Climate adaptability study on the roof buffer space of traditional Tujia folk dwellings

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Abstract. In order to research the climate responsive of roof buffer space in Tujia traditional folk dwellings, two typical dwellings were taken as the research objects to measure relevant environmental parameters. Subsequently, the measurements were compared to analyze the coupling relationship between roof buffer space and indoor thermal environment. Analysis shows that the roof buffer space has the remarkable ability to block solar radiation, with the cooperation of valley-mountain breeze, which makes up for the shortcomings of poor thermal inertia and small heat insulation of wooden-plank wall dwellings: The indoor temperature peak reduces 2 °C; the range of difference between indoor average radiant temperature and the air temperature is 0.46 °C all day. The findings can guide the construction of modern wood-framed dwellings.

Keywords. traditional dwellings, roof buffer space, climate adaptability, Tujia ethnic minority

1. Introduction

Tujia ethnic minority has a long history and the largest population among ethnic minorities in Chongqing, China. It is mainly distributed in the Wuling Mountain with the hot and humid climate. In the long-term development process, its dwellings have accumulated rich ecological experience and formed a unique construction technique. The major feature of the construction technique is the application of the roof buffer space, which belongs to the “climate buffer space”. The concept comes from the “intermediary space” of traditional Chinese architecture [1]. "Intermediary space" acts as a medium to connect different space or psychology. In the face of inappropriate climate, traditional dwellings do not use thick and closed building envelope, but use buffer space to naturally reduce unfavorable factors. Some research has qualitatively demonstrated the positive effect of traditional building buffer space on responding climate [2], which proves that the buffer space can effectively adapt the climate passively [3-4]. For the roof buffer space of Tujia folk dwellings, some conclusions have been summarized [5-6], but they are only limited to the qualitative description, lacking of quantitative description and analysis.

In this paper, field measurements were conducted to investigate the mechanism of roof buffer space on reducing thermal current from environment to the building envelope (including ceiling in this paper), and quantitatively evaluate its positive role in regulating indoor thermal environment.

2 Methodology

2.1 The typical dwellings and the roof buffer space

The climate of Wuling Mountain is a transition type from subtropical climate to temperate climate, characterized by high temperature, high humidity, rainy and gentle wind in summer. The type of wind in this area is valley-mountain wind [7].

Two typical dwellings, whose structure and form are shown in Figure 1(a), were selected in the study. Measurements focus on the halls of them. As the Cross-sections show in Figure 1(c), the former
has buffer space and the latter has not. Besides, the bedroom in the southwest corner of the typical dwelling 1 receives the most solar radiation during the day, so it is selected as the most unfavorable room (it has been marked in Figure 1(b)).

The typical dwelling 1 is oriented in the west direction. It crosses several platforms from east to west and falls along with the slope. The main room is arranged along the contour line. The hall is in the middle of it, and two elevated rooms, called “Diaojiaolou”, are on the sides. The roofs are horizontally connected to form the roof buffer space. The roof buffer space connects with the outdoor in all four directions, and its central height is 2.7m. The typical dwelling 2 differs from the typical dwelling 1 in that it has no roof buffer space, and indoor space is under directly the housetop.

2.2 Field measurements
The period of continuous measurements took place in 2018, from 0:00 on July 20th to 0:00 on July 23th. The temperature on July 21th reached 38 °C (the maximum in summer according to typical annual weather data), so the weather was extreme during this period. The measurement contents include the temperature of outdoor, the air temperature of the typical dwelling 1 (the height of the three measuring points are 2.1m, 2.9m, 4.2m), the air temperature of the typical dwelling 2 (the height of the seven measuring points are 0.1m, 0.6m, 1.1m, 1.9m, 3.7m, 4.2m, 4.7m), the wind velocity in outdoor and roof buffer space, and the wet-bulb-globe temperature of the most unfavorable room. The positions of instruments are shown in the cross-sections in Figure 1(c).

![Figure 1. The overview of two typical dwellings and the measured point positions.](image)

3. Results and analysis
3.1 Temperature
3.1.1 The air temperature in roof buffer space and surrounding space. The outdoor, roof buffer space and indoor temperature data within three days are shown in Figure 2-3. The outdoor temperature has typical rural climate characteristics: it is hot during the day and cool at night. Take July 21 as an example, the daily fluctuation range of temperature is 0-16 °C, which is higher than that of roof buffer space and indoor. The daily average temperature of the all three space is about 27.5 °C. So the difference is mainly reflected in the temperature peak and daily fluctuation range.
3.1.2 Gradient variation of air temperature in height. The highest temperature appears at 14:00 on July 21st during the three days. The temperature-height curves obtained by choosing the temperature data measured at different heights of the two halls are shown in Figure 4. It can be found that there is a significant difference: as the height of the measuring point decreasing, the air temperature both increases. However, the temperature-height curve of the hall without roof buffer space is basically linear, and the other has a sudden change in the ceiling position, which drops 2°C. Taking the ceiling as the dividing line, the slope of temperature-height curve is bigger in the upper space, and smaller in the under space. This shows that the roof buffer space temporarily stores the heat from the solar radiation in the buffer space, which makes the ceiling to be a barrier to avoid direct thermal convection between the upper and lower spaces, and as a result, two spaces with distinct temperature differences are formed.

3.1.3 Indoor average radiant temperature of the most unfavorable room with roof buffer space. To further analyze the influence of the roof buffer space on the building envelope, the most unfavorable room described above was selected to calculate the average radiation temperature \( t_r \) [8]:

\[
t_r = [(t_g + 273)^{4} + 2.5 \times 10^{8} \times V^{0.6} (t_g - t_a)]^{0.25} - 273
\]

Where \( t_a \) is the dry-bulb temperature (°C), \( t_g \) is the black globe temperature(°C), \( V \) is the wind velocity(m/s). Hourly result of the dry-bulb temperature, the indoor average radiant temperature and wet-bulb-globe temperature (WBGT) are shown in Figure 5. It can be found that the average radiant temperature is very close to the air temperature all day, and the temperature difference is 0-0.46 °C. It means that the temperature of envelope has little effect on the indoor thermal comfort. In addition, the WBGT is lower than 28 °C during the hottest time (14:00-18:00). Considering the local people have the habits of shaking the fan, the sweat evaporation makes the actual WBGT lower. In other words, the most unfavorable room has good thermal comfort.
3.2 Wind velocity

During the three days, the temperature and wind velocity were measured on the outdoor platform, and the hourly data are shown in Figure 6. It can be seen, because of the valley-mountain breeze, there is a significant periodicity in the wind velocity-time curve and a correlation between the two curves. Figure 7 shows the wind velocity of outdoor and roof buffer space on July 21. The average wind velocity differences between day and night of the two space are 0.4m/s and 0.28m/s respectively. This means that the wind velocity of roof buffer space is smaller and more stable in the whole day. Therefore, although the roof buffer space is directly connected to the outdoor, it is not conducive to the direct passage of the high-velocity airflow during the day, and more conducive to the slow airflow at night.

![Figure 6. Temperature, wind velocity hourly data](image)

![Figure 7. Wind velocity hourly data](image)

4. Discussion

In thermal comfort, the percentage of heat exchange of the human body is: radiant heat transfer 42%-44%, convective heat transfer 32%-35%, and evaporative heat transfer 20%-25%, so it is important to adjust the indoor average radiant temperature [9]. Through the analysis of a large amount of data, the difference between the indoor average radiant temperature and air temperature should be less than 4 °C in comfortable conditions [10]. Because of the poor thermal inertia and small heat insulation of the building envelope, the solar radiation will bring about a sharp rise in the envelope temperature and indoor temperature in the daytime [11]. As shown in Figure 8, since the roof buffer space avoids the indoor to contact the outdoor environments directly, the influence of solar radiation on the indoor thermal environment is greatly reduced. Therefore, the difference of the indoor average radiant temperature and air temperature is 0-0.46 °C all day, which is much lower than the standard value, and makes up the shortcomings of wooden-plank wall dwellings mentioned above.

As shown in Figure 9, the roof buffer space connects the external environment from the bottom rather than horizontally. So the valley breeze with large velocity will be blocked by the wall, however, the low can pass smoothly. Therefore, the unique structure can not only keep excessive hot air out of room during the day, but also allow the building envelope to cool quickly at night.

![Figure 8. Adaptability for solar radiation](image)

![Figure 9. Adaptability for valley-mountain breeze](image)
5. Conclusion

The roof buffer space of Tujia folk dwellings fully embodies the idea of "harmony between human and nature" in traditional architecture. The main conclusions of this paper are as follows:

1) The roof buffer space has the remarkable ability to block solar radiation, and makes up for the shortcomings of poor thermal inertia and small heat insulation of wooden-plank wall dwellings: The indoor temperature peak reduces 2 °C; the range of difference between indoor average radiant temperature and the air temperature is 0-0.46 °C all day.

2) The unique structure of the roof buffer space coordinates well with the valley-mountain breeze, which can not only keep excessive hot air out of room during the day, but also allow the building envelope to cool quickly at night.

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References

[1] Yang S S, Guan R M. (2002). South Architecture. “Intermediary space” in traditional Chinese architecture. 14.85-87.
[2] Feng L, Sang Z Q, Gao J. (2008). Sichuan Architecture. Design of climate buffer space for traditional buildings in hot summer and cold winter regions. 50. 56-57.
[3] LI Y J. (2015). Research on the passive regulation of intermediary space. 12-14.
[4] Song W, Li D X. (1999). Architectural Journal. The overall ecological architectural concept, ecosystem structural framework and bioclimatic buffer space. 1999(3). 4-9.
[5] Peng Y. (2013). Journal of Guangxi University for Nationalities. The establishment ceremony and skills of traditional Tujia folk dwellings in western Hunan. 120. 70-74.
[6] Zhang A W. (2012). Research on the construction techniques, Inheritance and Protection of Tujia hanging dwellings-taking Xing'an village as an Example. 85.3-11.
[7] WU X Z, MA J B. (2017). Journal of Chongqing Normal University. Analysis of the climate characteristics and resource value of "Wuling Night Rain". 113-119.
[8] Jin L, Meng Q L, Zhao L H, Zhang Y F, Chen L. (2013). Journal of Civil, Architectural & Environmental Engineering. On-site research on indoor thermal environment and thermal comfort of rural dwellings in eastern Guangdong [J]. 92. 105-112.
[9] Bachki L. (1987). The hot microclimate of the room. Fu Z C, translated. Beijing: China Architecture. 12-16.
[10] Zhang X L, Dong B Z, Ma Y, Fan Y J. (2007). Building Energy & Environment. Analysis of the influence of black ball temperature on thermal comfort of a room. 45. 79-81.
[11] Yang Z J, Xu Y N, Peng M X. (2016). Journal of Civil, Architectural & Environmental Engineering, Climate adaption of wooden-plank wall dwellings in hot humid climate region. 117.1-6.