

Research on the Indoor Thermal Environment of Several Traditional Chinese Residential Buildings

Huanyi Wang^{1,2, a}, Li Zhou^{1, b *}, and Chunyan Liu^{1,2, c}

¹ School of Architecture and Urban Planning, Guizhou University, Guiyang, 550003, China;

² College of Forestry, Guizhou University, Guiyang, 550003, China.

^a 1413707082@qq.com, ^b Lzhou5@gzu.edu.cn, ^c 1793569958@qq.com

Abstract. To study the indoor thermal environment characteristics and influencing factors of traditional Chinese residential buildings, the existing research studies on the indoor thermal environment of traditional residential buildings were collected and organized, and the relevant measured data was extracted using GetDate software. After data analysis, the construction characteristics of brick and wood structures, wood structures, and raw soil structures were summarized. The indoor and outdoor temperature changes of the residential buildings in summer and winter were revealed. Finally, the indoor thermal environment characteristics and influencing factors of three types of traditional residential buildings were summarized. The research results can provide a reference for the construction and low-carbon renovation of traditional residential buildings.

Keywords: Traditional residential building; Indoor thermal environment; Data analysis; Construction characteristic; Influencing factor.

1. Introduction

Traditional Chinese residential buildings are precious material cultural heritage of Chinese culture. In the long process of development, traditional buildings are not only a place for human habitation, but also a product of economic, social, and cultural development, with high research and protection values [1]. In recent years, people have put forward higher requirements for living conditions, especially in terms of the thermal comfort of buildings [2]. Therefore, exploring and improving the indoor thermal environment of traditional residential buildings has become a hot topic of concern for many scholars. The thermal environment refers to the conditions that affect the human body's sensation, including indoor air temperature, humidity, airflow velocity, and mean radiant temperature (MRT). The quality of the indoor thermal environment has a significant impact on the physical health, work efficiency, and learning of users [3].

At present, many scholars have conducted experimental research on the indoor thermal environment of traditional buildings [4-10], and numerical simulation studies were conducted based on experimental research [11-13]. Additionally, many renovation technologies for improving the indoor thermal environment of buildings have also been proposed [14-16]. It should be noted that although there have been numerous studies on the indoor thermal environment of traditional residential buildings. However, existing research mostly focuses on a single object and lacks comprehensive and systematic research on the same type of residential buildings. Therefore, this study analyzes the construction characteristics of traditional residential buildings, extracts relevant measured data using GetDate software, analyzes the changes in the indoor thermal environment of different types of traditional residential buildings, and summarizes the indoor thermal environment characteristics. The research results aim to provide a reference for the construction and low-carbon renovation of buildings.

2. Brick and Wood Residential Buildings

2.1 Construction Characteristics.

Brick and wood residential buildings refer to the structural system built with bricks and wood. Commonly, walls and columns are built with bricks and stones, and floors and roofs are built with wood. Traditional brick and wood residential buildings are widely distributed in China, with typical regions including southern Anhui [4], northern Hunan [7], southern Shaanxi [17], central Zhejiang [18], and western Fujian [19]. Fig. 1 shows the typical structural types of brick and wood residential buildings in China, which can be roughly divided into three categories: brick wall load-bearing system, wood frame load-bearing system, and brick wall and wood frame mixed load-bearing system. For the convenience of statistical analysis, Table 1 summarizes the construction characteristics of brick and wood residential buildings in different regions of China, mainly including structural load-bearing systems, building floors, wall construction measures, roof forms, and window settings.

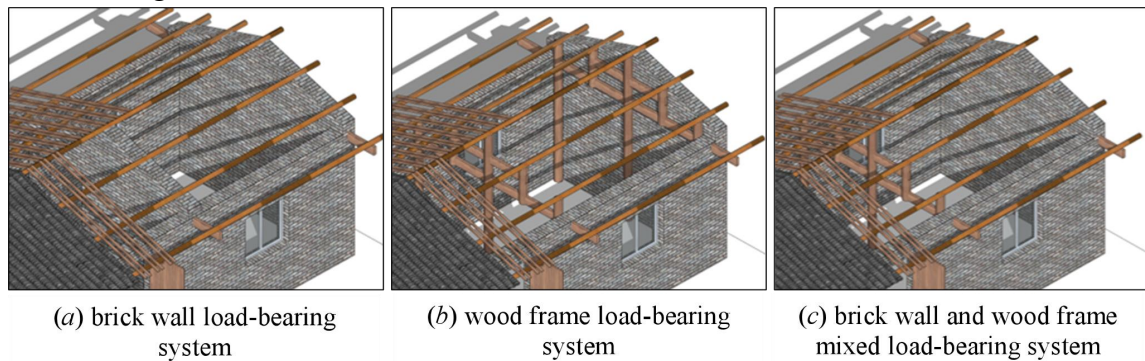


Fig. 1 Typical structural types of brick and wood residential buildings

Table 1. Construction characteristics of brick and wood residential buildings

Region	Load-bearing system	Number of floors	Wall construction measure (from inside to outside)	Roof form	Window setting
Northern Hunan [7]	Brick wall	1-2	12mm lime mortar 300mm grey brick wall	Grey tile roofs	Wooden grid window
Northern Henan [13]	Brick wall	1-2	240mm grey brick wall 320mm inner adobe	Grey tile roofs	Wooden framed glass window
Southern Henan [14]	Brick wall and wood frame	1-2	240mm grey brick hollow bucket wall 20mm inner plastering	Grey tile roofs	Aluminum alloy window
Southern Shaanxi [17]	Brick wall	1-2	20mm cement mortar 240mm clay brick wall 20mm cement mortar	Grey tile roofs	Wooden framed glass window
Zhejiang [18]	Wood frame	1-2	240mm clay brick empty bucket wall	Grey tile roofs	–
Fujian [19]	Brick wall and wood frame	1-2	500mm brick-clad soil wall	Grey tile roofs	Wooden grid window
Anhui [20]	Wood frame	1-2	20mm white-gray powder 270mm empty brick wall 20mm white-gray powder	Grey tile roofs Single layer board	Wooden lattice window
Inner Mongolia [21]	Brick wall	1-2	12mm cement mortar 490mm brick wall 40mm extruded board 12mm cement mortar	Grey tile roofs Double layer boards	Wooden framed glass window

2.2 Indoor Thermal Environment.

The research on the indoor thermal environment of brick and wood residential buildings mainly focuses on the thermal performance of the enclosure walls and roofs. The temperature response delay caused by the wall used in residential buildings in southern Henan during summer is 2 hours [14], while the temperature response delay increased to 3 hours after using extruded board insulation material in residential buildings in Hailar, Inner Mongolia [21]. The interior partition walls of Zhejiang residential buildings are made of 60mm pine wood panels, and the temperature response delay of the bedroom is only 10 minutes [18]. Thus, it can be seen that a reasonable design of the wall can alleviate the impact of outdoor temperature on the indoor environment. In addition, the utilization of traditional residential courtyards in Huizhou not only creates transitional spaces but also reduces the impact of outdoor temperatures on indoor environments [22]. Wang et al. [23] conducted a study on the indoor thermal environment of mountainous residential buildings in southern Shaanxi during summer. The findings show that the roof has a significant impact on the indoor thermal environment.

The indoor and outdoor temperature differences of brick and wood residential buildings in the different regions exhibit similar patterns. Taking the residential buildings in Southern Henan as an example [14], the indoor temperature (T_i) and outdoor temperature (T_o) were extracted from the relevant literature using GetDate software, and the difference between T_i and T_o ($T_i - T_o$) was calculated, as shown in Fig. 2. It can be seen that the difference between T_i and T_o is relatively small throughout one day in winter, indicating the poor insulation ability of brick and wood residential buildings in winter. During the summer, the T_i of brick and wood buildings is lower than the T_o during the day, but higher than the T_o during the night. It can be inferred that brick and wood buildings should strengthen night heat dissipation during the summer.

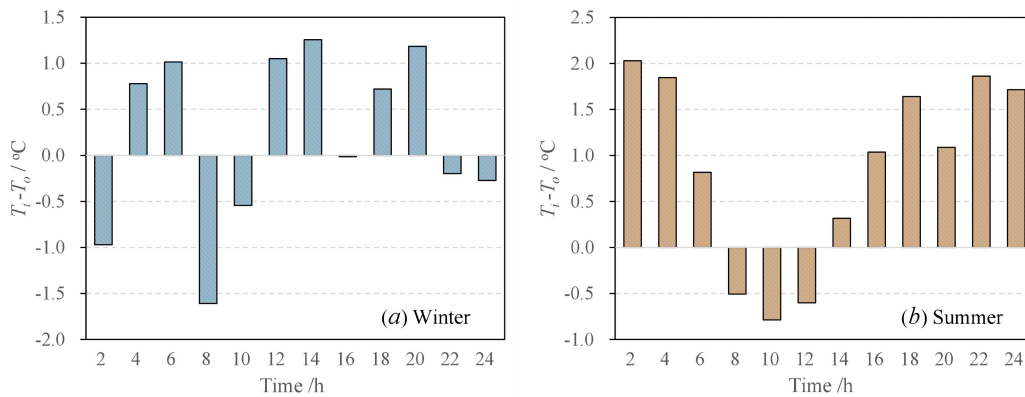


Fig. 2 Indoor and outdoor temperature difference in reference [14]

Based on the research results of numerous scholars on brick and wood residential buildings, the influencing factors of indoor thermal environment in brick and wood residential buildings are mainly manifested as (1) the thermal storage capacity of the walls; (2) the setting of openings for building doors and windows; (3) the thermal insulation capacity of the roof; (4) thermal bridge effect, etc.

3. Wood Residential Buildings

3.1 Construction Characteristics.

Traditional wood residential buildings have a long history in China. Based on their structural form, there are predominantly three types of classifications: lifting beam type, through-jointed frame type, and stack type. Among them, the through-jointed frame structure is widely used in residential buildings. This type of residential building is generally lower than 3 floors, and the enclosure walls are mostly made of 20~30mm thick cedar wood boards spliced together. The roof is

composed of purlins, rafters, tiles, etc. Fig. 3 shows a typical traditional wood residential building. From the figure, it can be seen that the through-jointed frame is the load-bearing system of wood residential buildings. Firstly, a plane frame is composed of beams and columns, and the wood beams and columns are connected by mortise-tenon joints. Secondly, multiple plane frames are connected by horizontal beams and purlins to form a whole frame. Finally, wooden wall panels are installed between the space formed by columns and beams, and wood floor panels are installed on horizontal beams.

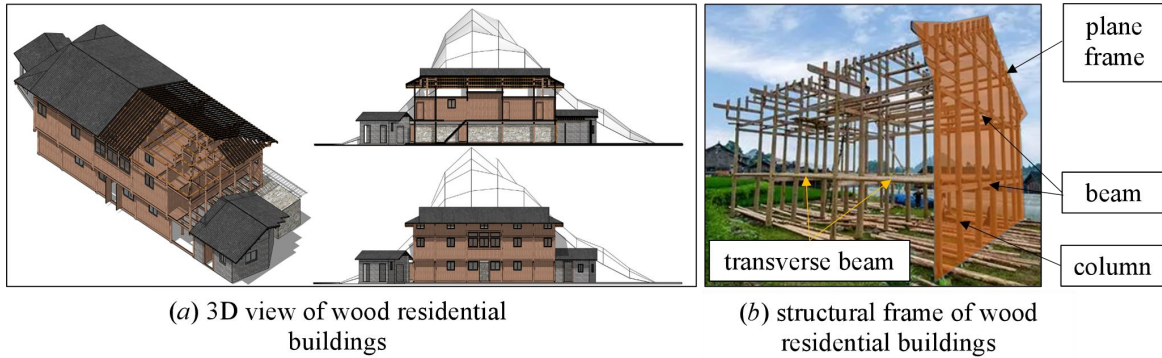


Fig. 3 Wood residential buildings

3.2 Indoor Thermal Environment.

Previous studies have shown that the average indoor temperature of traditional wooden houses in winter is slightly higher than the outdoor temperature. In summer, the indoor temperature is also slightly higher than the outdoor temperature at night [24-25]. As for the impact of the enclosure walls, the thinner the wood wall panel, the worse the thermal delay effect. Wood residential buildings in the Northern Guangxi region usually use 50mm thick uninsulated cedar boards as enclosure walls, which brings a thermal delay of about 1 hour [26]. In addition, due to the thermal inertia of wood, wood buildings have a lower risk of condensation on indoor walls compared to brick and wood buildings [27], which is not conducive to maintaining indoor thermal comfort. Research has shown that the attic space plays a good role in thermal insulation. A measured study on the thermal performance of ventilation roofs in traditional Tujia residential buildings in southeastern Chongqing shows that the attic space provides a thermal delay time of 3.6 hours [28].

The indoor thermal environment of wooden residential buildings in different regions has certain similarities. Taking the residential buildings in Northern Guangxi as an example [26], the indoor temperature (T_i) and outdoor temperature (T_o) were extracted using GetDate software. The differences between T_i and T_o ($T_i - T_o$) are shown in Fig. 4. In winter, the indoor temperature of wood residential buildings is generally higher than that of the outdoors, which may be due to the use of artificial heating devices. However, the temperature difference between indoor and outdoor is still relatively small, indicating that the heat-retaining capacity of wooden residential buildings is weak in winter. In summer, indoor temperatures are generally lower than outdoor temperatures during the day; At night, the indoor temperature is higher than the outdoor temperature. It can be seen that wooden residential buildings have poor heat dissipation at night during summer.

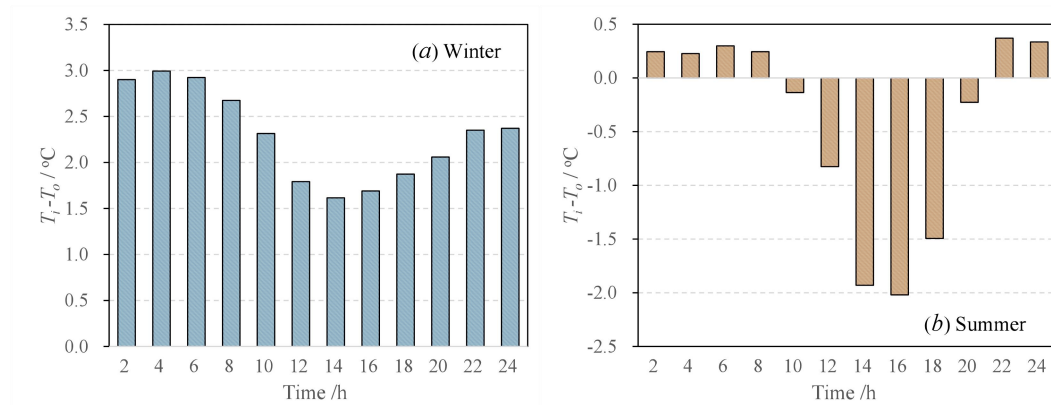


Fig. 4 Indoor and outdoor temperature difference in reference [26]

Based on existing research results, the factors affecting the indoor thermal environment of wood residential buildings can be summarized as follows: (1) the insulation capacity of the enclosure structure; (2) the airtightness of buildings; (3) the insulation effect of the attic.

4. Raw Soil Residential Buildings

4.1 Construction Characteristics.

Raw soil residential buildings are mainly distributed in the central and western regions of China. According to the architectural form, raw soil traditional residential buildings can be divided into earth-sheltered buildings, adobe buildings, and earth-rammed buildings, as shown in Fig. 5. Among them, earth-sheltered buildings are mainly constructed using natural terrain. The difference between adobe buildings and earth-rammed buildings lies in the different construction methods of the walls. adobe buildings are built with adobe bricks, while earth-rammed buildings are compacted with soil to form rammed soil walls. Table 2 summarizes the construction characteristics of raw soil residential buildings in different regions of China.

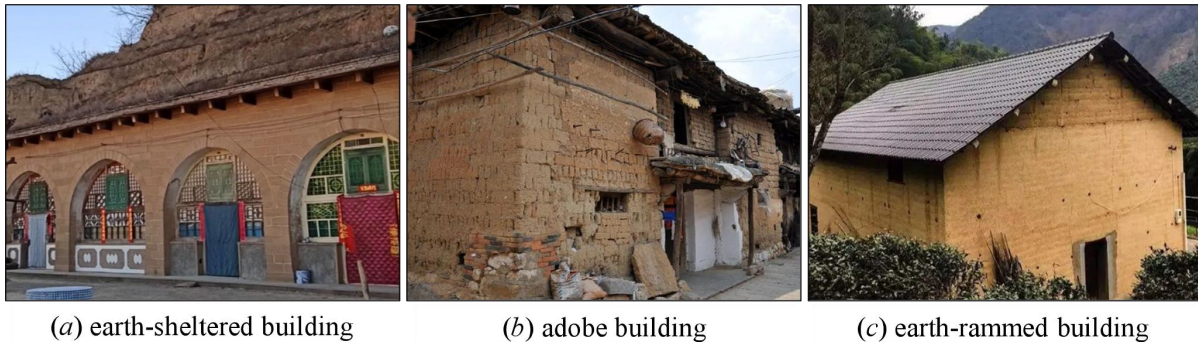


Fig. 5 Raw soil residential buildings

Table 2. Construction characteristics of raw soil residential buildings

Region	Building form	Number of floors	Wall construction measure (from inside to outside)	Roof form	Window setting
Yinchuan [30-31]	Adobe buildings	1-2	200-400mm adobe wall	Grey tile roofs or flat roofs	Wooden framed glass window
Southern Shanxi [32]	Earth-rammed buildings	1-2	Grass mud plaster 700mm rammed earth wall Grass mud plaster	Grey tile roofs	Wooden framed glass window
Chongqing [33]	Earth-rammed buildings	1-2	350mm rammed earth wall	Grey tile roofs	Wooden grid window
Northern Henan	Earth-rammed	1-2	400mm rammed earth wall	Grey tile roofs	Wooden framed glass window

[34]	buildings				
Northern Shaanxi [35]	Earth-sheltered buildings	1	Grass mud plaster Clay brick masonry (Openings)	Natural soil mass	Steel-framed glass window

4.2 Indoor Thermal Environment.

A study on the indoor thermal environment of raw soil residential buildings in Yinchuan region shows that these buildings have the characteristics of high humidity and low temperature, and high humidity is the cause of indoor low temperature [30]. The rectangular floor plan of raw soil residential buildings lacks thermal buffering between rooms [31]. In addition, studies have found that earthy dwellings have better summer indoor thermal performance compared to winter [32-33]. Besides, a large number of experimental studies have shown that the thickness of the outer enclosure wall of raw soil residential buildings is generally thicker than that of brick residential buildings, but the thermal delay induced by the wall is also about 2 hours [34-36]. It can be seen that the contribution of the raw soil wall to the indoor thermal comfort of the building is not high.

The indoor thermal environment of raw soil residential buildings in different regions shows certain similarities. Taking Chongqing's residential buildings as an example [33], the indoor temperature (T_i) and outdoor temperature (T_o) were extracted using GetDate software. The differences between T_i and T_o ($T_i - T_o$) are shown in Fig. 6. As shown in the figure, the indoor temperature of residential buildings is generally higher than the outdoor temperature in winter, but the temperature difference between T_i and T_o is not significant in most raw soil residential buildings. This indicates that the heat preservation effect of these types of residential buildings in winter is not significant. In summer, the indoor temperature of the residential building is generally lower than the outdoor temperature, especially during the day. Therefore, the indoor environment of raw soil residential buildings is relatively comfortable in summer.

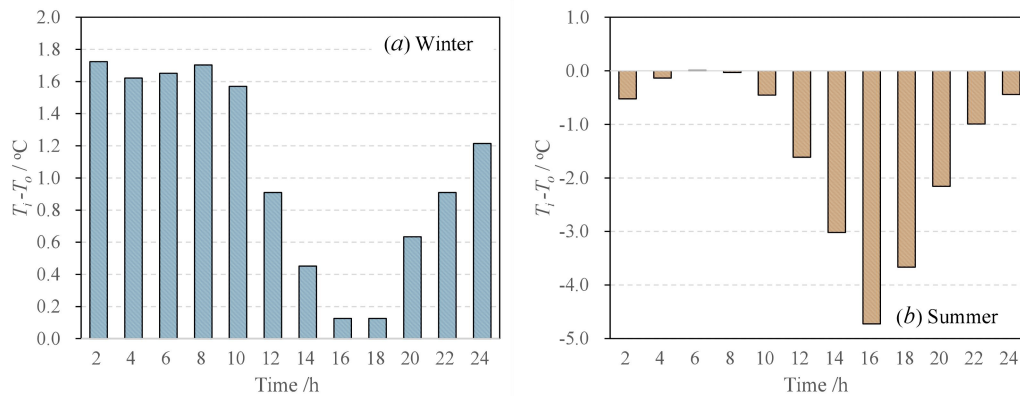


Fig. 6 Indoor and outdoor temperature difference in reference [33]

Based on existing research results, the main factors affecting the indoor thermal environment of traditional raw soil residential buildings are (1) the thermal resistance of the enclosure wall; (2) the architectural floor plan layout; (3) the insulation capacity of the attic; (4) indoor relative humidity.

5. Summary

This study investigated the indoor thermal environment of brick and wood residential buildings, wood residential buildings, and raw soil residential buildings in China. The main research conclusions are as follows:

(1) The walls of brick and wood residential buildings have no significant effect on improving the indoor thermal environment; The setting of door and window openings is not conducive to air convection; In winter, the temperature difference between indoors and outdoors is small, and the

insulation effect is poor; The indoor temperature is high at night in summer, and the heat dissipation effect is not good.

(2) The thermal stability of wood residential buildings is poor, and the high humidity during the rainy season leads to a decrease in indoor thermal comfort; The attic can form a good thermal buffer space; The indoor and outdoor temperature difference is relatively small in both summer and winter, and the thermal insulation ability of the residential building is poor.

(3) The thermal insulation ability of the walls of raw soil residential buildings is not high, but their moisture insulation performance is superior; Due to the rectangular layout of the raw soil buildings, there is no thermal buffering effect between the rooms; In winter, the temperature difference between indoors and outdoors is small, and the insulation capacity is insufficient.

Acknowledgments

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