Thermal Performance Analysis and Improvement Measures of Square Tulou Buildings, take the Instance of Zhenyang Tulou in Nanjiang Village, Yongding China

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Abstract

Tulou is mainly distributed in western Fujian and northern Guangdong, mostly in Yongding and Nanjing County. Previous studies focus more on the monomer space type of tulou. But the study of earth's physical properties is still insufficient. This paper has done a series of studies on thermal environment of tulou in Nanjiang Village, Yongding County, Fujian. Take the representative square Zhenyang tulou for instance, measurement has been done on its temperature and humidity and other environmental parameters, and an objective evaluation of physical environment in tulou has been given based on the comparison of the performance of tulou and local modern brick houses. On this basis, analyses have been done on the defects of thermal environment of tulou, and further generate the improvement measures proposal of building envelope, especially the wooden wall and wooden floor. Based on the before-and-after performance, the study will provide useful reference for the reuse and development of tulou under the premise of protecting its architectural form and spatial integrity.

Keywords: Tulou building; thermal environment; improvement measures

1. INTRODUCTION

Tulou buildings are mainly distributed in the junction of mountainous area in Fujian, Jiangxi and Guangdong province, especially the Yongding and Nanjing in Fujian, which are in the southeast China. The main material of tulou is raw soil and wood, and stone is also used in the construction in varying degrees. Tulou is a large residential building with the total number of over 30,000. It is a symbol of the Hakka...
culture, therefore, Fujian Tulou is also called "Hakka Tulou". In 2008, the Hakka Tulou of Yongding, as the main part together with other dozens of Fujian Tulou designated as UNESCO World Heritage site[1]. Tulou, as a kind of distinctive residential type, plays an important role in history, it always spreads along mountains to meet the demand of the life and defense, and is cost saving, solid and defensive. At the same time, it has good environmental adaptability. However, as modern life style changes, social environment and inhabited form also change fundamentally. Thus, tulou type of residence gradually declines with the time, and being replaced by the sprung up botched new dwellings. Additionally, because of bad maintenance and out of inhabitant, a number of tulou, which have not been included in the protection of cultural relics, have been deserted. It is bad for the protection of traditional building and the inheritance of traditional culture. In response to this situation, the protection, moderate development and utilization of tulou become urgent. And improving the quality of living environment to make local people willing to live in tulou is the precondition of the development and utilization.

In the study of Tulou, Hanmin Huang and some other researchers have made some discussions about the morphology[2-4], structure, space, history, protection and development about Fujian tulou. Also, Knapp has described the character of Fujian tulou[5]. Moreover, Li Q from Tsinghua University, carried out a questionnaire survey about indoor environment quality and energy consumption of Nanjing Tulou. The result shows: the residents in Nanjing Tulou buildings experience better thermal comfort with lower energy consumption for cooling than those in normal Nanjing rural buildings. Yuan Jiongjiong from Huaqiao University, has done the study on the wind environment simulation of round tulou. However, there are few studies on tulou's physical properties. Facing the situation that tulou local-style dwelling houses are gradually declining, it is necessary for us, with the goal of improving the living environment, to study the physical environment of tulou in technical interpretation.

2. METHODOLOGY

Zhenyang building, in Nanjiang village, was regarded as the research object. The main work of this study is to measure its thermal environment and make a comparison test analysis with local reinforced concrete and brick dwellings in order to evaluate tulou's physical environment in an objective way.

In this study, T-type thermocouples were used to monitor the internal and external surface temperature of walls. DataTaker DT600 type data loggers (range: 250~1800°C, accuracy: 0.1%) was used to record data. RHLOG-T-H type air temperature and humidity recorders (temperature range: -25~55°C, accuracy: ±0.3°C, humidity range: 0~100% RH, accuracy: ±5% RH) were used for indoor parameters monitoring. The Raynger ST60ProPlus type infrared thermometers (range: -32~600°C,
accuracy: ±1°C) were used for manual measurements of wall temperature to be contrasted with the thermocouples results. The accuracy of the instruments is the main cause of the experimental errors, so we calibrated the instruments before the tests. The activities of people indoors are also a factor for experimental errors.

The contrast was the office building of Nanjiang village, which was about 120m away from Zhenyang building. The measure points were in the second-floor room. This building, which was measured by temperature and humidity recording device, was a new-built building and its structure was made of reinforced concrete and brick. Each room was kept closed during the test and there were no heating facilities. The test time was January 5th to 7th in 2012. The parameters of light environment and sound environment were also conducted using relevant devices. The measure point in summer was basically the same, but a thermal comfort level meter was set in main hall on the ground floor in summer instead of using thermocouple to measure the temperature of walls, and the test time was July 28th to 30th in 2012. The contrast was the room on second floor of the office building of village.

3. EXPERIMENT RESULTS

Figure 2 shows the room temperature changes of Tulou and contrast building, from which we can see an obvious heat preservation effect that the temperature in the second floor room of tulou can reach to about 11°C when the outdoor temperatures is low (5°C or so), and it is about 2°C higher than the contrast, room of the village office building.

![Figure 2. Room temperature test of Tulou and contrast building.](image)

Figure 1. The measure spots of Zhenyang Tulou (drawn by author).

Figure 3 shows a temperature contrast of each room in first floor of Zhenyang building. The three halls on the first floor are open and used more frequently, due to a number of households living within the existing tulou. The temperature is consistent
in the main hall and the back hall, but the temperature of the entrance hall is 0.5°C lower, because it is an air vent by connecting the inner courtyard and outside. Figure 4, a temperature comparison between tulou and the office building, shows the room temperature of tulou is about 2°C lower in average than the village office building, which provides a cooler environment in summer. Moreover, the indoor temperature fluctuation is small, with the temperature difference of about 2°C between day and night. Figure 5 is a comparison between the temperature in second floor room, corridor and the temperature outside of tulou. It shows that when the outdoor air temperature and solar radiation change drastically, the corridor temperature difference between day and night can be up to 8°C. While the temperature in the room is very stable: in the second floor room the temperature difference between day and night is only about 1°C, and the average temperature is basically the same with that in the corridor, which reflecting the good thermal stability of tulou.

4. The analysis of measures to improve the physical environment of tulou

4.1. The analysis of advantages and disadvantages of tulou's physical environment

According to the experimental results and the situation we get during the research, we learn the character of tulou's physical environment and some existing problems:
(1) Tulou has an excellent insulation effect, and its thermal stability stands out from modern frame structure buildings. Through the specific experiments and analysis above, it can be found that in extreme environment in winter and summer, thermal comfort and thermal stability of tulou's interior room are better than that of the comparing modern frame structure buildings.

(2) The enclosed atrium of tulou brings higher winds that help air exchange between inside and outside of tulou, but the poor sealing quality of the existing wooden door of tulou causes a strong infiltration of cold air in winter.

(3) Tulou has a strong noise insulation capability to external environment. The research of acoustic insulation tests show that when the noise level of tulou's external noise source reaches 89.9dB(A), the level of the noise received in the third floor room of tulou is only 54.6dB(A), with the sound insulation factor of 35.3dB(A). Thus, the insulation capability of exterior walls is excellent.

4.2. Comparison of results before and after the renovation

In order to verify the results of renovation, DesignBuilder is applied to build an analysis model of the Zhenyang building in actual scale, and we have a simulation analysis on the indoor thermal environment and energy consumption before and after the renovation. The west-facing bedroom on the third floor was selected as the test room, and the test date for summer is July 5th, for winter is in January.

Winter simulation results are shown in Figure 6. As shown in the figure, the installing of insulation layer can significantly increase the indoor temperature, and can keep the temperature between 11 ℃ and 13 ℃, with the maximum temperature difference of only about 2 ℃ between day and night. By contrast, the maximum temperature difference between day and night can be 3.8 ℃ without the insulation layer.

Figure 6. Temperature on January 5th.
Simulation results in summer are as shown in Figure 7. We can see from the figure that the indoor average temperature increases after applying insulation layer with nearly the same peak temperature in daytime but bigger temperature difference at night. This is due to the bad influence to thermal environment in summer that caused by the insulation layer, which needs to be improved by better ventilation measures.

5. CONCLUSIONS

Firstly, this paper tests and simulates the thermal environment of Zhenyang building in Nanjiang village, Yongding County, making comparison on thermal environment between traditional square tulou and modern residential buildings. Then evaluation of tested tulou's physical properties is made, and the results are as follows:

(1) Both the thermal comfort and thermal stability of interior rooms in tulou are better than those in the contrasted modern frame structure building. More specifically, compared with the rooms in tested modern building, tulou rooms enjoy a higher temperature in winter, and a lower temperature and humidity in summer, which means tulou provides better insulation and thermal stability.

(2) Tulou has an excellent noise insulation capacity. But the thermal and acoustic insulation capacity of inner courtyard wall is not good enough. Besides, there is little light for inner rooms of tulou, the lighting environment is poor.

(3) The strategies to improve the physical environment of tulou, based on the existing physical environment problems, are to improve thermal and acoustic performance of tulou's existing wooden walls and floors by applying polystyrene insulation boards, mineral wool glass and sound-absorbing materials. Moreover, on the premise of remaining the architectural appearance of tulou, we add windows on the wooden walls close to hallway to improve ventilation and lighting performance.

In general, the architectural form of tulou can keep the building warm in the winter and cool in the summer. The ecological approaches also provide good references for modern architectural design. Moreover, specific improvements and adjustments based on its physical characters are needed in the process of protection.
and renovation, in order to meet modern living requirements and further make tulou's architectural form spread in the long history.

REFERENCES