Study of the thermal environment construction technology of the traditional residential of the Bai nationality

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ABSTRACT

The Bai nationality is concentrated in Dali Autonomous Prefecture, Yunnan Province, China. Its special geographical location and terrain--low-latitude plateau, formed the unique architectural form of the Bai nationality. Through the test and evaluation of indoor thermal environment in traditional Bai buildings, the paper analyses the correlation between indoor thermal environment and spatial form of the traditional Bai nationality's residence, and analyses the formation mechanism of indoor thermal environment by numerical simulation method. The study found that the traditional Bai residence has a good thermal comfort, and it responds to the local climate characteristics through the enclosed courtyard and the courtyard technology formed in the building, so as to realize the climate adaptability of the building.

INTRODUCTION

There are many well-preserved traditional dwellings of the Bai nationality in Dali Bai Autonomous Prefecture of Yunnan. These buildings not only have strong customs of the Bai nationality, but also incorporate a large number of architectural features of the Han nationality. The buildings have been changed according to national habits and climatic characteristics, forming their unique construction technology to obtain a comfortable indoor thermal environment. Through the investigation, mapping, indoor thermal environment test and computer simulation of traditional dwellings, this paper analyses the relationship between the architectural form, structure and detail treatment of traditional dwellings and the indoor thermal environment and even the local architectural climate, and puts forward the climate adaptability strategy of Bai traditional dwellings, which is of great significance to the protection and renewal of local traditional dwellings.

At present, some achievements have been made in the study of the thermal environment of traditional dwellings. Jinling measured and analysed the indoor and outdoor thermal environment of a typical traditional residential building in Chaoshan area in summer and winter, which showed that the comprehensive thermal environment of semi open space in Chaoshan area in summer was better than that of closed indoor space, the patio of traditional residence had significant thermal buffer effect in the daytime, and the potential of thermal pressure ventilation at night. Hu Rongrong others selected typical dwellings in Qinling Mountains as the research object, measured their winter thermal environment, and concluded that the climate adaptability of local vernacular dwellings was better than that of brick houses, and the heating energy consumption was far lower than that of brick houses. Yang Zhenjing measured and simulated the indoor thermal environment of rammed earth buildings in Bashu area, and found that the indoor thermal environment of Rammed Earth Dwellings in summer is better than that in winter, the loft in dwellings has a significant regulating effect on the indoor thermal environment, and the indoor thermal environment factors are closely related to the enclosure structure and living habits. Li Cheng selected the vernacular dwellings of different construction periods in Turpan for spring test, respectively from the indoor air temperature, air humidity, average radiation temperature, wall temperature and other aspects of comparative analysis, and concluded that the outdoor greening environment directly affects the indoor thermal environment, and the raw soil building has better heat storage and temperature delay. While in the existing research, there are few researches on the thermal environment of Dali Bai traditional buildings, and the mechanism of thermal environment construction needs further exploration.

In this paper, a typical Bai traditional architectural form of Three Houses and One Screen Wall（THOSW）was selected as the research object. THOSW is the most common architectural form in the traditional Bai folk dwellings shown in figure 1. The whole building is a regular rectangle, surrounded by a main house, two ear houses and a screen wall. In the middle of the houses is a courtyard, with the main house facing the screen wall and patios was formed between the main house and the ear houses. The external walls are enclosed, usually made of rammed local earth, with wooden walls on one side of the courtyard and tiled roofs. After the measurement and simulation of the thermal environment of a typical THOSW in summer, this paper analyses the techniques of constructing the thermal environment of traditional Bai buildings.

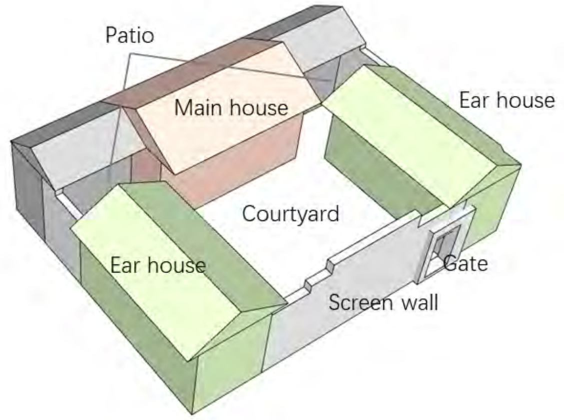

Figure 1. Form of Three Houses and One Screen Wall

Research object and region

Yunnan Province is located in the southwest of China and has a subtropical plateau monsoon climate. Dali Autonomous Prefecture is located in the northwest of Yunnan Province. It is located at the junction of Yunnan-guizhou Plateau and Hengduan Mountains. The mountainous area in Dali accounts for 70%, and the water area and dam area each account for 15%. The terrain is high in the northwest and low in the southeast, with complex and diverse landforms. Under the joint action of high altitude and low latitude, the low latitude plateau monsoon climate is formed. The annual average temperature in Dali is between 12 ° C and 18 ° C, and the four seasons are not distinct, with a small difference in annual temperature. The hottest month is in June, while the coldest month is January. The dry and wet seasons are distinct, the rainy season is from May to October, and the rainfall accounts for 78% of the annual rainfall. The prefecture is characterized by complex landforms, great differences in elevation and significant vertical differences in climate. This special geography and climate formed the local special traditional building construction technology to adapt to the local ecological environment.

Figure 2. Current situation of Ouyang compound

Ouyang compound, shown in figure 2, the object of this study, is located in the ancient town of Shaxi, Jianchuan County, Dali Autonomous Prefecture. Shaxi ancient town is located in a dam area among the mountains. It was an important post station on the ancient tea-horse road. Ouyang compound is located on the north side of Sideng Street in Shaxi Ancient Town, and the building faces east from the west. It is a typical building of Bai nationality with THOSW, consisting of a main courtyard in the form of THOSW and a THOSW garden shown in figure 3. The construction of Ouyang compound was started in the first year of the Republic of China (1912), which took 5 years to complete, and the wall painting was completed in 1919. The wall of Ouyang compound is made of local soil with a thickness of 500mm. The internal structure of the building is made of wood with a thickness of 60mm. The roof is covered with Chinese-style tiles. The whole building has two floors, and the main room is higher than the wings on both sides. Table 1 presents the detailed information of Ouyang compound. Choosing Ouyang compound as the research object can represent the majority of Bai nationality dwellings with THOSW.

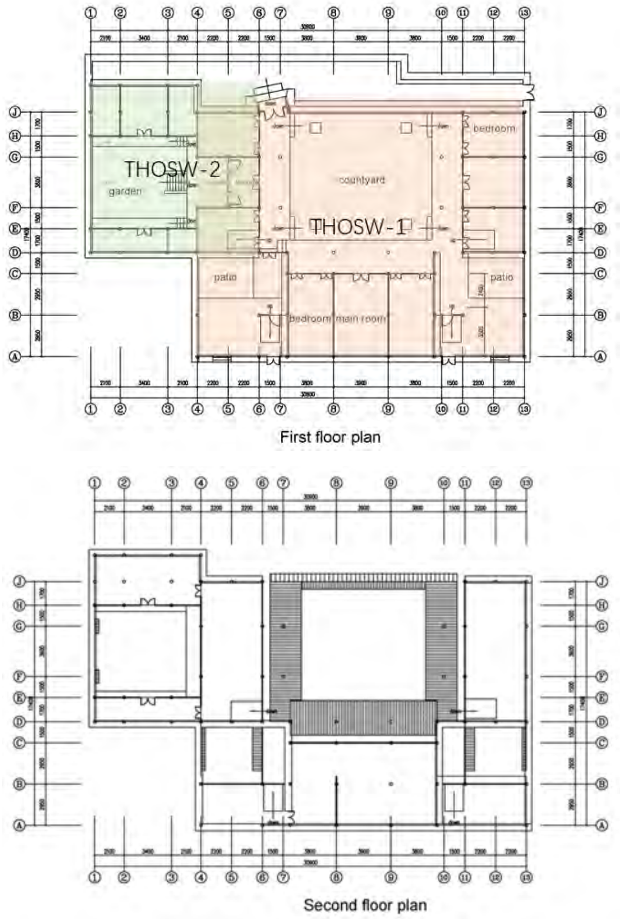

Figure 3. Plan of Ouyang compound

Table 1. Characteristics of the Ouyang compound

Characteristics	Description
Construction time	1912-1919
Orientation	West–East (East-facing)
External wall	Rammed earth 500mm U-Value = 1.45 (w/m²*k)
Internal wall	Wood 60mm U-Value = 1.73 (w/m²*k)

Roof	Tile 10 mm, air gap 5 mm, woods 50 mm U-Value = 1.58 (w/㎡*k)
Window	Ordinary single glass 6mm U-Value = 5.78 (w/㎡-k) G-Value = 0.82
Occupants	2 (An elderly couple)

METHOD

The measurement took place from 12:00 on July 2, 2019 to 11:00 on July 3, 2019. The content of the test includes temperature, humidity, wind speed and black bulb temperature in some rooms. Monitoring points are set up in the interior, courtyard， patio and garden of Ouyang compound respectively. The indoor monitoring points include bedrooms, main room and the side of stairs. Outdoor solar radiation and wind speed at the courtyard were also measured. Specific locations of measurement points are shown in the figure 4. The instrument counts every 10 minutes for 24 consecutive hours. The usage of the instrument information is shown in Table 2.

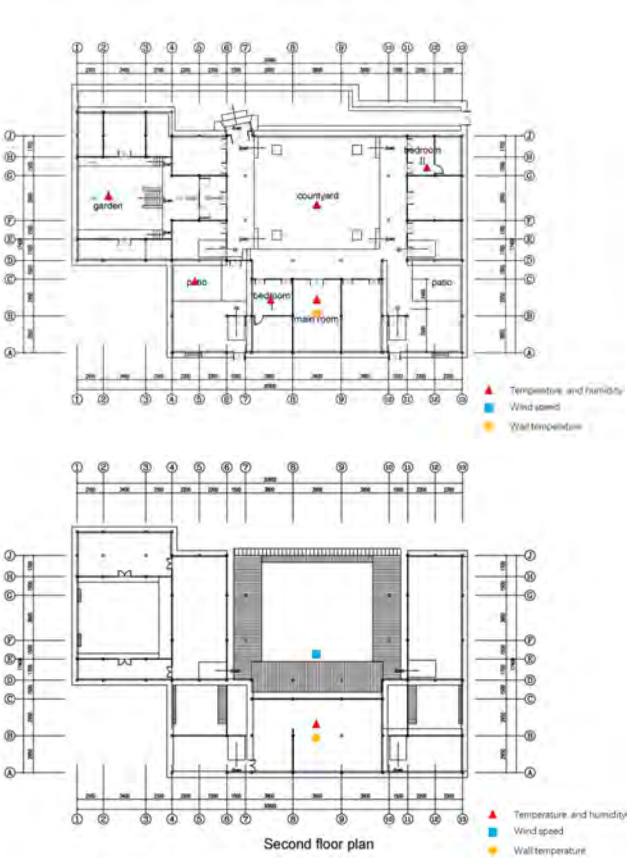

Figure 4. Measurement points in the building

Table 2. Introduction of instrument

Equipment	Photos	Function	Precision
HOBO Thermometer		surface temperature	±0.7℃
HOBO Digital hygrometer		Air temperature and humidity	±0.7℃ ±7.5%
Delta anemograph		Wind speed	±0.2m/s
TES Thermal stress index meter		globe temperature	±0.5℃ ± (4%value+0.1m/s)

RESULTS

The measurement data were processed to analyse the difference of indoor and outdoor thermal environment, so as to explore the architectural factors that caused the difference from the architectural space form and the building maintenance structure.

Temperature analysis

Compare the temperature of each space on the first floor, and the results are shown in the figure 5. It can be seen from the figure that the maximum temperature of 27.2 ℃ and the minimum temperature of 18.3 ℃ appeared in the courtyard, and the daily temperature difference reached 8.9 ℃ , which is because the temperature of the courtyard is directly affected by the external environment of the building. This can also be seen from the maximum fluctuation range of the courtyard temperature. As the buffer space of the external climate and the internal building, the yard temperature stability is poor. As a contrast, the temperature fluctuation range of the three indoor spaces is much smaller, and the maximum and minimum values of the temperature also have a big gap with the courtyard. The temperature of bedroom I and bedroom II is the most stable, and the daily temperature difference is 1.3 ℃ and 1.4℃respectively shown in table 3. The temperature stability of the main room is slightly poor, and the daily temperature fluctuation range is 2.4 ℃. This may be because the walls on both sides of the main room are in direct contact with the external environment, while only one side of the bedroom is in contact with the air in the courtyard. Different indoor and semi-outdoor temperature fluctuations show that the courtyard in traditional Bai architecture has a good temperature regulation effect. The existence of this space form plays an important role in the internal temperature stability of the building. Moreover, the rammed earth material is used in the wall of traditional Bai architecture, which is also conducive to maintaining indoor thermal stability.

The air temperature of the three semi-outdoor spaces is shown in the figure 6. It can be seen from the figure 6 that the temperature change trend of courtyard, patio and garden is the same, but the temperature fluctuation range of courtyard is larger than that of patio and garden, and the fluctuation range of patio and garden is relatively close. The difference of temperature fluctuation amplitude between courtyard and patio is probably due to the difference of courtyard and patio scale. The temperature of smaller patio is more stable. Besides the temperature in the patio is higher than that in the garden overall, because the transpiration of plants in the garden reduces the ambient air temperature, making the garden cooler in summer.

In the vertical direction of the main room, it can be seen in figure 7 that the temperature change of the second floor is more obvious than that of the first floor. The second floor is the buffer layer of the first floor and the outer space, and the temperature fluctuation range is more intense. The lower the height, the more stable the temperature is, and the temperature presents a gradient from the top to the bottom. The temperature of the inner surface of the tile is the highest in the daytime, the second floor is the second, the first floor is lower than both, and the indoor ground temperature is the lowest.

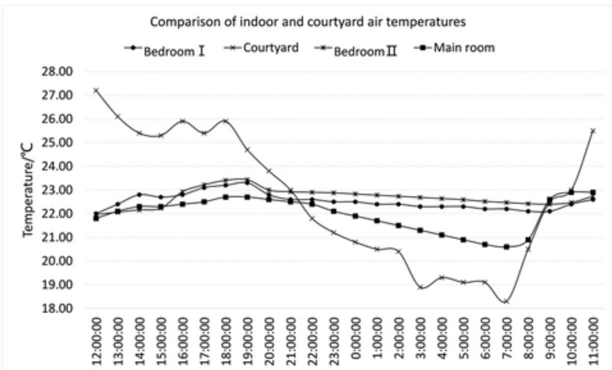

Figure 5. Comparison of indoor and courtyard air temperatures

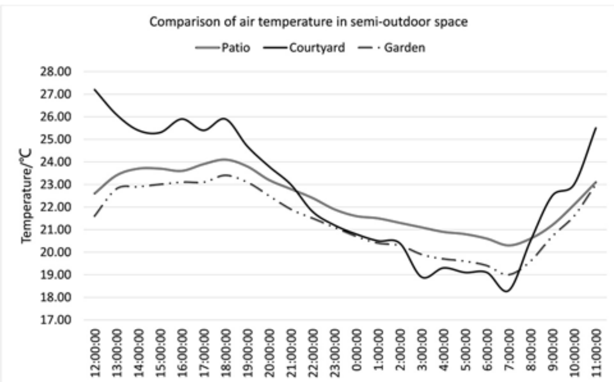

Figure 6. Comparison of air temperature in semi-outdoor space

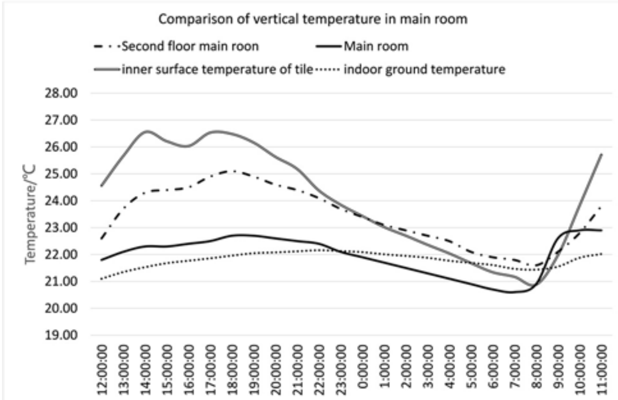

Figure 7. Comparison of vertical temperature in main room

Table3. Extreme temperature and temperature difference

Position	Minimum temperature/ ℃	Maximum temperature/ ℃	Temperature difference/ ℃
Patio	20.3	22.4	2.1
Bedroom I	22.0	23.3	1.3
Courtyard	18.3	27.2	8.9
Garden	19.0	23.4	4.4
Bedroom II	22.0	23.4	1.4
Main room	20.6	22.9	2.4

Table 4. Calculate APMV parameter Settings

Clothing Insulation	Metabolic Rate	Climate Zones	Building Type	Wind Speed	Adaptive Coefficient
0.5clo	1met	1	1	0.1 m/s	PMV≥0 0.21 PMV<0 -0.49

Analysis of indoor thermal comfort

The thermal comfort model is used to evaluate the comfort of indoor thermal environment. In this paper, APMV (adaptive predicted mean vote) is used to evaluate the indoor thermal environment. (1)

$$APMV = PMV/(1 + \lambda \cdot PMV) \quad (1)$$

where:
PMV is Predicted Mean Vote, λ is the adaptive coefficients. The values for different zones can be gathered from the standard GB/T 50785[9].

According to the indoor thermal and humid environment standard for civil buildings issued in 2012, the indoor thermal environment is divided into three levels: Level I is the thermal environment acceptable to 90% of the people, at this time -0.5 ≤ APMV ≤ +0.5, level II is the thermal environment acceptable to 75% of the people, at this time -1 ≤ APMV ≤ +1, level III is the thermal environment acceptable to less than 75% of the people, at this time

APMV < -1 or APMV > +1. The parameters used to calculate APMV are shown in the table 4.

The APMV calculation results of different indoor rooms are shown in the figure 8. From the figure, it can be seen that the thermal comfort of each room of Bai traditional folk house can reach level II in about 95% of the time in summer, and the time to reach level I is 45% - 59%. The time period for the second floor main room to meet the level I thermal comfort requirements is longer than that of the first floor room, while the other rooms on the first floor are relatively close, which can be attributed to the low temperature at local night, and the heat stored in the second floor room during the daytime is released at night, which improve the thermal comfort of the room. Generally speaking, the thermal comfort of Bai traditional dwellings in summer is satisfactory, which is due to the local climate and the construction methods of local buildings.

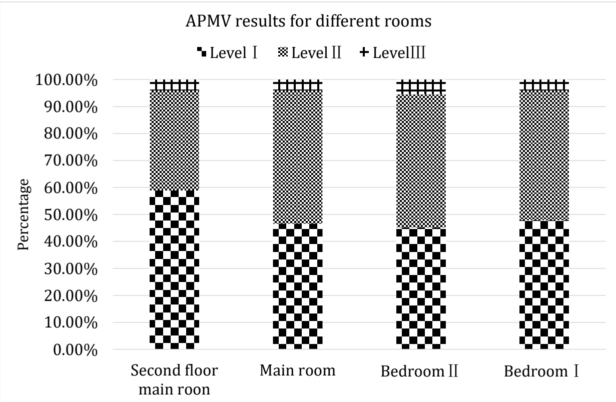

Figure 8. APMV results for different rooms

Wind environment simulation

In order to study the influence of courtyard and patio on the indoor wind environment of Bai traditional residential buildings, PHOENICS software was used to simulate the building ventilation. The model shown in the figure 10 is built according to the actual situation of the building, and the wind speed is 4m / s in July according to the typical meteorological year. Because the measured object is in a long and narrow valley between two mountains, the valley is southwest to northeast shown in figure 9, and the summer monsoon blows from the Indian ocean to the land, so the wind direction is S-S-W, the windows are open, and the doors are closed. The number of iterations is set to 1000.

From the courtyard simulation results as shown in Figure 11, it can be seen that the wind environment inside the courtyard of the Bai nationality building is quite different from that outside. This is because the walls around the Bai nationality building are tightly enclosed to prevent the wind from entering the interior. However, the courtyard and patio in the building partially improve the wind environment of the courtyard. The long and narrow passageway at the entrance of the building has a better wind environment, which is related to the direction of the passageway entrance facing the wind. This space can be used to lead the wind into the building courtyard. The wind environment of patio in the north side of the building is better than that in the south side. The north patio is connected with the gate to form a better ventilation effect. The south patio is greatly affected by the wall, and the wind speed is greatly reduced. The same situation also occurs in the courtyard. The courtyard is directly affected by the screen wall and the southern ear house, resulting in a large windless area. The wind environment in the garden is better than that in the courtyard, it may be because the wind was blocked by the higher screen wall on the north side of the garden, from which the wind blows into the garden. The existence of the eaves corridor also changed the wind environment below it, which played the role of guiding wind.

The indoor wind environment simulation results show in figure 12 that the ventilation effect of most rooms is not satisfactory. This is because most rooms have no or only one window and lack of air outlet when the door is closed, resulting in very small wind near the window. This can also be seen from the air age. The room without window has long air stagnation time and insufficient freshness. As a contrast, because there are windows on both sides between the courtyard and the garden, a through wind is formed in the building, which greatly improves the wind environment in the building, and the air age is relatively low. Therefore, in the case of natural ventilation, the indoor ventilation effect of Bai buildings is not good, and measures need to be taken to improve the indoor wind environment.

Figure 9. Location of Ouyang courtyard

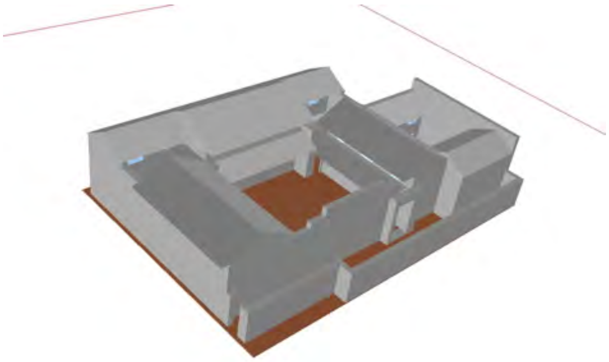

Figure 10. Simulated model

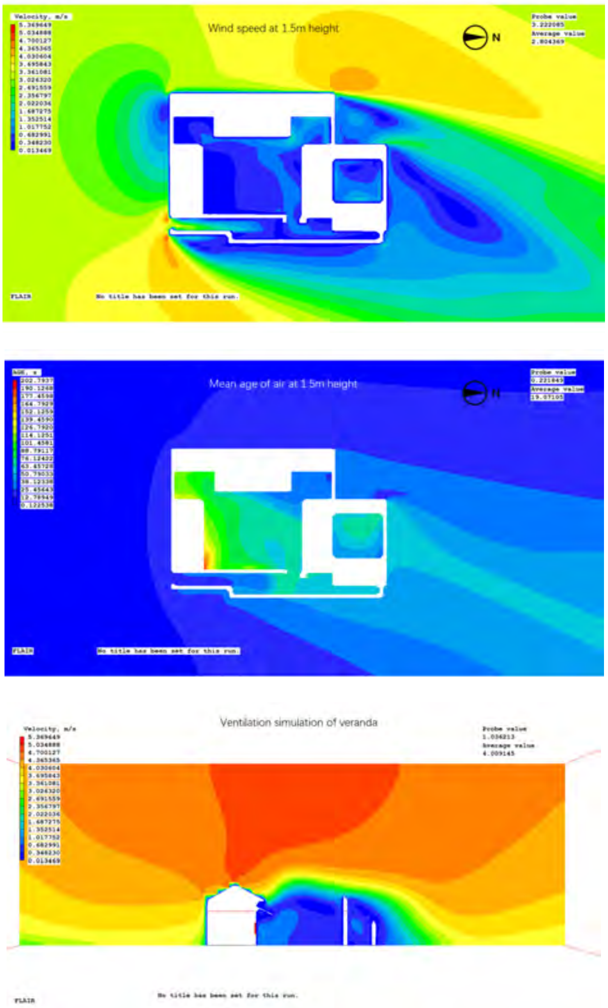

Figure 11. Simulation results of courtyard wind environment

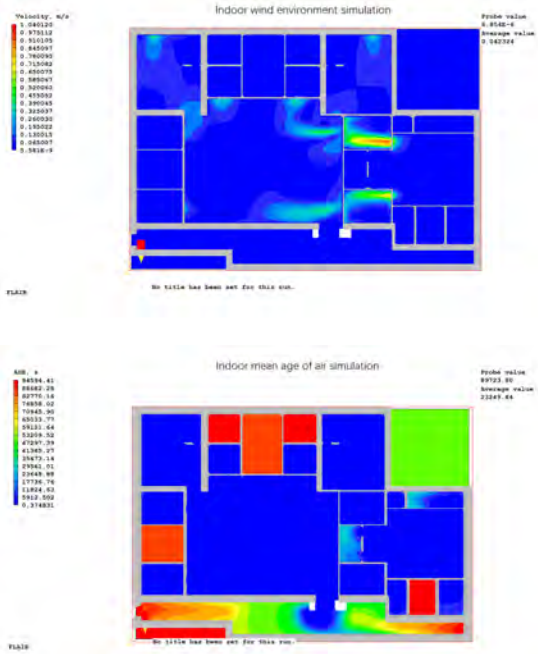

Figure 12. Simulation results of indoor wind environment

CONCLUSION AND DISCUSSION

Through the measurement and Simulation of thermal environment of traditional Bai residential buildings, the following conclusions can be drawn:

1. The residential buildings of Bai nationality have good climate adaptability, and their indoor thermal comfort is good in summer, which can meet the requirements of grade II thermal comfort in most of the time, and the time for the second floor room to meet the requirements of grade I thermal comfort is longer than that for the first floor room.
2. The traditional Bai People's THOSW residence creates a good indoor thermal environment in summer through the unique construction technology. Bai nationality dwellings are closed courtyard, thus various patios are formed in the building. These patios not only enrich the space diversity of the building, but also create a good indoor environment for the building. Due to the existence of courtyard and patio, there is a transitional space between the indoor space and outdoor space. These transitional spaces play a role in buffering the external climate, reducing the outdoor heat into the indoor when it is hot in the daytime, and maintaining the heat inside the building at night to prevent the indoor temperature from being too low at night. Planting green plants in the courtyard can play a better cooling effect in summer.
3. Due to the good airtightness of Bai nationality buildings, the indoor ventilation effect of buildings is poor, and the air freshness of most rooms is not enough. Therefore, measures should be taken to improve the indoor wind environment, such as the

formation of hot pressure ventilation by using the patio. With small area and high height, the patio is easy to generate hot pressure. In summer, when there is windless outside, hot pressure ventilation can also be used to drive the air flow inside the building, so as to achieve a good thermal environment inside the building. In addition, the space under the eaves of the building is not directly exposed to sunlight and has a temperature difference with the air in the courtyard, so as to form the wind under the eaves and improve the indoor thermal environment. It is also a good idea to open Windows in the building's exterior walls to bring in the wind in the summer and to take measures to prevent the wind from entering the building in the winter.

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