Analysis of Indoor Thermal Environment of Korean-Chinese Dwellings in Yanbian Area in Winter

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Abstract. In order to understand the construction technology characteristics of traditional Korean-Chinese dwellings in Yanbian area, traditional Korean-Chinese earthen and brick houses were used as the research objects in the analysis of the indoor thermal environment. In this study, temperature and relative humidity in each room were separately tested. Due to the particular heating method applied in the traditional Korean-Chinese dwellings, the indoor temperature and relative humidity are relatively stable, i.e. average temperature is maintained above 16°C, and average relative humidity is maintained at about 50%. The test results can effectively verify the superiority of Korean-Chinese traditional construction experience and technology.

1. Introduction

With the rapid economic development, people have increasing requirements for their living environment. Thus, the traditional Korean-Chinese dwellings have been gradually replaced by farmers’ self-built dwellings with brick house structure. However, many Korean-Chinese residents still live in traditional dwellings and the research on the indoor environment of these dwellings is important [1, 2]. Korean-Chinese traditional dwellings have distinct regional characteristics, culture, and contain climate-adaptive energy-saving technology that is warm in winter and cool in summer. In order to provide a reference for the green development of Korean-Chinese dwellings in Yanbian area, this study conducted a comprehensive comparison analysis between traditional dwellings and self-built dwellings in order to study the indoor environment of different types of Korean-Chinese dwellings in Yanbian area.

2. Overview of test objects

Winter in severely cold regions is long and cold with a large diurnal temperature range. The night temperature can reach -30°C, and the day temperature can reach 3°C. To increase the indoor temperature, heating equipment is installed indoors in addition to heating measures taken for the house structure. The heating facility for Korean-Chinese dwellings is called Ondol and it represents a full-bed low-fire Kang that is a unique heating method for these dwellings. It not only satisfies the traditional Korean-Chinese lifestyle, yet it also conforms to modern residential design standards [3]. There is generally a height difference of 20-30 cm between the Ondol and the ground. The Ondol is made of loess with good viscosity and slates or bricks. The investigation area is located in Longxin village, Toudao Town, Helong City, in the Jilin province. This article selected two typical Korean-Chinese dwellings and conducted a thermal environment test and comparative analysis (Figures 1 and 2). Dwelling A (built in 1960) has a Xieshan roof and its exterior wall is made of mud and grass and
then coated with white ash. Dwelling B (built in 1980) has a Xieshan roof relatively spacious internal space, and exterior wall made of bricks and other materials.

Dwelling A has a net height of 2.02 m and a main living space area of 35 m². It uses Ondol for heating. The wall thickness is 300 mm and it is filled with loess framed by wooden pillars. Its plane composition contains a Jeongi (storage room) and a warehouse (Figure 3). With the Jeongi and the Woobang (as the bedroom for the guest) becoming one room, the plane composition of this house is unique, and all living activeties are carried out in the Jeongi. When the house was built in 1960, it was a thatched house. Since grass roof needed repairing every other year, the roof material was replaced with tiles in 1980.

Dwelling B has a net height of 3.12 m and a main living space area of 53 m². It also uses Ondol for heating. The wall is made of bricks and is 370 mm thick. Its plane composition a Jeongi, a Woobang, a storage room, a cellar, and a wash room (Figure 4). The Jeongi serves as the main living space and it is set in the center of the house that is mainly used for reception and dining. However, it also serves as the bedroom for the old couple. The Woobang serves as a guest room.
3. Test scheme
An indoor thermal environment measurement campaign was conducted in two Korean-Chinese dwellings from 0:00 on December 27th to 0:00 on December 28th, 2017. The test content and method are as follows: 1) Measure indoor air temperature and relative humidity in each room using a temperature and humidity self-recording instrument (Tian Jian Hua Yi WSZY-1). The instrument measurement range is from -40°C to 100°C for temperature, and from 0.1 to 100% for relative humidity. The measurement precision is 0.1°C for temperature and 0.1% for relative humidity. The measurement locations are arranged in the Jonggi and kitchen (Figures 3 and 4) at a height of 1.5 m above the ground. Continuous measurement was performed for 24 hours, with data collected every 10 minutes; and 2) Use questionnaires to investigate indoor comfort and fuel consumption. The main purpose of the analysis is to compare the thermal environment of two Korean-Chinese dwellings, to analyse the objective thermal environment conditions and differences between the earthen house and the brick house, and to understand residents' satisfaction with the indoor thermal environment.

4. Thermal environment test results
During the measurement period (from 0:00 on December 27th to 0:00 on December 28th), the lowest outdoor temperature was -20°C at 05:00, while the highest temperature was -7°C at 13:30. Accordingly, the maximum temperature difference was 13°C, with the average outdoor relative humidity of 54%. During the measurement period, the indoor temperature fluctuation was mainly affected by the residents' cooking and Ondol heating. Through the analysis of the temperature in the kitchen and the Jonggi, the dynamic heating law of the dwellings could be understood. Cooking activities occur from 05:00 h to 07:00 h. After two and a half hours, the indoor temperature reaches the highest value and then gradually decreases until 16:30~18:30 when the cooking activities start again and the temperature increases again. Soybean stems and corncobs are used as fuel (Figure 5).

4.1. Temperature and humidity in dwelling A
During the measurement period the Ondol was firstly heated by using a 1/3 woven bag of fuel (woven bag size: 45 cm × 75 cm) at 5:00 AM on December 27th. Afterwards, the Ondol was heated again at 4:30 PM by using a 1/2 woven bag of corncobs and some soybean stems. (To give the child a bath, the Ondol was heated again at 19:00 PM by using some soybean stems.)

It can be noticed from Figure 6 that the temperature did not change substantially between the kitchen and the Jonggi of dwelling A. The average temperature difference is 0.3°C, while the highest (lowest) temperature difference is 0.6°C (0.2°C).

The Jonggi is the mainly used space of dwelling A. The average indoor temperature is 17.3°C, which meets the winter indoor thermal comfort requirements of the dwelling. The highest temperature of 20.5°C was measured at 10:30 AM and from 8:40 PM to 8:50 PM, while the lowest temperature of 11.2°C was measured at 5:10 AM. According to questionnaire survey, residents start to make fire and
cook at 5:00 AM. They fetch the fuel from outside when making the fire, thus the lowest temperature occurs during this period. The Jeongi has the temperature above 20°C occurring in periods from 8:40 AM to 1:00 PM, and from 8:30 PM to 10:30 PM.

The reasons behind the occurrence of higher temperatures in dwelling A are solar radiation heating up the room during the day, and the residents making fires and cooking. Accordingly, using Ondol for heating is an effective measure to increase the indoor temperature and to conform to the living habits of Korean-Chinese dwellings.

It can be noticed from the measurement results in Figure 6 that humidity changes to some extent in the kitchen and the Jeongi of dwelling A. It is mainly due to the large amount of water vapor released during cooking in the kitchen. The generation of water vapor is located in the cauldron in the Jeongi (Figure 3), thus the average relative humidity in the Jeongi is 3% higher than that in the kitchen.

Cooking activities start at 5 AM and they generate water vapor that will increase the indoor humidity. Outdoor air humidity fluctuates greatly with the maximum difference between the highest and the lowest values reaching about 40%. On the contrary, the indoor relative humidity difference between the highest and lowest values of each room is below 21% (Figure 4). The average relative humidity in the Jeongi was 54%, with a maximum relative humidity of 65.2% and a minimum relative humidity of 45.4%. The average relative humidity in the kitchen was 51%, with a maximum relative humidity of 70.6% and a minimum relative humidity of 48%. Furthermore, the highest relative humidity appeared at 7:40 AM, and the lowest relative humidity appeared at 2:40 PM.

4.2. Temperature and humidity in dwelling B

During the measurement period, the Ondol was firstly heated by using a 1/2 bag of fuel (bag size: 45 cm × 75 cm) at 6:00 AM on December 27th. Afterwards, the Ondol was heated again by using a 1/2 bag of corn cobs and some coal at 4:00 PM.

It can be noticed from the results in Figure 7 that the temperature did not change substantially between the kitchen and the Jeongi of dwelling B. The average temperature difference is 0.5°C, while the highest temperature difference is 0.6°C and the lowest temperature difference is 0.5°C.

The mainly used space of dwelling B is the Jeongi. Its average indoor temperature is 16.2°C and it meets the winter indoor thermal comfort requirements of the dwelling. The highest temperature is 19.2°C and it was measured from 10:10 AM to 10:40 AM. On the contrary, the lowest temperature is 12.2°C and it was measured at 5:20 AM. Through the questionnaire survey, the residents of dwelling B reported that they start making the fire and cooking at 6:00 AM. They do not fetch the fuel from outside when making the fire, and the lowest temperature occurs during this period. The Jeongi has the temperature above 18°C in the periods from 8:40 AM to 1:50 PM and from 4:30 PM to 6:30 PM.

The reason for the occurrence of high temperature of dwelling B is that in addition to the solar radiation heating up the room during the day, the residents have to make the fire and cook every day, thus making the Ondol an effective indoor heat source during the day, and the latter is the main reason. Accordingly, using Ondol for heating is an effective measure to increase the indoor temperature in winter.

It can be noticed from the results presented in Figure 7 that cooking activities in dwelling B start at 6 AM, and this activities generate water vapor that increases the indoor humidity. The outdoor relative humidity fluctuates greatly, with the difference between the highest and the lowest values of about 40%. The indoor relative humidity difference between the highest and lowest values of each room is below 12.5% (Figure 4). The average relative humidity in the Jeongi was 50.4%, with a maximum relative humidity of 55.1% and a minimum relative humidity of 43.8%. The average relative humidity in the kitchen was 52%, with a maximum relative humidity of 55.8% and a minimum relative humidity of 45.4%. The highest relative humidity appeared at 7:30 AM, and the lowest relative humidity appeared at 12:40 PM.
5. Comparative analysis of indoor environments

5.1. Comparative analysis of temperature (Figure 8)
With only the indoor temperature taken into consideration, the indoor thermal environment of dwelling A is better than that of dwelling B during winter, due to the high average temperature and a longer period with temperature above 16°C. The average indoor temperature of dwelling A (earthen house) and dwelling B (brick house) reached above 16°C, which is in line with the current Design standard for energy efficiency of rural residential buildings [4]. However, with the improvement of living standards, residents have higher requirements for indoor temperature that is expected to be from 18°C to 20°C in winter. Apart from the above objective values, temperature fluctuations due to entering and exiting houses, building layout, building plane size, and building height can have a great impact on thermal comfort.

5.2. Comparative analysis of temperature (Figure 9)
Relative humidity in two dwellings frequently fluctuates from 6 AM to 8 AM and from 4:30 PM to 7 PM, mainly as a consequence of cooking activities carried out during this period. There was a period of humidity fluctuation in dwelling A between 8 PM and 9 PM, and this is mainly due to showering in the Jeongi during this time. During the measurement period, the relative humidity of dwelling A was slightly higher than that of dwelling B. According to China's Indoor Air Quality Standard (GB/T18883-2002) [5] and China Building Energy Conservation Annual Research Report [6], the standard value of indoor relative humidity during the heating period in winter is from 30% to 60%. Therefore, both dwellings are in the range of health and comfort. With only considering the indoor relative humidity, dwelling B is more comfortable than dwelling A.
6. Conclusions
The indoor thermal environment analysis of Korean-Chinese dwellings showed that these dwellings have a good temperature and humidity adjustment capability and that they are in accordance with the thermal and humidity limits stipulated by GB/T18883-2002 Indoor air quality standard. Ondol, a heating method of Korean-Chinese, is a heating element and the house space is a heat storage body, thus the heat storage space is large. Nevertheless, the intermittent heating of the Ondol will cause low temperatures at night. In general, Korean-Chinese dwellings have good airtightness and thermal stability, which verifies the superiority of traditional Korean-Chinese dwelling construction technology.

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