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Physical Environment of Stilted Buildings in Rural Area of Southwest China
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Abstract

Stilted building is a unique kind of buildings distributed across the southwest mountainous area in China, especially the Miao and Dong dwellings in Qiandongnan area. In this paper, two local traditional stilted houses, old-fashioned and new-fashioned, were selected for case study to investigate indoor environmental quality by field survey. The indoor thermal, luminous and acoustic environment and CO\textsubscript{2} concentrations were tested and evaluated. Results indicated that the electric heating cannot meet the comfort requirements due to the bad thermal performance of the wooden envelope, while heating by the coal stove would cause indoor air pollution. The sound resistance effect of the wooden fabric is so poor that indoor human activities can bring the noise interference to the adjacent room. In addition, the indoor natural lighting illumination was much lower than the standard requirements due to improper interior space layout design, such as few windows with small open area. It is necessary to improve indoor environment for this traditional house for sustainable development. In this study, the indoor environmental conditions in the local traditional houses was objectively evaluated, which helps to guide the residence retrofit and improve indoor environment in the future.

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Keywords: Qiandongnan area; Stilted building; Traditional house; Indoor environmental quality

1. Introduction

Stilted building is a unique kind of buildings distributed across the southwest mountainous area in China, especially the Miao and Dong dwellings in Qiandongnan area. It maintains both unique architectural image and
profound national culture background despite the long time development and evolution. As a form of traditional architecture through generations, many of its characteristics reflect the harmony with nature, such as combination with landform, economical use of land, adaption to local climate, resource, economic and culture, energy saving, use of local materials and emphasis on ecological environment, etc. However, with the development of economy in China, rural residents’ living standards and their requirements for quality and comfort are improving. Recently, many local Miao residents directly change the wooden structure to brick structure at the first floor, or rebuild a simple brick house instead of their old wooden one. This trend will not only destroy the cultural characteristics of traditional local-style dwelling houses, but also cause the indoor environmental problem due to the lack of scientific guidance during the reconstruction. Previous study on traditional Miao dwelling houses in Guizhou area focused mainly on the cultural heritage and ecological environment of architecture [1,2], while objective evaluation on the indoor physical environment of Miao traditional local-style dwelling houses was seldom performed. The existence of these stilted buildings allowed an investigation of indoor environmental quality in the region.

In this study, a field investigation has been carried out in the Kaili area of Guizhou province in January, 2015. Two typical new-fashioned and old-fashioned dwelling houses has been selected to test respectively on the indoor thermal, luminous, acoustic environment and indoor air quality for evaluation of indoor environmental quality of the traditional local-style dwelling houses. Additionally, suggestions according to the existing problems has been given, hoping to guide the new residential construction in the future.

2. Objects and Methods

2.1. Test objects

The stilted houses are located in Leishan county of Kaili, Guizhou province, southwest of Qiandongnan Miao and Dong Autonomous Prefecture. They are located in the hot-summer and cold-winter climate zone in China. The local annual average temperature is 16.1°C with its highest temperature of 37°C and lowest temperature of minus 4-7°C, and the average annual sunshine hours are 1289h.

This test selected two typical new-fashioned and old-fashioned stilts in the same village, as is shown in Table 1. The old-fashioned house has a history of over 100 years, which is one of the most ancient houses in that village. The new-fashioned house adopts the traditional wooden structure in its most parts while adopts brick structure at the first floor. Besides, the aluminium alloy windows are used in the new-fashioned house.

Table 1. Comparisons of basic conditions between the old-fashioned house and the new-fashioned house

| Building type                      | The old-fashioned house                                                                 | The new-fashioned house                                                                 |
|-----------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Building appearance               | The old house is divided into two floors: the bottom floor is used for feeding livestock while the upper floor is used for daily function; Wooden wall structure, wooden window frame and single layer glass are used. | The new house is divided into three floors: warehouse is at the bottom, intermediate layer is used for daily function, guest-rooms are at the top floor; The first floor adopts brick structure, the above two floors adopt wooden structure; aluminium alloy window, single layer glass. |
| Building envelope and functional partition |                                                                                   |                                                                                       |
| Heating methods and energy consumption | The traditional house uses a coal stove for heating; since residents have few things to do for farming in winter, they spend most of their time staying at home, so the coal consumption is much higher than power consumption. | The new house adopts electric heaters for heating in winter, so the power consumption is very high. |
Testing items

| Testing items                          | Co2 concentration test in living room |
|----------------------------------------|----------------------------------------|
|                                        | Indoor/outdoor temperature and humidity test |
|                                        | Indoor natural light illumination test   |
|                                        | Indoor sound level test                  |

2.2. Test methods

![Building layout](image)

The test is conducted under the locally typical climate conditions in winter from January 24 to February 12, 2015, including indoor/outdoor temperature and humidity test, indoor natural light illumination test, indoor CO2 concentration test and indoor sound level test. The building plane layout and the field test point arrangement are shown in Figure 1. ● represents temperature/humidity test points, ■ represents CO2 concentration test point. Test equipment and their precisions are shown in Table 2.

**Table 2. Test equipment list**

| NO. | Name                     | Product model | Precision                          |
|-----|--------------------------|---------------|------------------------------------|
| 1   | Temperature and humidity recorder | TM-305U       | ±0.6°C; ±3%RH                       |
| 2   | Temperature recorder     | CENTER-309    | ±(0.3%rdg)                         |
| 3   | Sound level recorder     | TES-1359      | ±1dB                               |
| 4   | Multifunctional recorder | TESTO-480     | T: ±0.5°C; RH: ±(1.8%+0.7%rdg); CO2: ±(50ppm+2%rdg) |
| 5   | light illumination recorder | HT-1300      | ±(4%rdg+2d)                        |
| 6   | Co2 recorder              | HT-2000       | ±50ppm                             |

3. Results

3.1. Indoor thermal environment

Figure 2 shows the measurement results of indoor temperature in the new-fashioned and old-fashioned house during the test. The average outdoor temperature was 3.61°C. Both the new and old residential bedroom have no heating facilities, their average temperatures were 6.23°C and 5.65°C respectively. According to the Chinese Rural Residential Building Energy Efficiency Design Standard [3]: in the absence of any indoor heating and air conditioning measures, the indoor lowest temperature should not be lower than 8°C. By statistical analysis, we found that the time that the old residential bedroom temperature is lower than 8°C occupied 83.85% of the whole test period while the new one is 71.35%, both of which are below the minimum standard temperature for a long time. The measurement results of temperature indicated that the new-fashioned house still needs further improvement in terms of indoor thermal environment.
Because the new-fashioned house uses electric heater for intermittent heating in living room while the old-fashioned residential living room uses the coal stove for heating continuously, the average temperatures of them are 8.62°C and 14.30°C respectively. It can be seen that the building envelope cannot affect the indoor thermal environment significantly since both of the new-fashioned and old-fashioned house adopt wooden structure in living rooms, indicating similar thermal mass and thermal resistance. The most likely reason for the gap of thermal environment may be due to the heating measures and their use time difference.

Figure 3 shows the comparison of air relative humidity (RH) during the test. The outdoor RH ranged from 60% to 100% with an average value of 81.58%. In the new-fashioned house, the average RH of living room and bedroom are 63.37% and 70.87% respectively. The reason why the RH in the bedroom is 7.5% higher than the living room may lie in the fact that the bedroom has no heaters. In the old-fashioned house, the average RH of living room and bedroom are 49.58% and 84.28%. Such a big difference may be caused by the fact that the bedroom is located near the side of mountain with no outside window and poor ventilation.
3.2. Indoor luminous environment

![Image](image1.png)

Both the old-fashioned and new-fashioned buildings rely on natural lighting for illumination at day time. Through field investigation, we found a phenomenon that local traditional dwelling houses usually have few windows with small area due to traditional custom, which would be ineffective to collect sufficient natural light indoor. As shown in Figure 4, the old-fashioned residential kitchen is still very dark during the day. So an indoor natural light illumination test for the two houses was performed at noon on a clear day. The results indicated that the average natural light illumination value was just 16.7lux in the old-fashioned house, while such value in the new-fashioned house was 700.5lux. According to the Chinese Architectural Lighting Design Standards [4]: indoor natural light illumination should not be lower than 150 lux in residential corridor and dining room, and should not be lower than 300 lux in kitchen. Obviously, daylighting illumination of the old-fashioned house is far below the standard value. Therefore, indoor luminous environment of traditional dwelling houses need urgent improvement.

3.3. Indoor acoustic environment

It is often easy to make noise with wooden structure when residents are engaged in normal indoor activity. And the sound resistance effect of wooden fabric is poor, which is harmful to the acoustic environment of adjacent room. So the residential indoor acoustic environment of the new-fashioned house was tested. It is found that the indoor sound level is 30dB in absence of any human activity, while the indoor sound level is 62dB and the adjacent room sound level is 57dB when residents walked around and talked normally. The data above does not comply with the statement in the Chinese Standards for Acoustic Environmental Quality that the rural residential daytime sound level cannot be more than 55dB. Besides, the sound insulation quantity of wooden board in a 20mm thick is only 5dB, far lower than the standard value from The Sound Insulation Design Code of Civil Buildings in China [5], which states that the sound insulation between living room and its next room should not be lower than 45dB.

3.4. Indoor air quality

The old-fashioned house used the coal stove for cooking and heating, producing CO₂ and other harmful gases which would negatively affect human health when the concentration is too high. Therefore, the indoor CO₂ concentration was chosen as indicator of indoor air quality and a long-term test on indoor CO₂ concentrations of old-fashioned house was conducted. As shown in Figure 5, indoor CO₂ concentrations varied from 400 to 1200ppm. During most time CO₂ concentration is below 1000ppm, the standard value provided by the Chinese Indoor Air Quality Standards [6]. This may be related with poor air tightness of wooden wall and large ventilation rate.
It can be found from detailed analysis in Figure 6 that there will be three basic peaks in one day, almost at dinner time. The significantly higher indoor CO₂ showed the downside of indoor air quality mainly because residents would burn more coal during cooking. In addition, considering that the residents will artificially add more coal for heating when the outdoor temperature decreases, we performed analysis on the correlation between indoor/outdoor temperature and CO₂ concentration (see Figure 6). Compared with the situation when outdoor temperature is above 10°C, it is more obvious that the distribution of CO₂ concentration is higher than 1000ppm when the outdoor temperature is below 10°C. When indoor temperature exceeded 20°C in winter, the distribution of CO₂ concentration was significantly higher. Therefore, the burning of coal stove has a great influence on the indoor CO₂ concentration. It is suggested that when the indoor temperature is high because of too much use of coal for heating, residents should reduce the coal usage to avoid a further exposure to CO₂ and particles.

4. Discussion

Based on the test results above, the key factors affecting the residential indoor environment in winter can be concluded into the following three parts: building envelope, heating methods and interior space layout.
4.1. Building envelope

Since both bedrooms in the test did not take any heating measures, their indoor air temperatures are mainly affected by the envelope. We have known that temperatures of two bedrooms are lower than the standard minimum requirements for a long time in winter. So it is difficult for the wooden envelope to meet thermal performance requirement and prevent the indoor thermal environment from outdoor climate. Additionally, poor air tightness of wooden envelope can increase indoor ventilation rate to some extent, which is conductive to the spreading of indoor particle counts, CO$_2$, volatile organic compound (VOC), etc. Furthermore, sound resistance effect of wooden envelope is poor and human indoor activities can bring noise interference, which will have a negative impact on the indoor acoustic environment. Therefore, it is necessary to further research and develop new-style envelope which is suitable for the local characteristics, and to make improvement in terms of thermal performance, air tightness, sound insulation, etc.

4.2. Heating method

The living room is the place concentrated with human activities during the day time, of which the temperature is mostly affected by heating methods. The old-fashioned house adopts coal stove for heating while the new house uses electric heater. Both methods have a certain improvement for indoor thermal environment, but the coal stove will produce a large amount of CO, CO$_2$ and other polluting gases, while using electric heater will increase cost. It is advised that special research and analysis on heating methods suitable for Qiandongnan area in winter should be done to improve both the indoor comfort and air quality.

4.3. Interior layout

Traditional stilted houses are usually interior symmetrical with the axis of central room and two wings of bedroom and living room. Central room, as a semi-open space connecting the indoor and outdoor space, commonly faces north. To some extent, it can reduce residents’ expectations of comfort standards and make residents feel satisfied easily. Traditional Miao houses are usually built close to the mountains with few or even no windows at the mountain side, which would cause poor indoor daylighting and air ventilation. Therefore, interior space layout should be reasonably adjusted, and the mountain side windows should be added for improving indoor luminous environment and air ventilation.

5. Conclusions

In this study, a field investigation and test of traditional and newly rebuilt residential stilted houses in Qiandongnan area was conducted to evaluate indoor environmental quality. The following conclusions can be made:

1. The wooden structure envelope of residential building has a poor thermal performance. The indoor temperature of both new and old house cannot meet the requirement of the thermal comfort when there is no heating system. Since the sound resistance effect of wooden envelope is poor, indoor human activities can cause noise interference easily.

2. When the outdoor temperature is below 10°C, more coal would be used for heating, which will increase the indoor CO$_2$ concentration. But poor air tightness of wooden wall is conducive to the spread of indoor pollution gases to some extent.

3. Traditional Miao houses are usually built close to the mountains with few or even no windows at the mountain side, which would cause inadequate indoor daylighting and poor ventilation. In winter, it is prone to be uncomfortable since the relative humidity is high.

Therefore, it is necessary to further research and develop new building envelope and heating methods suitable for local characteristics and to optimize and improve interior space layout, which play an important role in the promotion of sustainable development of traditional houses and new rural construction.
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References

[1] N. Zhang, Stilted Buildings Implications for China's Modern Architectural Design, J. Lanzhou University (Social Sciences). 04(2013) 165-70 (in Chinese).
[2] J. Mei, J. Xiao, Miao Traditional Residential Building Ecological Concept in Southeast of Guizhou, J. Anhui Agricultural Sciences, 09 (2010) 4886-7 (in Chinese).
[3] China Academy of Building Research, GB / T 50824-2013 Rural Residential Building Energy Efficiency Design Standards, S. China Building Industry Press. 2013 (in Chinese).
[4] China Academy of Building Research, GB 50033-2013 Architectural Lighting Design Standards, S. Beijing: China Building Industry Press. 2013 (in Chinese).
[5] China Academy of Building Research, GB 50118-2010 The Sound Insulation Design Code of Civil Buildings, S. Beijing: China Building Industry Press. 2010 (in Chinese).
[6] The State Environmental Protection Administration, GB / T 18883-2002 Indoor Air Quality Standards, S. 2002 (in Chinese).