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# Research on the Optimization Technology of Indoor Thermal Environment of Traditional Folk Houses in Liangshan Mountains

Baofeng Liang, Yueyan Liang, Minghui Pan, Yang Zhao
Southwest Minzu University, Chengdu, China

## Abstract

**As a significant component of China's historical architectural heritage, traditional dwellings in the Liangshan region offer a wealth of ecological construction experience. However, due to the age-old limitations of traditional construction techniques, the indoor thermal environment of these dwellings during winter is a salient issue. This paper investigates the current status of the indoor thermal environment in winter using a multifaceted research method that incorporates Climate Consultant climate analysis software, on-site measurements, numerical simulation and theoretical analysis. The study focuses on the Aqiu Lajia, a representative traditional house from Sijiji Village, to provide a case study for analysing and optimising the indoor thermal environment. The study's findings indicate that enhancing the thermal performance of the enclosure structure can lead to an increase in indoor temperature ranging from 2.4°C to 3.2°C, achieved through the incorporation of thermal insulation layers in the roof and wall sections.Furthermore, the simulation of various building orientations revealed that the south-eastern 15° orientation is effective in reducing wind speed and pressure during winter months, thereby enhancing the natural ventilation effect. The transformation of traditional single-glazed windows into double-glazed windows has been shown to increase indoor temperature by up to 2.69°C whilst simultaneously enhancing thermal insulation performance.The findings of this study provide a scientific basis and technical support for the conservation, protection and renewal of traditional houses in the Liangshan area, and represent a significant theoretical and practical contribution to the sustainable protection and renewal of traditional buildings.**

## Keywords

**Liangshan traditional houses, indoor thermal environment, optimization techniques.**

## 1. Introduction

As the core component of the rural residential system, traditional houses are characterised by their unique regional historical lineage, rich cultural connotation and ecological wisdom. The research, inheritance and development of traditional houses is of great significance to the protection of vernacular architectural heritage[1]. From an academic history perspective, the systematic study of traditional Chinese houses can be traced back to the 1930s. During this period, scholars of the Construction Society, such as Liu Dunzhen, Lin Huiyin, and Liang Sicheng, were among the first to employ Western classical architectural research methods. They undertook systematic mapping and surveys on typical houses in the southwest and northwest regions, thereby establishing the theoretical foundations and methodological frameworks for research in this field[4]. Subsequent generations of scholars have built upon this academic tradition, achieving significant advances in theoretical construction, methodological innovation, and practical application, culminating in the establishment of a comprehensive academic system.

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A review of the extant literature on traditional residential buildings reveals three predominant research directions. (1) Architectural ontology research, which focuses on exploring the plan layout, spatial morphology, structural techniques, and decorative features of traditional residential buildings, as well as evaluating the current status of their conservation[7]; (2) Research methodology innovation, which focuses on the construction of the research methodology and the development of tools for the enhancement of the performance of the thermal and humid environment[11]; (3) technology optimization research, focusing on exploring innovative measures and energy-saving technologies to improve the indoor physical environment[15]; and (5) research on the optimization of technology. The findings of this study provide a robust theoretical foundation for the modernisation of traditional houses and offer a range of research frameworks.In this study, a typical adobe residential house in Si Ji Ji village in Liangshan region, the A Bitter Raja house, was selected as the research object. The indoor thermal environment characteristics and its influencing factors of this house were systematically analysed by combining software simulation and on-site measurements. The study's findings, derived from the actual needs of local residents, propose targeted technical strategies for the optimisation of the thermal environment. The primary objective of these strategies is to provide a scientific basis and practical guidance for the sustainable inheritance and conservation renewal of traditional houses in the Liangshan region.

## 2. Thermal Environment On-site Measurement

### 2.1. Test subject

Siji Ji Village is located in Yiguojue Township, Meigu County, Sichuan Province, with geographic coordinates of 102°53′~102°55′ E and 28°19′~28°21′ N (Figure 1). It is bordered by Muzuo Luo Village in Waxi Township, Animu Village in Yiguojue Township, and Waliwu Village in Waliwu Township. The village has maintained a high degree of morphological integrity due to its low level of external intervention, and was selected as one of the "Chinese Traditional Villages List" in 2013.In terms of population composition, more than 98% of the population is of Yi ethnicity, forming a typical Yi settlement and preserving the traditional Yi cultural landscape. The topographic features of the study area are marked by significant changes, with an overall topographic elevation difference that displays a spatial pattern of low in the centre and high in the northeast, in contrast to the generally higher elevations in the south. The distribution of slopes ranges from 0.14° to 42.44°, exhibiting clear spatial differentiation: the central area is characterised by northeasterly and easterly slopes, while the eastern and western ends are predominantly marked by westerly and northwesterly slopes. With respect to the distribution of settlements, residential buildings are predominantly concentrated in the central, northwestern, and southeastern regions of the village. These sites have been fully adapted to the prevailing topographic conditions, with the building layout either parallel or perpendicular to the direction of the mountain. The majority of these buildings are constructed The residential construction area is characterised by a slope range of 0.14° to 14.41°, with the predominant orientation of residential buildings being towards the south and southwestern directions(Figure 2).

In this study, the Sijiji village A Bitter Raja house was selected as a typical sample, which adopts the traditional triad form, with a complete spatial system consisting of the main house and the two side rooms (Figure 3). The architectural scale of the main house is consistent with that of traditional houses, with an eaves height of 3.5m and a ridge height of 5m, and its layout follows the traditional spatial organisation pattern of "one bright and two dark": a living room of 5-10m is set in the centre, and bedrooms with a depth of 3m are arranged symmetrically on both sides. The compartments maintain a distance of 1.2-2m from the primary structure, and their architectural scale is slightly diminished relative to the main structure, with a height of 3m at the eaves and a height of 3.5m at the ridge, thereby achieving a flush visual effect with the eaves of the primary structure.The three groups of buildings are enclosed by a 1.8m high wall, thus forming a typical spatial pattern of the Yi triad. In view of the elevated levels of solar radiation experienced in Meigu County, the local population initiated the creation of more comfortable spaces. Concurrently, as economic conditions evolved, plastic PVC panels became a prevalent shading material for courtyards.

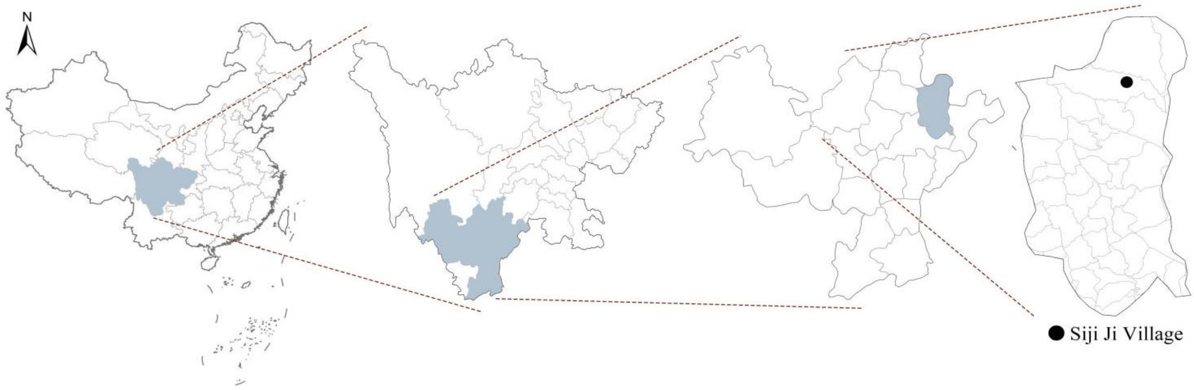


**Figure 1.** Geographic location plan

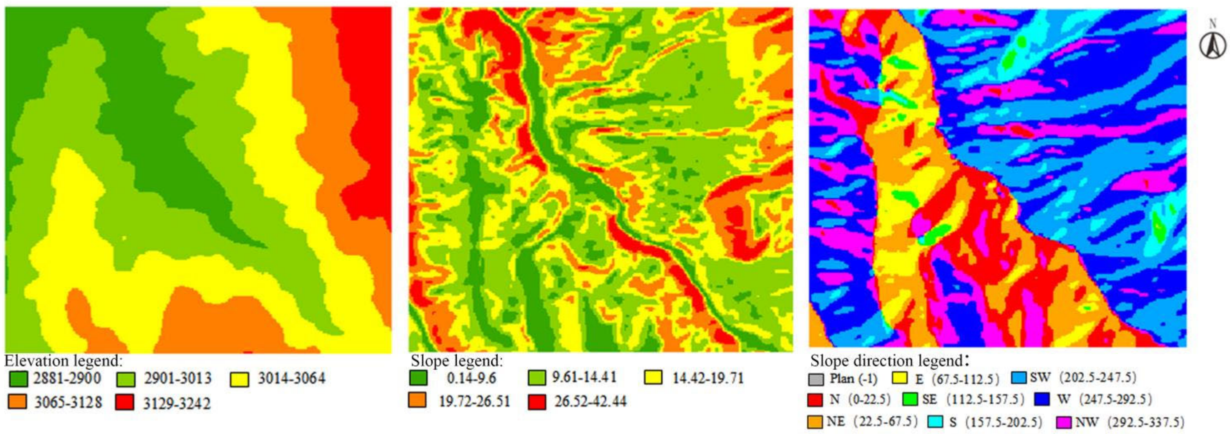


**Figure 2.** Elevation, Slope, Slope Direction Map

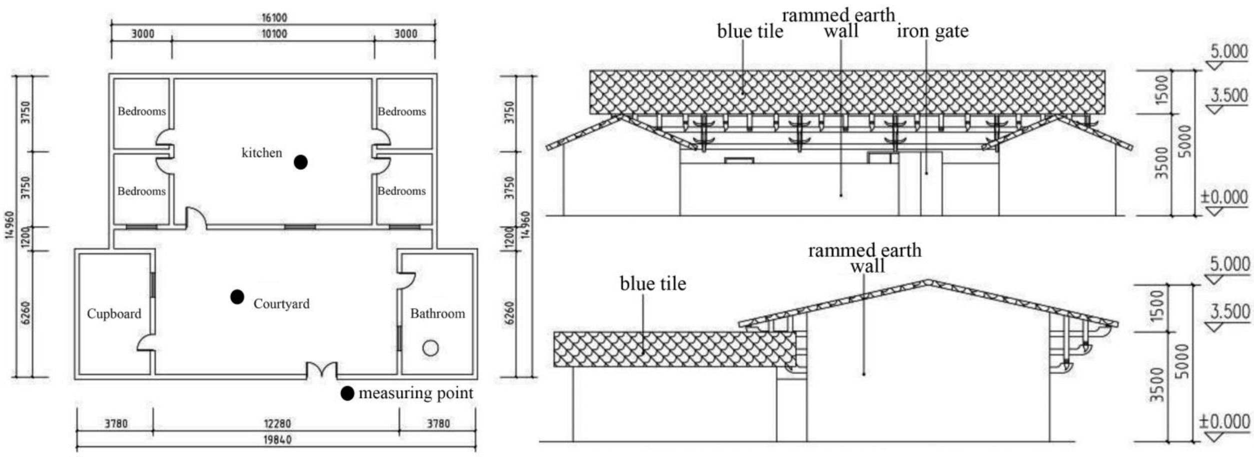


**Figure 3.** Flat Elevation of A Bitter Raja's House

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## 2.2. Test procedure

In this paper, the representative traditional rammed earth dwellings in Sijiji Village were selected for indoor and outdoor thermal environment measurements from January 2 to 5, 2024. The test period was from January 2 to 5, 2024, respectively. The instruments selected for measurement included the AZ8758 black sphere temperature and humidity tester, the TES-1333R solar power meter, the AS-803 illuminance meter and the UT362H hot-wire anemometer, respectively. The accuracy of the black sphericity tester was determined to be ±0.6°C and ±3% RH, with a resolution of 0.1°C and 0.1% RH, respectively. The illuminance meter exhibited an accuracy of ±4%+10, with a resolution of 1 lux and 0.1°C. The black sphericity tester demonstrated an accuracy of ±3% RH, with a resolution of 0.1% RH. According to JGJ/T 347-2014 "Building Thermal Environment Test Methods Standard"[18], the specification requirements for the main living space of the A Bitter Rajah's home included the actual point selection, temperature and humidity measurement, and air flow velocity measurement point location for the room plane diagonal intersection, distance from the ground 1.5 m at the arrangement. During the test period, the doors and windows of the residential rooms were kept closed, and the residents continued to live in the room as usual.

## 2.3. Analysis of measured results

The real measurements of the indoor and outdoor thermal environments in the house of A bitter Raja found that the changes in indoor and outdoor temperatures (Figure 4), humidity, wind speed and solar radiation intensity of the traditional dwellings in the village of the Four Seasons showed a certain regularity. The temperature measurement data of the residence at night shows that the outdoor temperature is lower at night and in the early morning hours, down to -2.8°C, and the temperature rises gradually with the rising sun during the daytime, with the daytime temperature reaching up to 13.8°C. The indoor temperature, on the other hand, is relatively stable, fluctuating throughout the day from 4.5°C to 6.3°C, significantly better than the outdoor environment. In terms of humidity regulation, the outdoor nighttime humidity is relatively high, up to 93.4%, while in the daytime humidity is relatively low, down to 52.6%. The indoor humidity relative to the temperature is always maintained in the range of 51.2% to 73.5%. The wind speed was generally low, with a maximum of 0.4 m/s. Solar radiation increased from 154 W/m2 in the morning to 789 W/m2 at noon, and then gradually decreased in the afternoon. It can be seen that the outdoor day and night temperature fluctuations are large and the indoor temperature fluctuations are small in Si Ji Ji Village, but the temperature is too low in the early morning hours, and the heat loss of the enclosure structure is obvious at night. According to the Rural Residential Building Energy Conservation Design Standard GB/T 50824-2013, the more comfortable indoor temperature for heating rooms in winter in cold regions is 18°C~20°C[19].It can be seen that the traditional residential houses in Siji Ji Village have insufficient heat preservation and insulation performance, and the indoor temperature is much lower than the comfortable temperature range of the standardized winter-heated rooms, and the indoor thermal environment of the residential houses is poor, which can not satisfy the requirements of its standards. Therefore, solar heating technology and high thermal storage walls are used to enhance the thermal performance of the enclosure structure, improve the winter indoor thermal environment of the traditional residential houses in Sijiji Village, and improve the living comfort of the residents.

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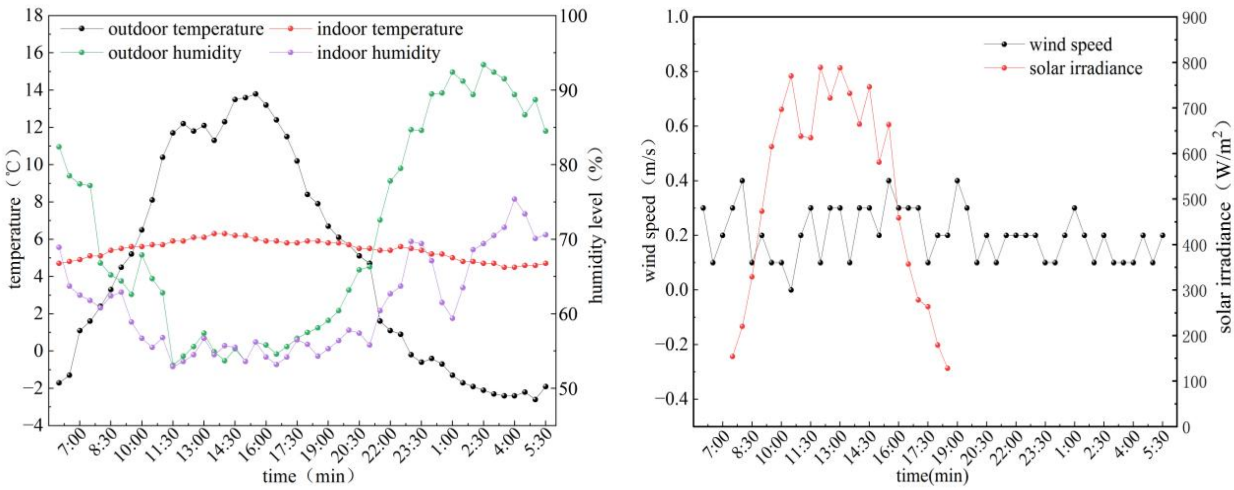


**Figure 4.** Indoor and outdoor thermal environment measurement

## 3. Questionnaire Analysis

In order to gain a deeper understanding of the residents' actual needs and experience of the indoor thermal environment, this study used a combination of questionnaires and semi-structured interviews to conduct a systematic research on the residents of Sijiji Village(Figure 5). The results of the study show that 71.27% of the respondents think that the indoor temperature is low in the winter thermal environment, of which 39.75% think it is “very cold” and 31.52% think it is “generally cold”; in the outdoor environment, 60.97% of the respondents feel cold, of which 23.45% think it is “very cold” and 36.52% think it is “generally cold”. Cold”. In terms of humidity perception, residents generally reflected that the environment was humid, with the indoor humidity perception rate being 40.7% and the outdoor humidity perception rate being as high as 64.42%. It is worth noting that in the indoor environment satisfaction survey, 65.31% of the residents indicated that they were “dissatisfied” or “just dissatisfied”; in terms of comfort, 74.75% of the residents considered it “uncomfortable” or “just uncomfortable”.

Through in-depth interviews, it was found that the main reasons for the above problems include: (1) the traditional residential enclosure structure is in disrepair, and the moisture-proof and heat preservation performance has significantly decreased; (2) the window opening area of the building is too small, which leads to poor natural ventilation; and (3) the energy efficiency of the existing heating facilities is low. Research data show that local residents mainly use heating methods such as roasting fires (45.6%), electric stoves (38.2%) and solar water heaters (16.2%), with electric stoves being the most commonly used, with an acquisition cost of about 100 yuan per unit and an average monthly expenditure of more than 200 yuan on electricity. It is worth noting that the penetration rate of air conditioning equipment is extremely low, which is mainly due to (1) the relatively comfortable indoor thermal environment in summer, with a low demand for cooling; and (2) the economic constraints, which make residents prefer electric stoves, which have lower operating costs, for heating. In terms of solar energy utilization, despite the abundance of local solar energy resources (annual average radiation amounting to 5,890 $MJ/m^2$), the use of solar water heaters is still faced with two major technical bottlenecks: (1) low temperatures in winter lead to the freezing of water pipes, which affects the normal supply of water; (2) the strong radiation during the daytime is prone to cause ordinary water medium collector bursting, which poses a potential safety hazard.

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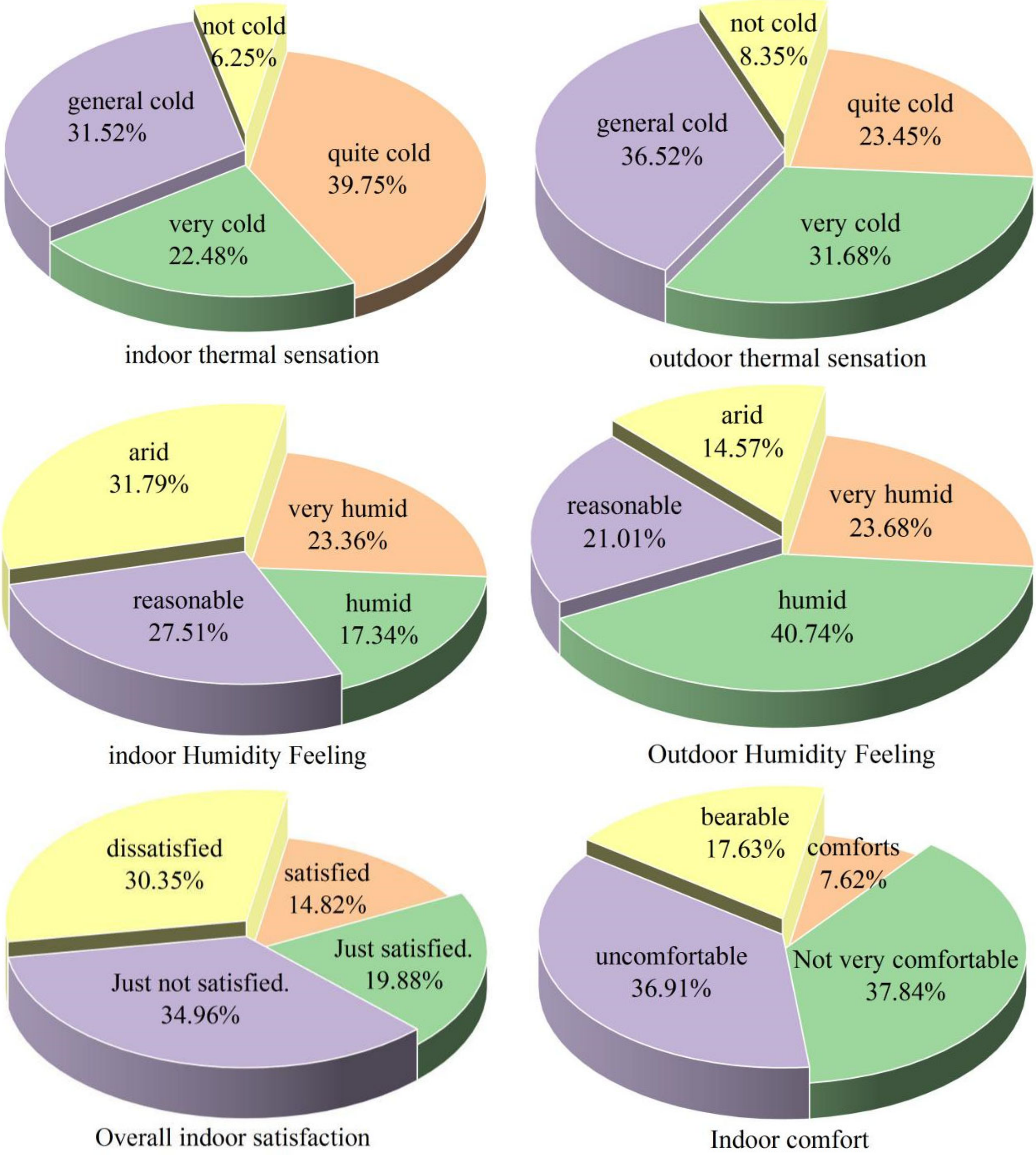


**Figure 5.** Questionnaire analysis

# 4. Strategies for Optimizing the Indoor Thermal Environment

## 4.1. Roof and wall insulation optimization strategies

Walls and roofs are the main channels for heat dissipation in buildings, and enhancing the thermal insulation performance of walls and roofs can greatly improve the indoor thermal environment in winter, as well as reduce the impact of solar thermal radiation on the thermal stability of the indoor environment[20]. Currently, the main wall insulation practices are: external insulation, internal insulation and sandwich insulation. Siji Ji village belongs to the national traditional village, in order not to destroy the traditional local traditional residential

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building facade traditional style, the use of external internal thermal insulation system for residential wall renovation, that is, in the internal wall set up 60mm thick polystyrene board (EPS) for insulation, the surface of the interlayer is coated with a strong reflective material of 5mm and coated with plastic treatment. The roofs of residential buildings are made of grass clay or yellow mud as the thermal insulation material of the roofs, which has the function of thermal insulation but the effect is not ideal, and even some residential buildings do not have thermal insulation layer, which seriously affects the thermal comfort of the indoor in winter. According to the “energy-saving design standard for rural residential buildings” GB/T50824-2013[19], the heat transfer coefficient of the roof of the enclosure of rural residential buildings in cold and cold regions should not be greater than 0.5 w/m2-k. The original roof of the A Bitter Lajia house, 0.986 w/m2-k, does not meet the requirements of the specification. In upgrading the thermal insulation performance of the roof, by lifting off the original existence of green tiles on the roof of the residential building, replacing the bonded mud layer of the existing roof with a layer of waterproofing membrane, and embedding extruded plastic board (XPS) in the rafters and then re-laying the wooden boards. In order to enhance the thermal insulation performance of residential buildings and solve the traditional rammed-earth residential construction problems such as leakage of dust and rain(Figure 6).

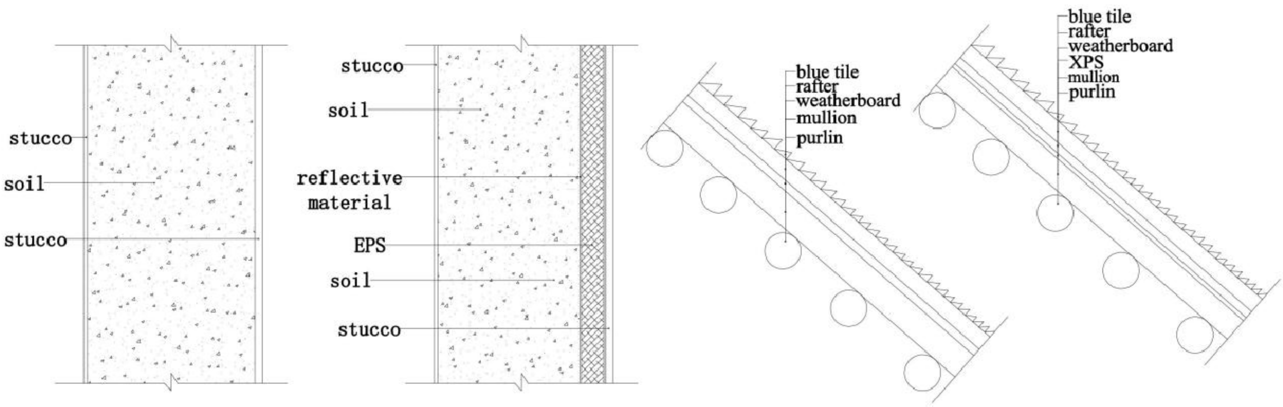


**Figure 6.** Roof and wall construction remodeling plans

The results obtained from the roof and wall retrofit simulation of the residence through the designbuilder software found that the indoor thermal environment of the residence was significantly improved after the addition of the wall insulation layer. The average daily indoor temperature before the improvement was 5.44°C, the maximum temperature was 6.3°C and the minimum temperature was 4.5°C. The indoor temperature was improved by 3.2°C, with a maximum temperature of 10.8°C and a minimum temperature of 9.6°C. The addition of roof insulation has improved the indoor thermal environment of the Four Seasons Gee Villagers' Residence in winter, and the insulated roof is more effective After optimizing the roof construction, the indoor temperature is improved by 2.4°C, with the highest temperature being 8.6°C. The lowest temperature was 7.1℃(Figure 7). It can be seen that the addition of wall insulation reduces the heat transfer coefficient of the indoor-outdoor temperature difference to about 35%, while the roof insulation construction further reduces the overall heat loss to about 28%, thus effectively reducing the heat loss coefficient of the building envelope and improving the indoor thermal stability.

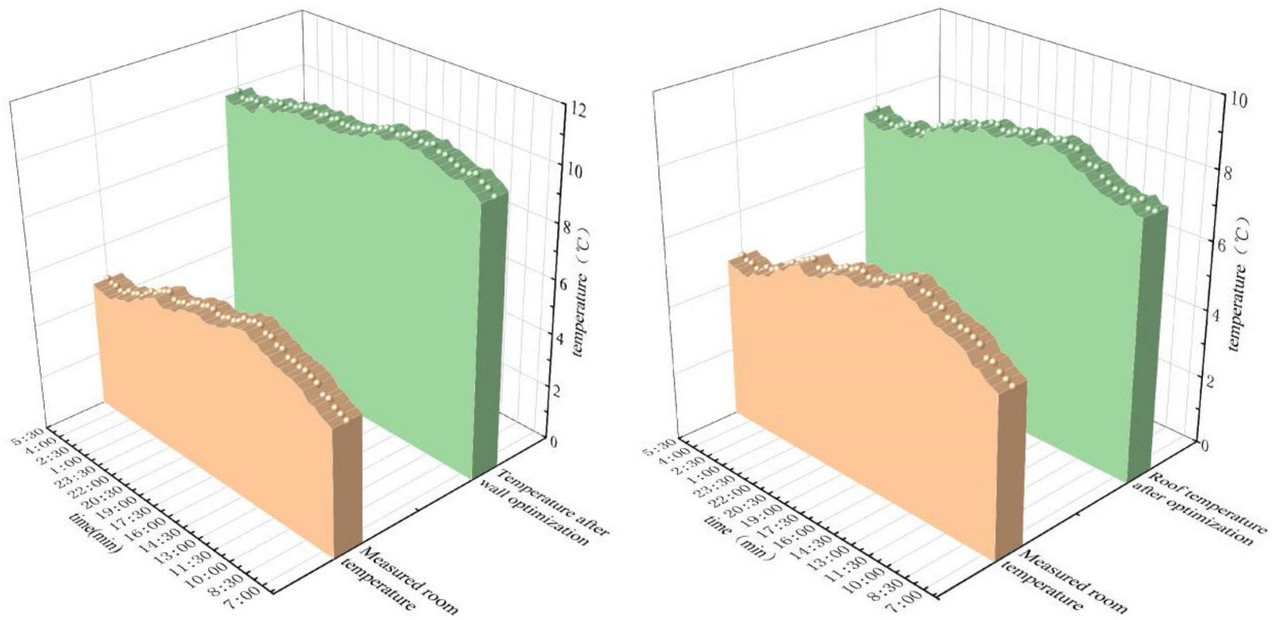


**Figure 7.** Comparative analysis of roof wall before and after optimization

## 4.2. Building Orientation Optimization Strategies

Based on the geographic location and climatic characteristics of the village of Sijiji, the afternoon solar azimuth during its coldest month is in the range of 2° S.E. to 45° S.W. The village of Meigu is a low-latitude plateau with a high climate. Considering that Meigu County has a low-latitude plateau climate and needs to strive for the most solar radiation in winter, the residential houses should be oriented in the range of 2°SE to 45°SW. In addition, according to the relevant provisions of the Sichuan Province Public Building Energy Efficiency Design Standard DBJ51/ 143-2020, the south orientation of a building is defined as a range of values from 30° south by west to 30° south by east. However, the current building orientation of the A Bitter Raja House is 45° south by east, which is a certain deviation from the local standard.

In order to determine the optimal building orientation, this study used numerical simulation to analyze the optimal orientation of the A Bitter Raja's house by changing the orientation of the building in the simulation software, and the building was simulated with 30° as a variable to derive the wind speeds and pressures of the residential buildings with different building orientations(Figure 8). According to the simulation results in winter, the wind speed and wind pressure around the buildings at 45° S.E. and 75° S.E. are significantly greater than those at 15° S.E.. In summer, the wind speed and pressure are lower as the angle increases for 15° S.E., 45° S.E., and 75° S.E(Figure 9). Therefore, the optimal building orientation for this building is 15°S.E., taking into account the needs for heating in winter and ventilation in summer.

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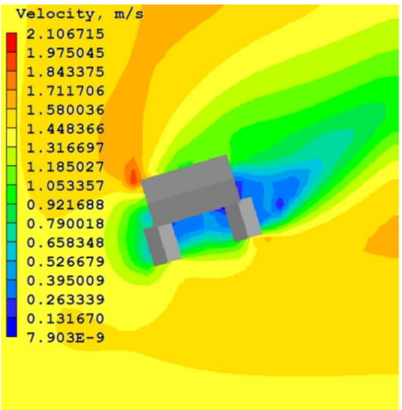
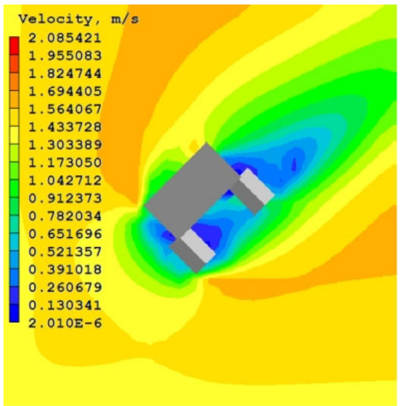
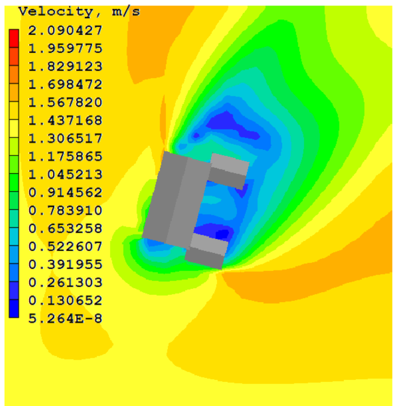


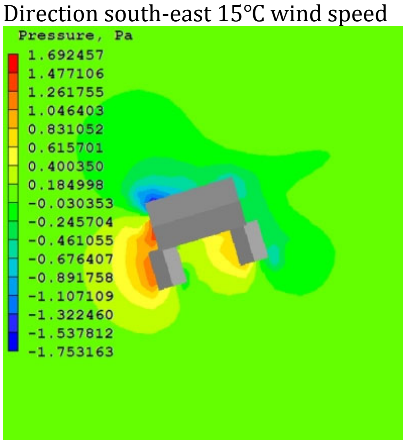
Direction south-east 15°C wind speed



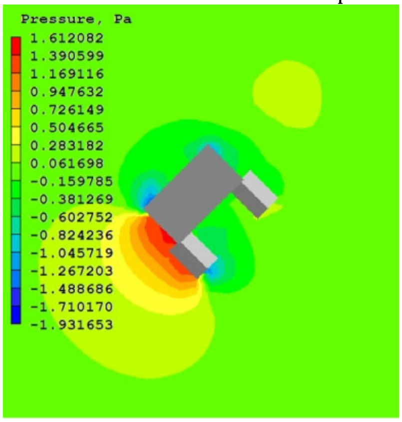
Direction south-east 45°C wind speed



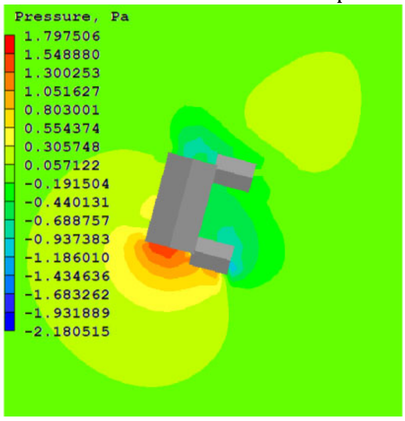
Direction south-east 75°C wind speed



Direction south-east 15°C wind pressure

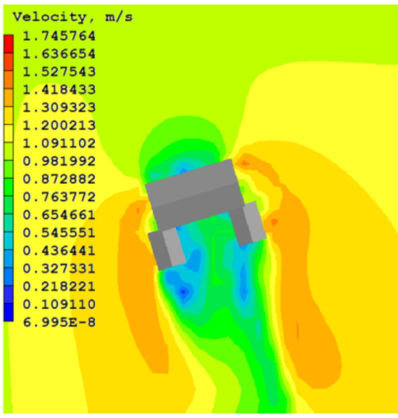


Direction south-east 45°C wind pressure

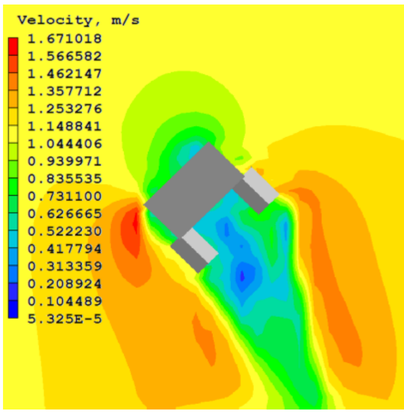


Direction south-east 75°C wind pressure

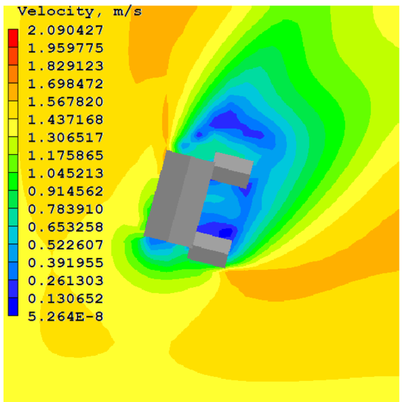
**Figure 8.** Analysis of the wind environment of residential houses in winter



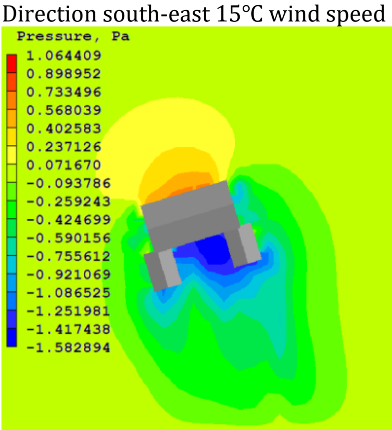
Direction south-east 15°C wind speed



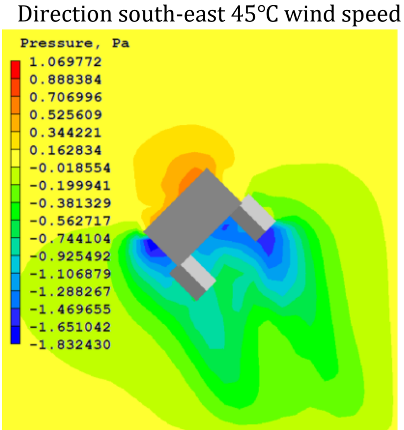
Direction south-east 45°C wind speed



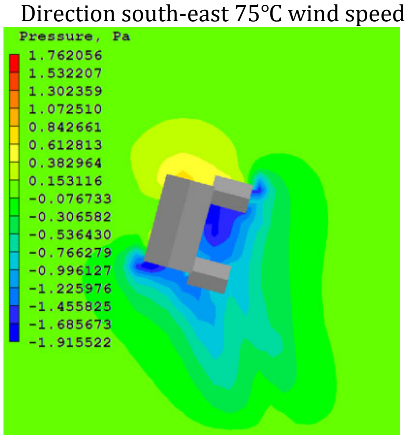
Direction south-east 75°C wind speed



Direction south-east 15°C wind pressure



Direction south-east 45°C wind pressure



Direction south-east 75°C wind pressure

**Figure 9.** Summer residential wind environment analysis

## 4.3. Window Optimization Strategy

The windows in the main house are in the form of straight lattice windows, with only two windows in the south direction and no windows in the north direction, and they are small and damaged to a certain extent, and the materials and construction still follow traditional practices. Although the thermal performance of wooden window frames is better, they are prone to deformation and damage after long-term use, and some villagers use wooden boards or transparent glass cloth to seal the windows, resulting in poor airtightness and affecting lighting and ventilation. The windows of the compartments have been transformed into aluminum alloy window frames with ordinary plate glass, which improved the durability of the window frames and the sealing of the windows and doors to a certain extent, but the aluminum alloy material and the plate glass have high heat transfer coefficients, which can't effectively reduce the indoor heat loss, resulting in their poor indoor thermal comfort in winter. When conceptualizing the window optimization scheme, the analysis should follow the Energy Conservation Design Standard for Rural Residential Buildings GB/T 50824-2013 and other relevant norms. Constrained by the traditional architectural style, villagers' acceptance, and economy, the window frame material adopts locally produced pine and cedar as the wooden window frame, and the glass selects double insulating glass with small and economical heat transfer coefficient for simulation to compare the effect on indoor thermal comfort in winter.

Simulation and analysis through Design Builder software found that in winter, ordinary flat glass can not effectively block the outside cold air, and even in extreme weather conditions may lead to a drop in indoor temperature, can not meet the demand for thermal insulation in winter, which in turn affects the comfort of the indoor thermal environment. Double insulating glass has better thermal insulation properties, the use of double insulating glass indoor average daily temperature of 8.13 ℃, an increase of 2.69 ℃,. Therefore, it is recommended that double insulating glass with an air layer thickness of 12 mm be selected as the main glazing material in residential window retrofits.(Figure10)

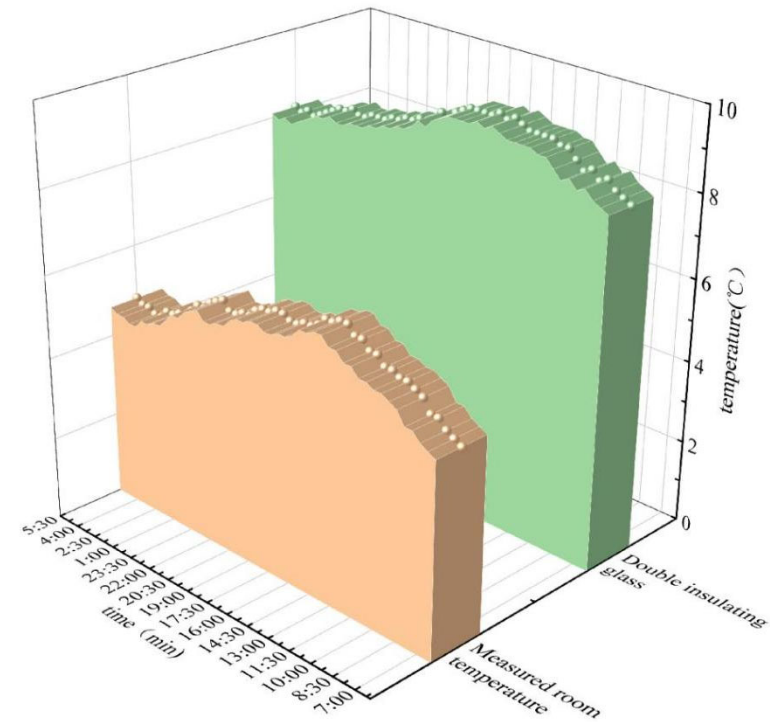



**Figure 10.** Comparative analysis before and after window optimization

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## 5. Conclusion

In this study, it can be concluded through the analysis of field research and simulation data that the current status of the indoor thermal environment of the traditional residential buildings in Siji Ji Village is poor: the average indoor temperature in winter is 5.44℃, the humidity is about 55%, the degree of physical comfort is poor, and the average temperature in winter doesn't satisfy the specification requirements of GB/T 50824-2013 "Energy Conservation Design Standard for Rural Residential Buildings". Through data analysis and interviews, it is found that the main problems are focused on poor thermal insulation performance of the building envelope, poor natural ventilation, and poor airtightness of the door and window structures.

(1) The wall and roof thermal insulation performance of traditional residential buildings in Siji Ji Village is poor. In this study, the thermal insulation performance of residential buildings is improved and the indoor temperature fluctuation is reduced by adding a polystyrene board thermal insulation layer on the roof and using extruded plastic board for internal thermal insulation modification of the wall. Simulation results show that the optimized indoor temperature is increased by 2.4℃~3.2℃, which improves the indoor thermal environment of residential buildings.

(2) By simulating the wind speed and pressure data of buildings with different orientations, it is found that building orientation is closely related to natural ventilation, and a reasonable orientation can effectively introduce natural light. The study shows that the orientation of 15° south-east of the residential building is the optimal choice, which can improve the indoor natural ventilation conditions and reduce the energy consumption in cold weather by utilizing sunlight, thus enhancing the indoor thermal environment.

(3) The traditional wooden window frames and ordinary plate glass can not effectively prevent the invasion of cold air from outside, in the window renovation, this study preferred the use of double-layer insulating glass with an air-layer thickness of 12mm as the main glass material, the indoor temperature is effectively increased by 2.69℃, which effectively improves the indoor thermal comfort in winter in residential houses.

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