar radiation intensity is 500.6 W/m² while the average value is 236.75 W/m². The peak value of scattered solar radiation intensity is 184.5 W/m². The average value is 102.96 W/m². So the direct solar intensity accounts for 56.5% of the total intensity. As Guanzhong is dominated by plains and there are no high mountains around it, the duration of solar radiation is longer and the solar radiation intensity is higher.

4.1.2. Outdoor Air Temperature and Humidity. The test results of outdoor air temperature and humidity are shown in figure 4. During the winter test, the highest outdoor temperature on that day was 3.45°C. The highest relative humidity was 80.81%. The average outdoor temperature was 2.35°C. The average relative humidity was 78.01%. The daily temperature range was 1.65°C. The test results show that the area is relatively wet and cold in winter mean while the temperature and humidity changes little.

4.2. Indoor Thermal Environment Test
Now compare the test temperatures of the master bedroom on the first floor, the living room on the first floor, and the master bedroom on the second floor. The test results are shown in figure 5. The temperature difference between 0 and 23 is mainly caused by personnel activities. In addition to the master bedroom on the first floor, the living room on the first floor is also a place where residents move more frequently, while the master bedroom on the second floor is rarely inhabited and does not have any heating tools, so it also joins the ranks of comparison.

The test results show that the average 24 h temperature of the master bedroom on the first floor of the tested farm house is 5.85°C, and the temperature difference on the day is 1.02°C, with no obvious change. The average temperature of the master bedroom on the second floor of the tested farm house was 4.59°C. In the case of using heating tools (coal stove), the temperature of the master bedroom on the first floor increased by only 1.26 °C. Relative to the average outdoor temperature of 2.35 °C, it only increased by 3.50 °C. According to the requirements of "China Building Energy Conservation
Annual Development Research Report", the indoor comfortable temperature in winter the minimum is 14 °C, this test object did not meet the requirements.

4.3. Calculation and Analysis of Building Energy Consumption

4.3.1. Energy Consumption Per Building Area. Take the test house as an example. During the test period, electric blankets are used for heating to maintain the indoor temperature, and the electricity used by the electric blankets will be used as the total energy consumption of the houses. The energy consumption per unit area of the building is calculated by the following equation [7].

\[ \Phi = \frac{278Q}{At} \]  

Among them, \( Q \)--the total energy consumption of the building during the inspection time, MJ. \( A \)--the total area of the building, m\(^2\). \( t \)--the inspection duration, s.

During the heating period of the farm house, the monthly electricity fee is 100-150 yuan. According to the local 0.5 kWh/yuan, the average daily power consumption is 8.4 kWh, and the energy consumption per building unit is 97 MJ/m\(^2\). Due to the simple and traditional heating mode of residents, and no complex heating system has been formed. So that the building energy consumption is low. However, the expected heating temperature of residents has not been reached at the present stage.

4.3.2. Analysis of Building Energy Consumption. By using The Swire software, the thermal load of the building in the test stage was simulated and calculated with the setting temperature of the main function room at 14°C. The setting temperature of the secondary function room and the auxiliary room at 10°C. Figure 6 was obtained. In winter, the peak heating energy consumption reached at 9 am in the slack season while most people went out for a stroll after lunch break. As a result, the heat load was low.

![Figure 6. Functional room heat load.](image)

Due to the serious penetration of cold wind in farm houses, more electricity is required to maintain the indoor temperature in a relatively comfortable state, so more building energy consumption is required.

5. Analysis of Thermal Insulation and Energy Saving of Farm Houses

The Guanzhong area is a cold area with long winters and low temperatures. In order to ensure adequate comfort in the indoor thermal environment in winter, appropriate insulation measures need to be considered. In the investigation and test, it was found that some new residential houses have begun to apply thermal insulation materials and put the main bedroom on the south side to improve the problem of indoor winter cold. However, most of farm houses have not undergone formal thermal design due to the curing thinking of artisans. So that it causes various bad indoor thermal environments. Generally speaking, the Guanzhong residential buildings have the prototype of
designing houses based on the regional climate. To economically improve the indoor thermal environment of the residential buildings, it is necessary to utilize the local climate characteristics [8].

5.1. Envelope Structure
Most residential buildings in Guanzhong area have adopted attic design. The function of the attic is one for heat preservation and the other is to store sundries. To a certain extent, it provides an effective role in keeping warm in winter. However, the roof and exterior wall materials of residential buildings are of common material structure. The outer wall is basically a clear water brick wall without facing material protection, which increases the cold air penetration of the wall in winter and the heat transfer of the wall. So that it is not conducive to the insulation of the indoor thermal environment in winter.

Based on actual investigations, a thermal insulation construction method that combines thermal insulation and load-bearing can be adopted. The original solid bricks are replaced by materials with small heat transfer coefficients such as hollow blocks and light solid blocks, which are simple in structure and convenient to construct. The roof structure uses an inverted roof method. In other words, the waterproof layer is inverted under the insulation layer to prevent the insulation layer from being exposed to the air, which is prone to aging and damage.

The outer window is beneficial to the introduction of solar radiation, but at the same time there is the problem of cold wind penetration. In order to ensure the sunshine requirement, the outer window still needs to retain a certain size. During the investigation, it was found that the ratio of window area to residential buildings in Guanzhong area is generally too large, and most of them are single-glass aluminum alloy windows and wood frame windows. Excessive heat transfer loss is not conducive to heat preservation. In order to improve the indoor thermal environment, the air tightness of external windows should be improved. The penetration of cold air should be reduced. Households with economic conditions can also use double glass windows. Tests show that the indoor temperature of new-style houses with double-glass windows is higher than that of single-glass windows 1.09℃ higher.

In addition, some rooms of the tested farm house are equipped with large windows in the north and south. Due to improve the indoor thermal environment, the area of windows from the north to the outside can be appropriately reduced to keep the window-to-ground ratio above 0.3.

5.2. Space Layout
The heat dissipation in rural restaurants in Guanzhong, Shaanxi Province is the largest [9]. Residents’ activities are mainly concentrated in bedrooms and kitchens. Especially the bedroom, which also has the functions of the customer hall, dining room as well as bedroom. It also serves as a customer hall. The functions are too concentrated. Therefore, the functional zoning of old farm houses is not clear. The suggestion for improvement is to set up the kitchen adjacent to the brick bed. Keep the original form of the stove connected to the brick bed. So that it can use the residual temperature during cooking to heat the brick bed to save energy. The living room is set up next to the brick bed. The sun room is set on the south side of the living room and the entrance [10].

5.3. Solar Energy Resource Utilization
In the survey, it was found that most of the test farm houses are three-part L-shaped layouts while the second floor is mostly for children. However, the juniors go out to work all the year round and their rooms are idle. It plays as storage rooms. So that the second floor can be transformed into a balcony from the south which can be a platform for drying clothes. As is illustrated in figure 7.
6. Conclusion
1) A winter indoor thermal environment test of typical folk houses in Guanzhong, Shaanxi province shows that the indoor temperature in the winter is below 10°C. So that the thermal comfort of human body is cold with poor indoor thermal environment. The meteorological conditions in Guanzhong were tested. It was found that the local solar energy resources had certain potential.

2) The self-built houses in Guanzhong, Shaanxi are simple in structure, with no systematic functional division in layout. The building height is too large and the heating method is simple and traditional, so that the indoor thermal comfort is bad.

3) A simple calculation of building energy consumption shows that farm houses are generally higher in winter. In order to reduce building energy consumption and improve winter thermal comfort, it is proposed to fully integrate the characteristics of the local climate and region, residents’living habits and economic conditions. And it proposes new roofing practices, measures to reduce the window area from the north to the outside and add a balcony on the second floor.

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