Effects of Different Materials on Indoor Thermal Environment in Guangxi Miao Village

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Abstract. With the development of the social economy, the reinforced concrete residences in the Miao village in Guangxi were gradually appearing, which shows a threat to the traditional wooden residence to some extent. Which one was more suitable for the local environment? This paper investigated three representative residences in the Jiangzhu village, Liuzhou city, Guangxi province of China. Residence No.1 belongs to an old carpenter's family was built with traditional building materials (wood) fifty years ago. Residence No.2 was also a wooden house with a history of over one hundred years. Residence No.3 was a recently built residence with modern materials (brick and reinforced concrete). The temperature and humidity of these three houses were measured respectively, and the results show that, in Guangxi Miao village, the traditional building materials and constructions were superior to that of modern building in terms of their indoor thermal performance.

1. Background

Thermal environment is closely related to the health and comfort of human. People have been trying to improve the living environment by developing new technologies. However, through historical screening, the traditional folk houses created by the ancestors uses various simple constructions and local materials to cope with the regional climate and environment in different places. [1] This paper compares and analyzes the indoor thermal performance of traditional residences and modern residences in a Guangxi Miao village in China.

Located in the southwestern part of the hot-summer and cold-winter zone, the county is located in the mid subtropical monsoon climate. Surrounded by mountains, the climate obviously turns like mountain climate. In Rongshui, the weather is greatly influenced by monsoon and the heat and humidity are intense. However, the climate is quite mild. The extreme maximum temperature was 38 °C in 2017. The annual extreme minimum temperature in the county was 3°C. The lowest temperature in the cold mountain area was -4.1°C. The rainfall is abundant but not evenly distributed. The four seasons are uneven. Summer is the longest, then winter and the shortest season is spring. The annual total evaporation was 1478.2 millimeters. [2]

Rongshui always has the reputation of "the kingdom of China fir ", which means it is rich in the resources of China fir. Besides, China fir has good quality and toughness which is suitable to be used as building materials. Therefore, the traditional building and furniture in this area mostly use China fir as raw materials forming a very local style stilt house (Figure 1). The advantage of the stilt house

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is that it can be built without land formation. The house can be built after a fire on the burnt place. Besides, it can play a good role in moisture-proof, ventilation and cooling. [3]. However, with the development of the social economy the construction of new rural residence, reinforced concrete, shows a great influence on the traditional residences built with wood and other traditional building materials. The modern residences were generally 3-4 floors, with flat roof, and the bottom was selectively elevated (Figure 2).

Figure 2. Modern residence (Masonry house).

Figure 2. Modern residence (Masonry house).

2. Field investigation

2.1. Purpose of the investigation

In order to analyze the thermal environment of Miao village in Guangxi, there were three representative houses in the Jiangzhu village of Rong Shui county selected as test subjects.

Residence No.1 was an old carpenter's house, which was built fifty years ago. The building locates on the south slope of a hill. The main entrance and living room faced north, and its main material was wood. Its first floor was used to raise livestock. The second floor was used for daily life with Huotang (means fire pond, a special space in the local traditional architecture, surrounded with family member and providing heat both for cooking and air). There was an attic used as storeroom.

Residence No.2 was a 100-year-old local residence. Located within a group of buildings, it was built on the mountain and faced south. Its first floor was used for storing and raising livestock. The second floor was used for daily life with better lighting.

Residence No.3 was a house with modern materials. Its first floor was partly built on a stream, partly used for storage and the second floor was used for daily life. It has terraces on the top floor and its roofs were flat.

The temperature and humidity of the three houses were measured respectively. They were less than 300m apart. So, they had the similar outdoor environmental and climatic impacts.

2.2. Instruments and measurement methods

2.2.1. Layout of the measurement instruments. A total of 6 temperature and humidity self-recording instrument were used to measure the temperature and humidity of the three houses. Positions of the instruments (① to ⑤) were shown in Figure 3-5.

Residence No.1: ① was set in the guest hall, half opened to outside space, without direct sunlight. So, it represents outdoor environment. ② was set in the bedroom, representing the traditional house indoor environment.

Residence No.2: ③ was set in the bedroom, representing the indoor data of traditional buildings. ④ was set in the living room.

Residence No.3: ⑤ was set in the bedroom, representing the indoor environment of modern house.

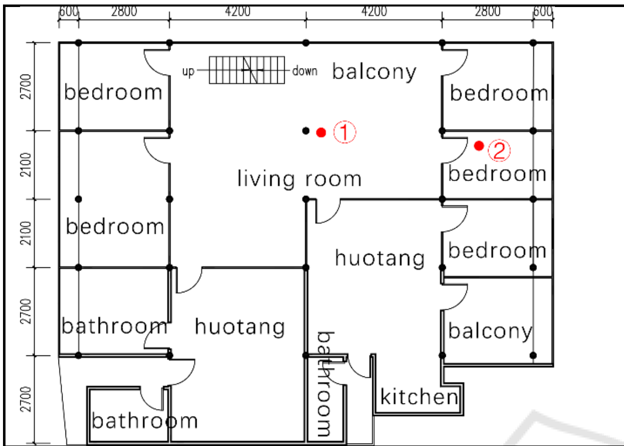

Figure 3. Positions of the instruments in Residence No.1.

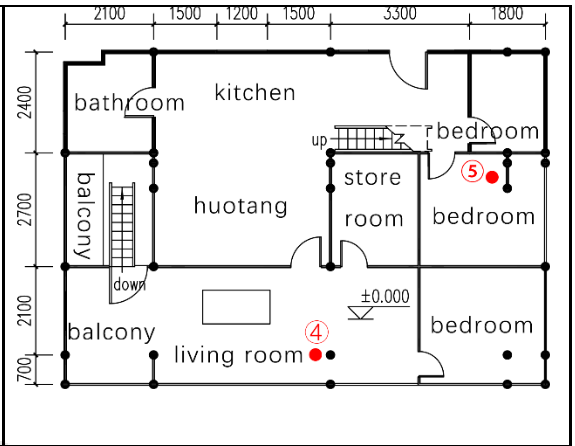

Figure 4. Positions of the instruments in Residence No.2.

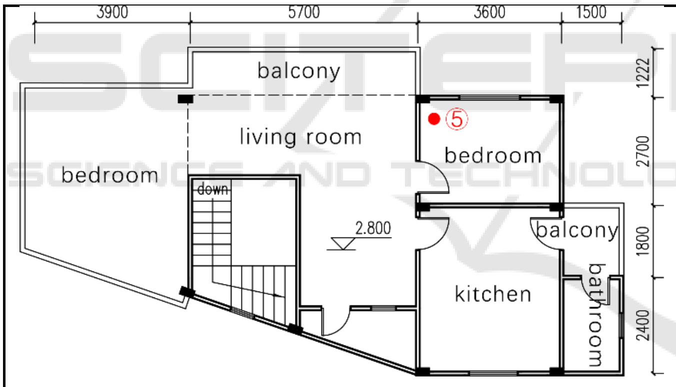

Figure 5. Positions of the instruments in Residence No.3.

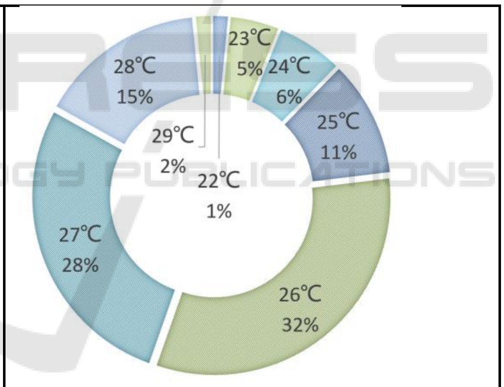

Figure 6. Daily average temperature frequency.

2.2.2. Method of Measurement. Temperature and humidity self-recording instrument were set to collect temperature, humidity data every 10min. It continuously recorded for 64 days. All the collected data was read into the computer.

3. Data analysis

3.1. Data processing

3.1.1. Temperature. In order to simplify the large amount of data, the common average temperature was selected from typical days to represent summer time. The specific process was:

I. Calculate the daily average temperature. II. Determine the frequency of different temperatures. It was found that the occurrence frequency of 26-27 ℃ was the highest (Figure 6). So 26-27 ℃ was selected as the typical day, 25 and 28 ℃ as the floating range. III. The corresponding time range was

2017.8.30 00:00AM-2017.9.5 11:30PM. IV. Calculate the average temperature every 30 min. V. Convert the data into line chart.

The analysis results were expected to reveal the differences of indoor thermal environment between the modern and traditional houses.

3.1.2. Humidity. Because of the abundant rainfall in summer, the data shows a great turtbulence by rainfall. [4] So weather was considered as the mainly influence factor of indoor humidity. Sunny weather and rainy weather were the most common weather in the researched area. Data between 2017.8.30 00:00AM-2017.9.1 11:30PM were selected to represent the change of humidity indoor and outdoor in the sunny days, and data between 2017.8.9 00:00AM-2017.8.11 12:00PM were selected to represent the changes of humidity in the rain days.

3.2. Temperature analysis

3.2.1. Comparison of residence No.1 and No.3. This part was going to analyse the influence of different structures and materials on indoor temperature under the same orientation and the same climate.

According to Figure7, the mean outdoor temperature among the selected period was 27 ℃, and the maximum temperature was generally between 16:30-17:30. The selected time period was sunny, and the temperature fluctuates within the range of 22.7-31.4 C. The mean indoor temperature of the traditional residence (Residence No.1) was 27.8 ℃, the daily maximum temperature was floating at 28.5 -30.5 ℃, the minimum was about 24.2 ℃ -26.9 ℃, and the amplitude of temperature fluctuation was about 3.5 ℃, which was lower than that of outdoor. The average indoor temperature of the modern house (Residence No.3) was 31.1 ℃, the daily maximum temperature was floating at 30.5 -36.4 ℃, the minimum was about 26.3 ℃ -29.9 ℃, the temperature fluctuation was about 5.5 ℃, and the overall level was higher than that of the outdoor.

According to Figure 7, the heating time of Residence No.1 was about 11 hours, and the cooling time was about 13 hours. The temperature of Residence No.3 was about 11.5 hours, and the cooling time was about 12.5 hours. Both of their time were similar. Therefore, it was not the length of heating time but the amount of radiant heat that rise the temperature.

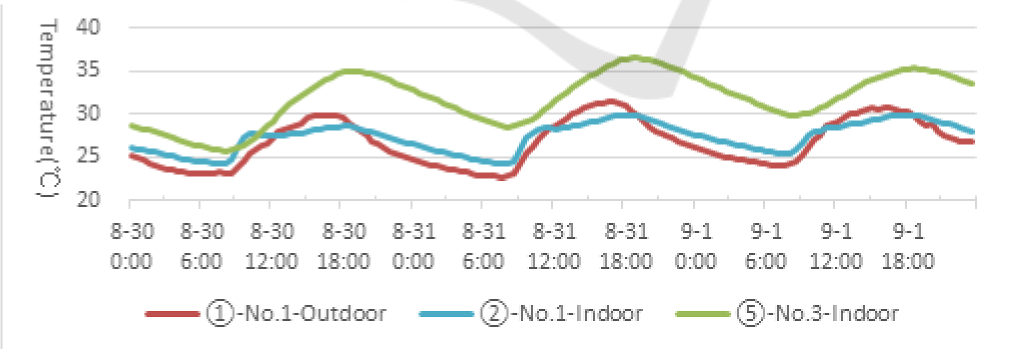

Figure 7. Temperature comparison between Residence No.1 and Residence No.3.

According to Figure7, the daytime heat absorption of traditional dwellings was approximately equal to the night heat release. Although both of No.1 and No.3's heat exotherms during night were almost equal, the heat accumulation in the day of modern dwellings was greater than that at night, resulting in the accumulation of heat and the increase of temperature. The slope of both warming and cooling part can be found to be almost the same as that of heat release. But during the heat accumulation the slope of the traditional house had an obvious change. In each cycle, the heating rate of traditional buildings before 10:30 was faster, while slower after 10:30. With the increase of outdoor temperature, the heat transfer rate of the envelope decreased obviously, the rate of indoor temperature increased slowly, and the total amount of heat was less than the modern residence. This shows that compared with modern houses, the envelope of traditional buildings had better thermal performance, and to a certain extent reduced the heat transfer from outdoor to indoor.

In addition, the highest outdoor temperature was around 17:00 and the highest indoor temperature was around 19:00, delay 2 hours. However, the minimum temperature in and outside the room was similar. From the same time at night, the traditional building showed a more comfortable temperature, about 25.5 ℃, 5 ℃ lower than modern buildings.

3.2.2. Comparison between residence No.1, residence No.2 and residence No.3. The following discussions were conducted to compare the impact of building structure, material selection and building orientation on indoor temperature.

After comparing the outdoor temperature of Residence No.2 and No.3 (Figure 8), it was found that both of them were almost identical. Because the living room of the traditional house in this area was half opened to outdoor space, so the temperature was similar to that of the outdoor air. That is to say, the main factor affecting the temperature of living room was outdoor air, and the influence of building orientation on the temperature of living room was very small.

After excluding the influence of orientation, the following part will compare the indoor temperature of Residence No.1, Residence No.2 and Residence No.3 (Figure 9). Except for a slight difference in the fluctuation range, the traditional residence (Residence No.1 & No.2) was basically similar in terms of cycle and mean value, keeping at around 26-27 ℃. The temperature of modern houses (Residence No.3) was higher than that of traditional houses (Residence No.1 & No.2) at the same time, which was 6-7 ℃ higher than that of traditional buildings.

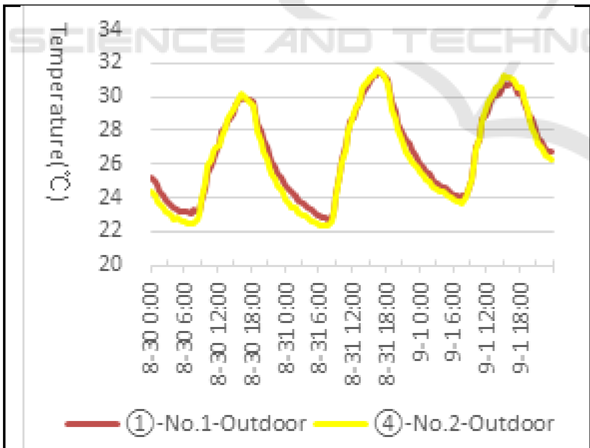

Figure 8. Outdoor temperature comparison (No.1 & No.2).

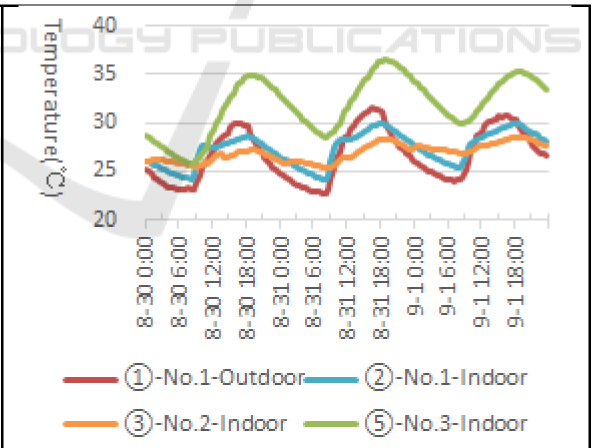

Figure 9. Temperature comparison (No.1& No.2 & No.3).

3.3. Humidity analysis

3.3.1. Comparison between residence No.1 and residence No.3. According to Figure10, the average humidity was 77.5% during the continuous sunny days in summer, and the highest was around 9:00AM. It fluctuated periodically in the range of 60.5%-89%. Average indoor humidity of the traditional residence was 80.6%, the daily maximum humidity was about 85%, which was slightly lower than outdoor. And the lowest was about 77%, which was obviously higher than the outdoor. Besides, the moisture fluctuation amplitude was about 5 percentage points, which was less than that of the outdoor. It can be seen that the envelope of traditional houses had strong hygroscopicity and kept indoor humidity at a high level.

The indoor average humidity of the modern house was 60.8%, the daily maximum humidity was about 68%, which was obviously lower than outdoor and the lowest was about 55%. And the humidity fluctuation was about 12 percentage points, which was less than the outdoor corresponding data. Therefore, the envelope of modern residential buildings had better moisture resistance and can kept indoor humidity at a low level.

According to the annual development report of China building energy conservation [5], indoor comfort relative humidity range from 30% to 70%. Modern houses can basically reach a relatively comfortable humidity environment, but traditional houses were much higher than this standard.

In the continuous rainy days, Residence No.1 and Residence No.3 basically kept the same, at around 80%, and slightly lower than outdoor humidity.

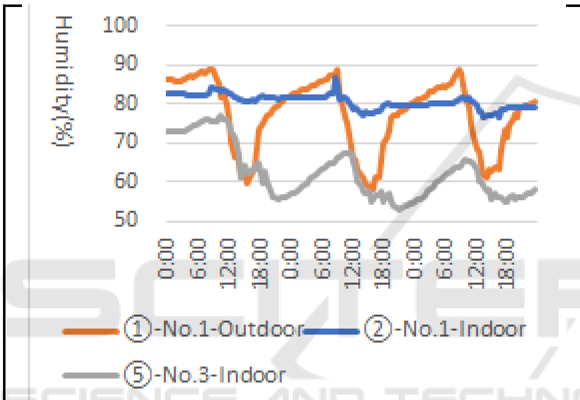

Figure 10. Humidity comparison (No.1& No.2 /Sunny).

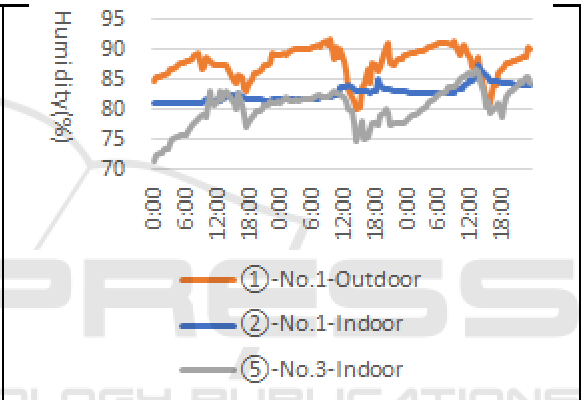

Figure 11. Humidity comparison (No.1& No.2 & No.3 /Rainy).

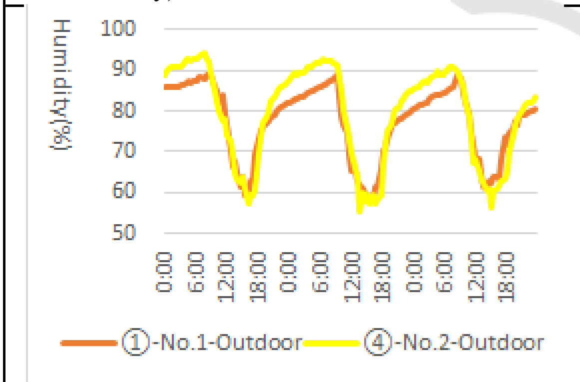

Figure 12. Outside humidity (No.1& No.3 /Sunny).

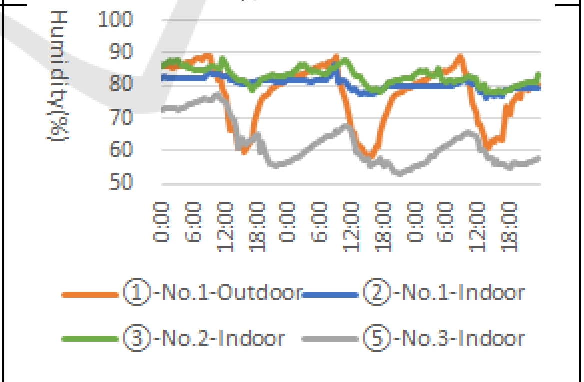

Figure 13. Humidity comparison (No.1& No.2 & No.3 /Sunny).

3.3.2. Comparison between residence No.1 and residence No.2. The following discussions were conducted to compare the impact of structures, materials selection and orientation on indoor temperature.

After comparing the outdoor humidity of No.1 and No.2 (Figure 12), it was found that No.1 was slightly lower than that of No.2 at night, and it was similar in the daytime. Because No.1 was a single building, the surrounding area was mainly field, and the air was easy to spread; and No.2 was in a group of building. So, the air was difficult to spread, which result in a circumstance that the humidity changes slowly.

Compare indoor humidity of No.1, No.2 and No.3 (Figure 13). Except for a slight difference in the fluctuation range, the traditional houses (Residence No.1 and No.2) were basically similar in terms of periodicity and average value remaining at around 83%. The humidity of modern houses (Residence No.3) was lower than that of traditional houses (No.1 & No.2) keeping about 60%.

4. Conclusions

By testing the indoor thermal environment of traditional houses and modern houses in Miao village, Guangxi in summer, the following conclusions can be drawn:

- The envelope of traditional buildings had obvious advantages in controlling indoor temperature. It was mainly due to the traditional material, wood, whose maximum amount of heat absorbing capacity was lower than the concrete. Besides, the tightness of the wood envelope was poor, so the heat can be quickly taken away through air infiltration to maintain a cooler indoor environment.
- During the continuous fine weather, modern houses had better effect on indoor humidity and it can be basically maintain below 70%. While the traditional house was higher than 75%. In the following designs the moisture proof performance of the envelope needs to be improved.
- There were both advantages and disadvantages in temperature and humidity control. But under the circumstances of non-air-conditioned environment, ASHRAE55-2010 clearly pointed out that there was no humidity limit [6] when the temperature was among the given range.

In general, the traditional houses are more suitable for the local environment and are more comfortable in summer, especially at night.

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