buildings

Article

New Insights into Traditional Construction Behind Sibe Dwellings with Swastika Kang for Space Heating in North China

Menglong Zhang, Zhiyuan Shang, Keqian Luo and Kai Xie *

School of Architecture, Southwest Minzu University, Chengdu 610225, China; z18768972650@163.com (M.Z.); 13503702479@163.com (Z.S.); luokeqian@swun.edu.cn (K.L.)
* Correspondence: 80300177@swun.edu.cn; Tel.: +86-136-8409-6927

Abstract: Due to massive urbanization and industrialization, modern constructions tend to be designed as technique-dependent, at the cost of high consumption and emissions for indoor environment control such as heating ventilation and air conditioning. Space heating accounts for about 40% of total building energy usage in northern China in winter. This calls for self-reflection and tracing of local traditional architectural wisdom. In this paper, Sibe Traditional Houses were chosen as a typical illustrative example to reveal the building mechanisms behind such local-adaptive traditional constructions. Based on the field investigation in Shifosi Village, a traditional Sibe settlement in Shenyang City, northern China, thermal modeling and indoor heating effects are studied in Sibe Traditional Houses with unique building spatial patterns. The indoor thermal environment is comparatively analyzed for both passive envelope insulation and active heating considerations. Preliminary results indicate that enhancing roof thermal insulation enhancement is the key passive strategy for improving indoor thermal comfort in winter. It also suggests that a space-heating configuration that combines the traditional "kang" with the architectural layout has a more significant effect on the enhancement of indoor thermal comfort in Sibe dwellings. This paper can provide methodological support and an application reference for the improvement of indoor thermal environment of traditional village dwellings.

Keywords: built environment; historical buildings; Sibe dwelling; heating; thermal comfort; optimization design

check for updates

Academic Editor: Vincenzo Costanzo

Received: 2 February 2025
Revised: 26 February 2025
Accepted: 26 February 2025
Published: 28 February 2025

Citation: Zhang, M.; Shang, Z.; Luo, K.; Xie, K. New Insights into Traditional Construction Behind Sibe Dwellings with Swastika Kang for Space Heating in North China. *Buildings* **2025**, *15*, 795. https://doi.org/10.3390/buildings15050795

1. Introduction

In recent years, with the continuous progress of urbanization, China has shifted its focus towards rural revitalization. The rural living environment stands as a crucial foundation for this revitalization effort, playing a pivotal role in establishing sustainable spaces and creating beautiful countryside landscapes [1]. The issue of rural residents has been a focal point of concern for governments at all levels in the country, given its direct impact on the living standards of farmers [2]. As the living standards of rural inhabitants improve, their demand for thermal comfort indoors is steadily increasing [3]. The indoor thermal environment significantly affects human health and comfort, as adverse indoor thermal conditions are detrimental to human health [4]. Indoor thermal comfort is generally predicted based on environmental parameters such as temperature, humidity, air velocity, and personal parameters including activity levels and clothing resistance [5].

Nowadays occupant thermal comfort has been a research focus for people's increasing indoor time and its potential influence on productivity [6]. To enhance indoor thermal comfort, analysis can be bifurcated into passive strategy and active heating. Buildings have been regarded as one of the major energy consumption sources [7]. If no attention is paid to savin energy in buildings, a 70% increase in building consumption can be expected by 2050 [8]. Passive design measures aim to improve thermal comfort without consuming energy during heating season through reasonable building orientation, improved thermal performance of windows, increased glazing area, enhanced heat capacity, and insulation of building constructions [9]. Passive strategies are more energy-efficient technologies for application in buildings. These have a much longer history associated with their use in buildings than active strategies. Early passive technologies, such as cave dwellings, kang (For a detailed explanation, please refer to Nomenclature), hypocaust, etc., have existed for thousands of years [10]. However, studies from Sweden indicate that achieving passive house standards requires wall insulation of approximately 335 mm (U-value of 0.10 W/m^2K) and roof insulation of about 500 mm (U-value of 0.067 W/m^2K), surpassing the thickness of both exterior walls and roofs beyond 500 mm. This increase in thickness incurs costs far beyond just those of insulating materials [11]. On the other hand, the active heating system relies on special heating equipment, such as the boiler heating system, air source heat pump system, and so on, to meet the requirements of building heating [9]. Different countries, regions, and ethnicities exhibit diverse choices in heating facilities. For instance, central heating systems are prevalent in European and American countries, while stove heating methods are common in Asian and African regions. Underfloor heating systems are popular in North America and some Asian areas. These heating facilities notably elevate indoor thermal comfort.

Both passive insulation and active heating systems can contribute to improving the indoor thermal environment. However, the effectiveness of passive insulation alone in enhancing indoor thermal conditions is often limited, while relying solely on active heating tends to increase building energy consumption.

Therefore, this study focuses on the traditional dwellings of the Sibe ethnic group, employing simulation methods to investigate indoor thermal comfort:

- Validating and analyzing traditional construction wisdom using modern technologies.
- Conducting an in-depth analysis of the "Swastika kang", a traditional heating system (For a detailed explanation, please refer to Nomenclature).
- Exploring optimization strategies by integrating passive insulation with active heating systems.

2. Literature Review

2.1. Indoor Thermal Comfort

The enhancement of indoor thermal comfort has been studied by many scholars. Scholars in China have carried out related research on indoor thermal comfort. Hou JiaWun [4] conducted an optimization study of the indoor thermal environment in winter, and proposed an optimization strategy to improve the thermal performance of the building and the use of solar energy resources by increasing the indoor temperature of the building by up to 18 degrees Celsius in winter. Liu Jiao [12] conducted a study on traditional dwellings in Jia County, implementing optimization measures such as internal insulation for external walls and ceilings with gypsum boards combined with EPS insulation layers. These interventions led to an increase in indoor temperatures during winter and a decrease during summer, without the use of heating or cooling equipment, significantly improving indoor thermal comfort. In China, research on indoor thermal comfort has predominantly focused on the eastern and northern regions, with relatively limited attention given to the southwestern areas. Therefore, Dong et al. [13] evaluated indoor thermal comfort in rural southwestern China, analyzing residents' thermal adaptation behaviors and proposing a thermal neutral temperature of 29.33 °C for local dwellings. Furthermore, they emphasized that passive cooling measures should be more widely adopted in the design and renovation of rural homes. Wang Yan et al. [14] established a new thermo-neutral temperature for residents through methods such as subjective questionnaire surveys and objective data measurements, and proposed different performance enhancement strategies for old and new traditional dwellings: old traditional dwellings should focus on strengthening the thermal performance of the enclosure structure, while the new traditional dwellings should address the problem of low indoor temperatures in winter. Due to the long-standing issue of poor indoor thermal environment quality in Tibetan dwellings on the western Sichuan plateau, He et al. [15] conducted a study on the indoor thermal environment of these residences. Through field measurements, they proposed optimization strategies that include the utilization of both passive and active solar energy, the application of modern insulation materials, and the addition of sunspaces to improve the indoor thermal environment.

Zhang Chen et al. [16] conducted a systematic evaluation of integrated systems with radiant heating/cooling and ventilation, summarized various system configurations, and assessed system performance in terms of thermal comfort and air quality. Due to the issue of frost formation on the outdoor coil of air source heat pumps (ASHP) during heating in low-temperature environments, which interrupts heating supply during defrosting and affects indoor heating performance, Qu et al. [17] developed a novel reverse-cycle defrosting method based on thermal energy storage (TES). Experimental results demonstrated that this approach significantly reduces defrosting time and achieves higher indoor air supply temperatures. Mohammed [11] introduces the basic concept and some illustrative simulated performance results of a new Void Space Dynamic Insulation (VSDI) technology that couples low-cost conventional insulation materials with efficient ventilation to deliver low-loss building envelopes and high indoor air quality in thin wall construction. Joon Are Myhren and Sture Holmberg [18] conducted a study on how different heating systems and their locations affect the indoor climate in exhaust ventilation offices under Swedish winter conditions, and the general conclusion of the study was that low-temperature heating systems can improve the indoor climate and thus reduce the indoor wind speeds and temperature differentials in comparison to conventional high-temperature radiator systems. The disadvantage of low-temperature systems is that they cannot offset the cold of the ventilation supply units. Therefore, the location of heat emitters and the design of the ventilation system proved to be particularly important.

2.2. Kang

Research on the kang system has primarily been conducted by Chinese scholars. Zhuang [19] reviewed the basic principles of heat transfer and airflow in traditional Chinese kangs and presented the thermal performance of the kang through field investigations, discussing future research needs. Yu [20] addressed the limited scope of existing kang research by reviewing the detailed structures, flue configurations, and thermal performance of three traditional Chinese kang systems. They also introduced and analyzed recently improved systems, proposing directions for future research. Wei [21] focused on the maze pattern kang, analyzing its cultural significance and extending its interpretation through connections to other cultures, emphasizing the ethnic spirit and cultural value of the kang. Zhang [22] studied traditional fire kangs in Northeast China, testing the thermal performance of full-room and "Swastika kang". Zhang also proposed a method for evaluating thermal performance, simulating heat transfer in the flue system, and providing recommendations for optimal fuel usage and flue design to maximize energy efficiency and maintain reasonable temperatures. Liu [23] compared ground-level and raised kangs in rural Northeast China, finding that raised kangs are a low-cost, high-efficiency heating solution that aligns with sustainability principles.

2.3. Research Status

The current research on indoor thermal comfort in residential homes primarily focuses on passive and active methods aimed at enhancing indoor thermal comfort. Passive methods involve increasing the thickness of building enclosures, using higher-quality insulation materials to improve the thermal properties of the building envelope, or adjusting factors such as building orientation or window-to-wall ratios to enhance indoor thermal comfort. Simultaneously, in the realm of active heating systems, there are explorations into utilizing renewable energy sources like solar power to reduce the energy consumption of building heating and thus improve indoor thermal comfort.

As illustrated in Table 1, current research on indoor thermal comfort predominantly focuses on the impact of either passive or active elements in isolation. Moreover, studies on the influence of active heating systems on the indoor thermal environment often employ modern technologies and advanced materials, thereby overlooking the traditional heating wisdom inherent in many vernacular dwellings. As shown in Table 2, due to the diversity of kang types, a significant number of scholars have conducted research in the form of reviews. Additionally, most studies have focused on the structural aspects of kang and its cultural significance, while relatively few have explored its integration as an active heating device with passive strategies.

Table 1. Literature Review on Indoor Thermal Comfort.

Number	Indoor Thermal Comfort	Passive	Active	
			Modern Technologies	Traditional Wisdom
[4]	✓	✓	✓	
[11]	✓	✓	✓	
[16]	✓	✓		
[17]	✓	✓		
[18]	✓	✓		
[19]	✓	✓		
[20]	✓		✓	
[21]	✓		✓	
[22]	✓		✓	

Table 2. Literature review of kang.

Number	Types			Structure	Indoor Thermal Environment	Cultural
	"Swastika Kang"	Other	Review			
[14]			✓	✓		
[15]			✓	✓		
[23]	✓					✓
[24]	✓			✓		
[25]		✓			✓	

Consequently, this study integrates passive insulation and active heating strategies in traditional northern Chinese residences to validate traditional architectural wisdom and propose optimized strategies for enhancing indoor thermal environments. The study evaluates the potential of passive strategy methods to improve indoor thermal comfort by enhancing the thermal properties of the building envelope. The study also delves deeper into the active heating system embodying traditional wisdom known as the 'kang'. By simulating the heating systems with modern technology, the study explores the impact of this traditional wisdom on indoor thermal comfort, affirming the traditional construction wisdom of the residents in cultural village.

3. Methods

3.1. Geographic and Climatic Information

Positioned along the southern bank of the Liao River, Shifosi Village is situated in Shenyang's Shenbei New District, at the foothills of Qixing Mountain (Figure 1). The village layout exemplifies the classic Feng Shui pattern of ancient northern Chinese villages, surrounded by natural barriers on three sides: water on two sides and mountains on the other.

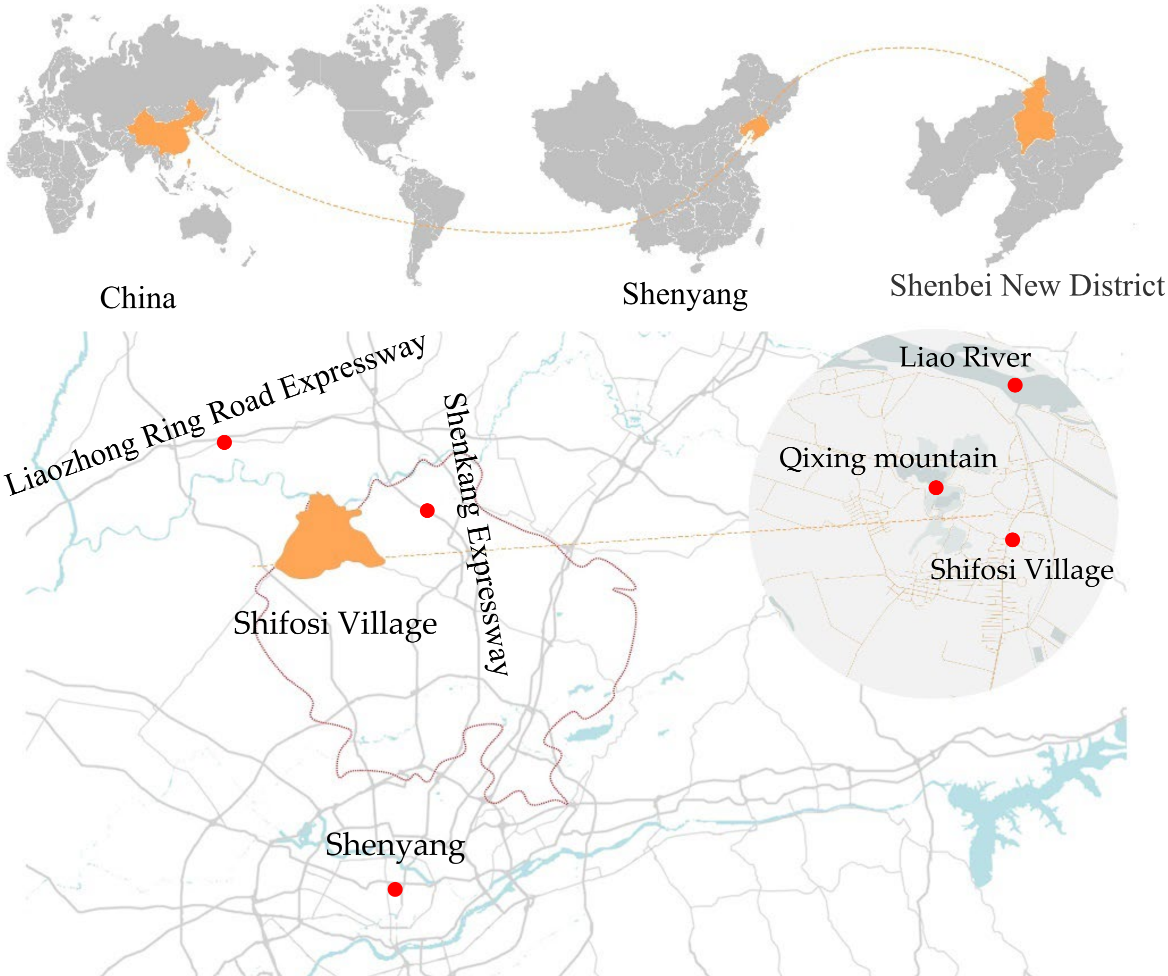

Figure 1. Case study of Shifo Sibe traditional village location in northern China.

Shifosi Village is located in the temperate continental monsoon climate of the northern zone. Summers are characterized by high temperatures and frequent rainfall, while winters are cold and dry, falling within an intensely cold region. As shown in Figure 2, the hourly temperature variation and daily average temperature of Shifosi Village in 2023 reveal the climatic conditions of the area. The data indicate that summer temperatures in Shifosi Village can reach as high as 30 °C, although the season is relatively short, spanning only from July to August. In contrast, the winter is harsh and prolonged, with approximately five months experiencing temperatures below 0 °C, and the minimum temperature approaching −30 °C.

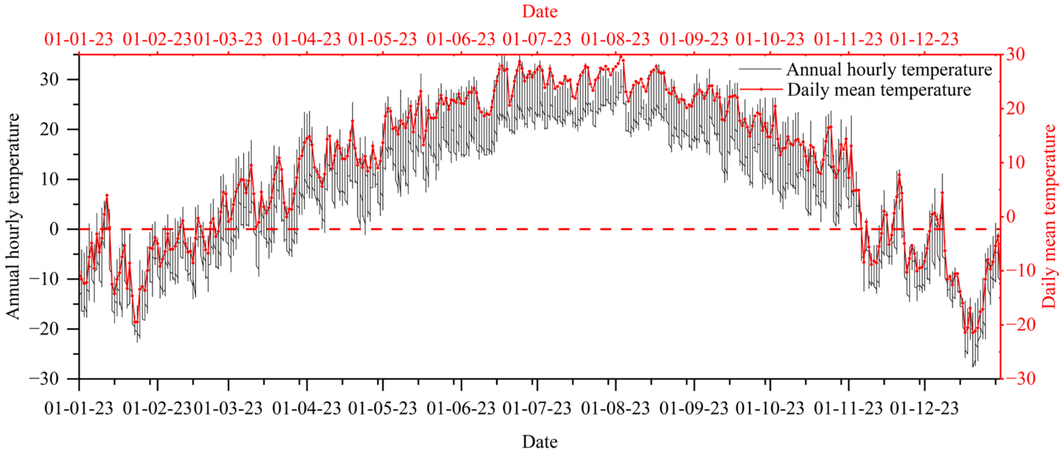

Figure 2. Temperature information of Shifosi Village (Data sources: https://xihe-energy.com/#climate, accessed on 16 November 2024).

3.2. Building Thermal Model

The Village of Shifosi is located in a cold region, and according to the code, building design in this area must fully satisfy the requirements for winter insulation, and can generally be disregarded for summer heat protection [24]. Thermal performance of external walls and other enclosure structures play an important role in building winter heat preservation. The heat transfer coefficient, heat storage coefficient, and thermal inertia of the envelope are usually used to measure the thermal performance of the envelope. For a detailed explanation of the thermal performance parameters, please refer to Nomenclature.

3.3. Folk Houses and Kang

Based on the sixth national census of the People's Republic of China in 2010, 70.2% of the Sibe people reside in Liaoning Province. Within this province, Shenyang's Shenbei New District originally comprised two Sibe townships and one Sibe town, which underwent reorganization in 2017 and were redesignated as Shifosi Street [25]. Shifosi Village was designated as one of the first historical and cultural villages in Liaoning Province in 2007 and was included in the seventh batch of national historical and cultural villages in 2019. In the same year, it was listed in the fifth batch of China's traditional villages. In addition, Shifosi Village has preserved a rich national intangible cultural heritage, especially the traditional culture of the Sibe people. Cultural heritage is "the expression of the way of life produced from social development and passed down across generations" [26]. Therefore, the Sibe residential houses have become the typical representatives of the traditional architecture of the Sibe people.

This study takes Shifosi Village as a case study to analyze traditional Sibe dwellings. As mentioned earlier, winters in Shifosi Village are extremely harsh, with minimum temperatures approaching −30 °C. Therefore, Sibe people's dwellings must thoroughly consider requirements for winter insulation, cold resistance, and frost prevention (Figure 3).

Based on the actual conditions, the building structure is input into the simulation software. Utilizing the thermal parameter calculation formulas provided in Table 3, the thermal parameters of the building materials can be derived. Table 4 illustrates the composition of the outer protective structure of traditional dwellings of the Sibe people, primarily consisting of the roof, walls, and external windows. The roof's structure, from top to bottom, comprises concrete tiles of 20 mm, lime mortar of 20 mm, a layer of clay mixed with grass of 20 mm, and a wooden board of 20 mm. The total thickness of the roof is 80 mm, providing a total thermal resistance of 0.426 ($m^2 \cdot K/W$), a thermal inertia index of 1.301, and a total heat transfer coefficient of 1.74 $W/(m^2 \cdot K)$. The wall primarily employs bricks, with a thickness of 450 mm, offering a thermal resistance of 1.698 (m^2·K/W) and a thermal inertia index of 16.981. The external windows are double-glazed, constructed with wood and plastic, and have a heat transfer coefficient of 2.50 W/(m^2·K).

Figure 3. Typical Sibe traditional dwelling structure in Shifosi Village.

The following are the formulas for heat transfer coefficient, thermal inertia index, and thermal storage coefficient [27]:

Table 3. Tables of equations.

Number		Equation	Define
(1)	Material Layer Thermal Resistance	$R = \delta/\lambda$	R: Material Layer Thermal Resistance (m^2·K/W). δ: Material layer thickness (m). λ: Material thermal conductivity [W/(m·k)].
(2)	Heat transfer resistance of the envelope	$R_0 = R_i + R + R_e$	R_0: Enclosure heat transfer resistance (m^2·K/W). R_i: Internal surface heat transfer resistance (m^2·K/W). R: Enclosure flat wall thermal resistance (m^2·K/W). R_e: External surface heat transfer resistance (m^2·K/W).
(3)	Heat transfer coefficient	$K = \frac{1}{R_0}$	K: Heat transfer coefficient of the enclosure [W/(m^2·K)].
(4)	Heat storage capacity	$S = \sqrt{\frac{2\pi\lambda c\rho}{3.6T}}$	S: Heat storage capacity [W/(m^2·K)]. c: Specific heat capacity [KJ/(kg·K)]. ρ: Densities (kg/m^3). T: Temperature fluctuation period (h), generally T = 24 h. π: The circular ratio, π = 3.14.
(5)	Thermal inertness index	$D = R{\cdot}S$	D: Thermal inertness index.

Table 4. Thermal-physical properties of Sibe building external envelopes.

Material	Thic Thickness (mm)	Thermal Conductivity (λ) W/(m·K)	Heat Storage Coefficient (S) W/(m^2·K)	Correction Factor α	Resistance (R) (m^2·K/W)	Thermal Inertia D = R × S	Heat Transfer Coefficient K = 1/(0.15 + ∑R) W/(m^2·K)
Concrete Tile	20	0.93	10.583	1	0.022	0.228	1.58
lime mortar	40	0.81	10.07	1	0.049	0.497	
Sagebrush clay	40	0.58	7.723	1	0.069	0.533	
Planks	20	0.058	1.627	1	0.345	0.561	
Brickyard	450	0.265	10	1	1.698	16.981	0.54
Wood-plastic windows							2.5

Due to the severe cold climate in Shenyang, relying solely on passive strategy in residential building enclosures is insufficient to meet indoor heating demands during winter. Therefore, residents in the Shenyang area often install active heating facilities indoors to ensure warmth, including a combined stove-kang-chimney structure known as "kang". As an ancient home technology, a typical Chinese kang consists of a stove, a kang body (similar to a bed), and a chimney. It allows at least four different home functions of cooking, bed, domestic heating, and ventilation to be integrated into one system [19]. The operation of the kang can be divided into three phases: heating, stabilization, and cooling. During the heating phase, the surface temperature of the kang rapidly rises through the combustion of wood and other fuels. In the stabilization phase, the surface temperature remains constant and ceases to increase. In the cooling phase, fuel combustion is halted, and the surface temperature gradually decreases. A schematic of these operational phases is shown in Figure 4.

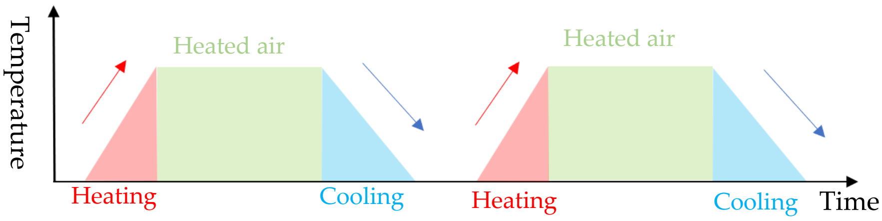

Figure 4. Operation process and construction of Swastika kang.

Additionally, the Sibe ethnic group residing in Shifosi Village developed their unique form of active heating, called the "Swastika kang", which is installed on either side of the bedroom within the traditional three-room layout, evolving over time in the course of history. Chinese kang, which serves as the main space-heating equipment in rural residences of cold regions of China, has received increasing attention due to people's increasing requirements of thermal comfort and concerns about indoor air environment in recent years [20].

3.4. Indoor Thermal Comfort Evaluation

Thermal comfort is defined as a person's subjective satisfaction with the thermal and humid environment. Thermal comfort is mainly affected by six parameters, including two human factors, i.e., the amount of human activity and clothing, and four environmental requirements, i.e., the effects of air temperature, air humidity, air speed, and radiation on human thermal comfort. Different scholars have proposed different evaluation criteria for thermal comfort, and in this paper, we will introduce the PMV-PDD [17] evaluation model as well as the Anticipated Adaptive Thermal Sensory Metrics (APMV). PMV is the predicted mean thermal sensory index and PDD is the percentage of predicted dissatisfiers. The relationship between the two is shown in the following equation [28]:

$$PPD = 100 - 95\exp\left[-\left(0.03353PMV^4 + 0.2179PMV^2\right)\right] \tag{6}$$

The specification [29] states that in a humid-heat environment with natural heating and cooling sources, the expected adaptive mean thermal sensory index (APMV) should be used as the basis for evaluation, and the APMV should be calculated according to the following formula [30]:

$$APMV = \frac{PMV}{(1 + \lambda \cdot PMV)} \tag{7}$$

APMV: Expected adaptive mean thermal sensory index
λ: Adaptive coefficient

PMV: Projected average thermal sensory indicators

This paper will also evaluate the thermal environment of residential houses according to the evaluation standard of the time proportion of indoor thermal environment parameters of the main functional rooms of the building in the adaptive thermal comfort zone in the specification. The indoor thermal comfort time ratio refers to the proportion of hours throughout the year during which the indoor hourly temperature falls within the thermal comfort temperature range.

The range of the indoor thermal comfort temperature zone for the dwelling is determined as illustrated in Figure 5, with the monthly average outdoor temperature derived from outdoor meteorological data.

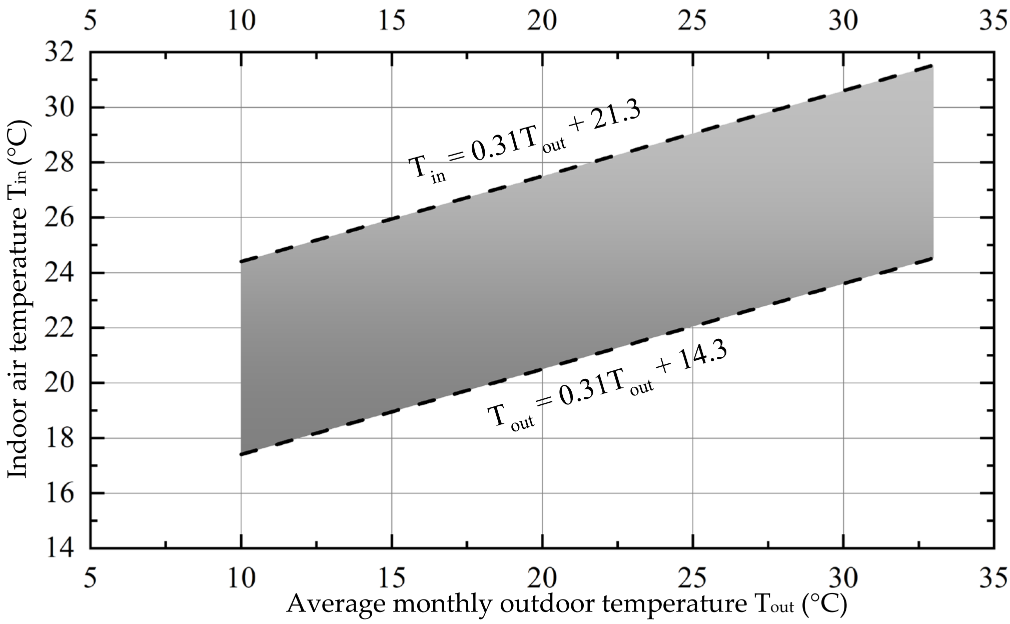

Figure 5. Indoor comfort temperature range for naturally ventilated or composite ventilated buildings.

Table 5 presents the relationship between outdoor temperatures and the corresponding range of indoor thermal comfort temperatures. The outdoor monthly average temperatures are based on typical year averages. Thus, the initial conditions for subsequent simulation modeling are set according to these temperature values.

Table 5. Indoor thermal comfort temperature range.

Months	Average Monthly Outdoor Temperature (°C)	Indoor Thermal Comfort Temperature Range (°C)
1	−11.5	17.4–24.4
2	−6.5	17.4–24.4
3	1.7	17.4–24.4
4	10	17.4–24.4
5	16.7	19.5–26.5
6	21.5	21.0–28.0
7	25.7	22.3–29.3
8	23.2	21.5–28.5
9	17.2	19.6–26.6
10	10.3	17.5–24.5
11	1.1	17.4–24.4
12	−7.5	17.4–24.4

3.5. Building Simulation

The residence adopts a traditional three-room layout with bedrooms on either side to meet the occupants' daily activity needs, while the central area serves as a living room cum kitchen. The building has a width of 16,700 mm and a depth of 8000 mm. In terms of its construction, the non-transparent parts consist of 450-mm-thick walls made of green bricks, and the roof is composed of materials layered from top to bottom: 20 mm of concrete tiles, 20 mm of lime mortar, 20 mm of clay mixed with straw (ρ = 1400), and a 20-mm template. The transparent sections are constructed using wooden and plastic double-glazed windows, with a spacing of 100 to 140 mm between the two panes of glass.

The study utilized Sware ITES2023 (20220401) to investigate the impact of the building envelope of Shifosi traditional dwellings on the indoor thermal environment. Simulation experiments were conducted on the external walls, roof, and windows of the dwellings as follows:

1. External Walls: Two sets of experiments were performed:

Maintaining a constant wall thickness, exploring the influence of different wall constructions on the indoor thermal environment.

Keeping the wall construction unchanged, investigating the effect of varying wall thicknesses on the indoor thermal environment.

2. Roof: Three sets of experiments were conducted:

Increasing the thickness of each roof layer.

Maintaining a constant roof thickness, examining the impact of different construction materials on the indoor thermal environment.

Adding an insulation layer and incrementally increasing its thickness.

3. Windows: three sets of experiments were carried out using different modern window constructions to study their effects on the indoor thermal environment.

Figure 6 presents a simplified floor plan of the residence and a schematic diagram of the preliminary simulation model.

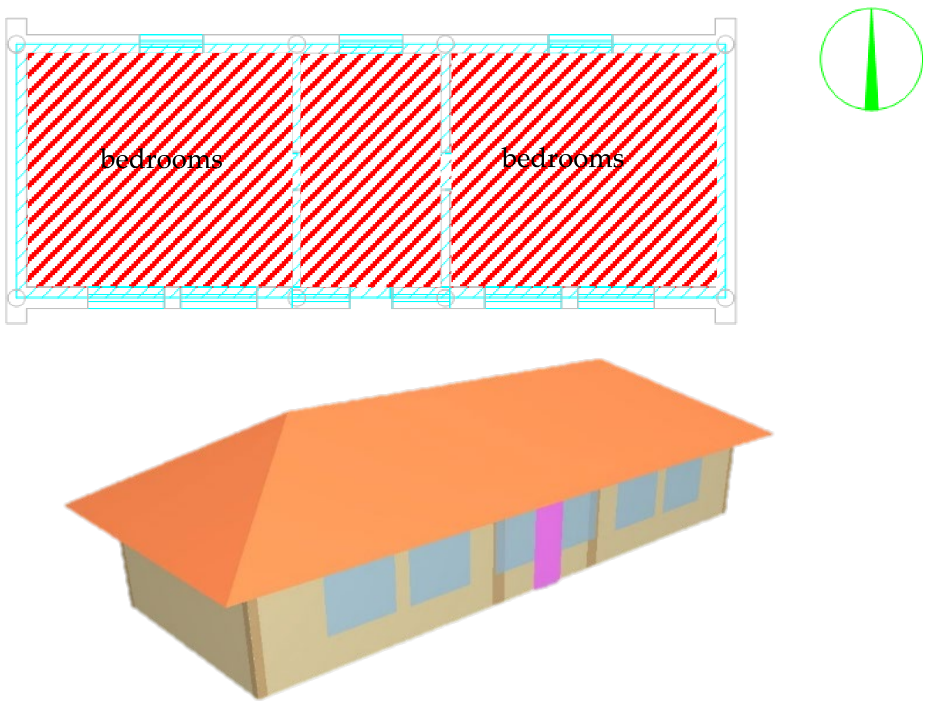

Figure 6. Floor layout of typical Sibe house for case study.

The month with the highest average temperature is July, with an average temperature of 25.7 °C. During this period, the corresponding indoor thermal comfort temperature range is between 22.3 °C and 29.3 °C. Conversely, the month with the lowest average temperature is January, recorded at −11.5 °C, where the corresponding indoor thermal comfort temperature range is between 17.4 °C and 24.4 °C. The passive thermal insulation design of the building envelope is evaluated based on the proportion of time the indoor temperature complies with the thermal comfort standards.

Figure 7 illustrates the model setup of the active heating system within the traditional residential interior at Shifosi Village. The "Swastika kang", typically constructed using materials like adobe and bricks, incorporates thermal adobe bricks made by mixing wheat straw and thatch with mud. These bricks are exceptionally hardy and proficient in retaining heat [31]. The surface of the "kang" is usually coated with plaster, utilizing the technique of "inserted plaster": a mixture of one part white lime, three parts loess, and one part hemp blade, followed by a 1 mm-thick layer of yellow mud containing dry straw, then further smoothed by inserted plaster using a hemp blade [15]. The surface of the "kang" is usually coated with plaster, utilizing the technique of "inserted plaster": a mixture of one part white lime, three parts loess, and one part hemp blade, followed by a 1 mm-thick layer of yellow mud containing dry straw, then further smoothed by inserting plaster using a hemp blade.

For the kang, an active heating device, the study selected Airpak3.0.16 software as the simulation tool. In the simulation model, the parameters for the building envelope of the dwelling were set based on the configurations described earlier. The outdoor temperature was set to −11.5 °C. Considering that the surface of the kang is usually covered with blankets, bedding, and other materials, it is recommended that the comfortable temperature of the surface of the fire bed fluctuates between 24 °C and 28 °C, with the maximum temperature not exceeding 40 °C for human comfort. Therefore, the temperature variation on the "Swastika kang" surface is set within the range of 20 °C to 45 °C. In the simulation process, considerations were made regarding the temperature and area of the "Swastika kang" and their impact on indoor thermal comfort. Therefore, the simulation model for the kang does not consider its internal structure but focuses on its surface temperature and the area of the kang surface.

As the human body is typically seated or standing above the "Swastika kang," the main torso region is usually positioned at approximately 1.2 m above the indoor floor level. Therefore, the simulation experiments primarily investigate temperature and PMV variations at a height of 1.2 m above the floor, with the indoor ground level set as the zero-elevation reference. This plane effectively represents the thermal environment at the torso level when a person is either sitting on the kang or standing on the ground.

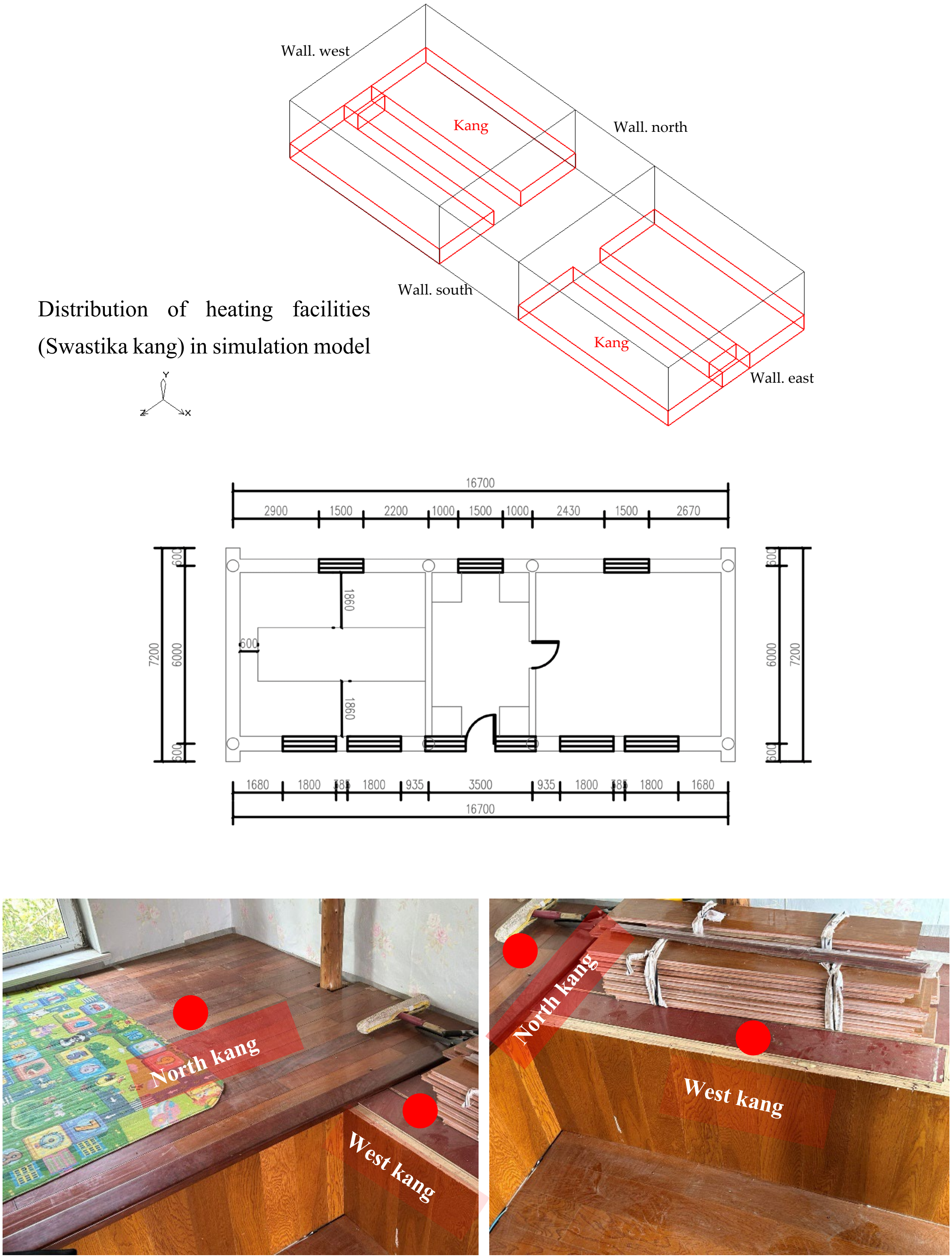

Figure 7. Building simulation model of Sibe house with Swastika kang for indoor space heating.

4. Results

4.1. External Wall Impact

Table 6 presents the simulation results for optimizing residential wall structures. Using 450 mm green bricks in the construction of traditional Sibe ethnic dwellings as the benchmark, the wall's heat transfer coefficient is 0.54, with a thermal inertia index of 16.981. Under these conditions, the proportion of time within the thermal comfort zone reaches 24.03%.

Table 6. Influence of external wall construction on indoor thermal comfort.

	Analogue Serial Number	Materials (From Outside to Inside)	Thicknesses (mm)	Heat Transfer Coefficient (k) $K = 1/(0.15 + \sum R)$ ($W/m^2 \cdot k$)	Thermal Inertia $D = R \times S$	Thermal Comfort Time Percentage
External wall	Standard	Brickyard	450	0.54	16.981	24.03%
	1	Brickyard	400	0.6	15.094	24.03%
		Brickyard	500	0.49	18.868	24.13%
	Total thickness of the wall remains the same, changing the wall construction					
	1	Brickyard (430 mm) Extruded polystyrene foam (with skin) (20 mm)	450	0.41	16.453	24.03%
		Extruded polystyrene foam (with skin) (20 mm), Brickyard (430 mm)	450	0.41	16.453	24.03%
	2	Brickyard (410 mm), Extruded polystyrene foam (with skin) (20 mm), lime mortar (20 mm)	450	0.42	15.944	24.03%
	Changing the total thickness of the wall					
	1	Brickyard (450 mm), Extruded polystyrene foam (with skin) (20 mm)	470	0.40	17.208	24.03%
	2	Brickyard (450 mm), Extruded polystyrene foam (with skin) (50 mm)	500	0.29	17.548	24.03%

Firstly, adjusting wall thickness:

- The wall thickness was increased and decreased by 50 mm to 500 mm and 400 mm, respectively. The overall heat transfer coefficients were 0.49 and 0.60, while the thermal inertia index was 18.868 and 15.094, respectively. Simulation results indicated that whether increasing or decreasing wall thickness, the proportion of time meeting the criteria for thermal comfort remained at 24.03%, similar to the baseline case.

Secondly, maintaining the total wall thickness but adjusting wall construction:

- Maintaining a constant wall thickness, adding 20 mm extruded polystyrene foam insulation for both interior and exterior walls resulted in overall heat transfer coefficients of 0.41 and 0.42, with thermal inertia indices of 16.453 and 15.944, respectively. At this point, the proportion of time meeting the criteria for thermal comfort remained at 24.03%.
- Maintaining a constant wall thickness, adding 20 mm extruded polystyrene foam and 20 mm lime mortar for external wall insulation led to a heat transfer coefficient of 0.42 and a thermal inertia index of 15.944. The results showed that the proportion of time meeting the criteria for thermal comfort remained at 24.03%.

Finally, altering the total wall thickness:

- By maintaining consistent insulation materials and thickness while increasing the total wall thickness, constructing interior and exterior walls with 450 mm bricks and 20 mm extruded polystyrene foam for the simulation, the overall heat transfer coefficients and thermal inertia indices reached 17.208. Under these conditions, the proportion of time meeting the criteria for thermal comfort remained at 24.03%.
- Adjusting wall thickness and increasing the insulation material thickness, with walls composed of 450 mm bricks and 50 mm extruded polystyrene foam, yielded a heat transfer coefficient of 0.29 and a thermal inertia index of 17.548. The results showed that the proportion of time meeting the criteria for thermal comfort remained at 24.03%.

According to the simulation results for the walls, neither changing the wall thickness, altering the insulation material, nor combining both approaches led to significant improvements in the indoor thermal environment. Therefore, in further optimization efforts, the impact of walls on the indoor thermal environment can be disregarded. This also highlights the wisdom embedded in the construction of traditional dwellings.

4.2. Roof Impact

Table 7 presents the optimized simulation results of residential roof structures. Taking the traditional roof structure of the Sibe ethnic group as the baseline, the structure comprises layers of 20 mm concrete tile, 20 mm lime mortar, 20 mm mixed clay (ρ = 1400), and 20 mm template, totalling 80 mm in thickness, with a heat transfer coefficient of 1.74 and a thermal inertia index of 1.301. At this stage, the proportion of time within the thermal comfort zone reaches 24.03%.

Table 7. Influence of roof construction on indoor thermal comfort.

	Analogue Serial Number	Materials (From Outside to Inside)	Thicknesses (mm)	Heat Transfer Coefficient (k) $K = 1/(0.15 + \sum R)$ ($W/m^2 \cdot k$)	Thermal Inertia $D = R \times S$	Thermal Comfort Time Percentage
	Standard	Concrete tiles (20 mm), Lime mortar (1) (20 mm), Grass-filled clay (ρ = 1400) (20 mm), Wooden boards (20 mm)	80	1.74	1.301	24.03%
	1	Concrete tiles (30 mm), Lime mortar (1) (30 mm), Grass-filled clay (ρ = 1400) (30 mm), Wooden boards (30 mm)	120	1.27	1.951	24.03%
	Changing the roof structure while keeping the total thickness of the roof structure unchanged					
Roof	1	Concrete tiles (20 mm), Aerated concrete, foam concrete (ρ = 700) (20 mm), Grass-filled clay (ρ = 1400) (20 mm), Wooden boards(20 mm)	80	1.51	1.399	24.14%
	2	Concrete tiles (20 mm), Lime mortar (1) (20 mm), Rigid-foam polyurethane sheet PUR (ρ ≥ 35) (20 mm), Wooden boards (20 mm)	80	0.73	4.612	24.03%
	Changing the total thickness of the roof and the thickness of the insulation					
	1	Concrete tiles (20 mm), Lime mortar (20 mm), Rigid-foam polyurethane sheet PUR (ρ ≥ 35) (1) (60 mm), Wooden boards (20 mm)	120	0.33	11.770	24.35%

Firstly, variations are made in the total roof thickness: All roof materials were increased by 10 mm, resulting in a total roof thickness of 120 mm, yielding a total heat transfer coefficient of 1.27 and a thermal inertia index of 1.951. Under these conditions, the proportion of time within the thermal comfort zone remained at 24.03%.

Secondly, while maintaining the roof thickness unchanged, adjustments were made to the roof structure to investigate its impact on the indoor thermal environment of the dwelling.

- With the total roof thickness unchanged and other roof materials held constant, the 20 mm lime mortar was replaced with the same thickness of aerated concrete and foam concrete (ρ = 700), resulting in a heat transfer coefficient of 1.51 and a thermal inertia index of 1.399. In this scenario, the proportion of time within the thermal comfort zone increased to 24.14%, an increment of 0.11% compared to the baseline roof structure.
- Maintaining the total roof structure thickness and other roof materials unchanged, the 20 mm mixed clay was replaced with 20 mm rigid polyurethane foam board PUR

(ρ ≥ 35), resulting in a heat transfer coefficient of 0.93 and a thermal inertia index of 4.612. Under these conditions, the proportion of time within the thermal comfort zone remained at 24.03%, consistent with the baseline roof structure.

Finally, adjustments were made to both the total roof thickness and the thickness of insulating materials. Keeping other roof materials constant, the 20 mm lime mortar was replaced with 60 mm rigid polyurethane foam board PUR (ρ ≥ 35), resulting in a heat transfer coefficient of 24.35% and a thermal inertia index of 11.770. Under these conditions, the proportion of time within the thermal comfort zone reached 24.35%, representing an increase of 0.32% compared to the baseline roof structure.

In conclusion, for traditional residential roofs, altering thickness has a minimal impact on enhancing thermal comfort, whereas adjusting the insulating materials in residential roofs significantly improves thermal comfort. Therefore, in further studies, it is recommended to improve the indoor thermal environment by adding insulation to the roofs.

4.3. External Window Impact

Table 8 presents the optimization of residential windows. Using the traditional window structure of the Sibe ethnic group as the baseline, consisting of wooden and plastic double-layered windows (double glass spacing of 100 to 140), with a heat transfer coefficient of 2.50, the proportion of indoor thermal comfort time is 24.03%.

- Replacing the window structure with 6 mm + LE35AMARL film glass, with a heat transfer coefficient of 4.60, resulted in a thermal comfort time ratio of 22.83%, representing a decrease of 1.2% compared to the baseline structure.
- Substituting the window structure with plastic + 6Low-E + 12A + 6 mm transparent hollow glass, with a heat transfer coefficient of 1.90, yielded a thermal comfort time ratio of 23.31%, exhibiting a decrease of 0.72% compared to the baseline structure.
- Changing the window structure to [5 mm + 9A (air) + 5 mm] nanometer-coated glass (HJ-N-series) + 9A (air) + 5 mm white glass (warm edge seal), with a heat transfer coefficient of 1.56, resulted in a thermal comfort time ratio of 24.09%, indicating an increase of 0.06% compared to the baseline structure.

Table 8. Influence of external window construction on indoor thermal comfort.

	Analogue Serial Number	Materials (From Outside to Inside)	Thicknesses (mm)	Heat Transfer Coefficient (k) $K = 1/(0.15 + \sum R)$ ($W/m^2 \cdot k$)	Thermal Inertia $D = R \times S$	Thermal Comfort Time Percentage
External wall	standard	Wooden, plastic-double-glazed windows (double-glazed spacing (100–140)		2.50		24.03%
	1	6 mm + LE35AMARL film glass		4.60		22.83%
	2	Plastic +6Low-E + 12A + 6 mm white transparent insulating glass		1.90		23.31%
	3	[5 mm + 9A (air) + 5 mm] nano-coated (HJ-N-series) + 9A (air) + 5 mm white glass (warm edge sealing)		1.56		24.09%

It is evident that altering the window structure has a minimal effect on enhancing indoor thermal comfort and might even diminish it. Furthermore, for rural residences, investing in superior window structures is economically unfavourable due to the relatively insignificant improvement in indoor thermal comfort. This reaffirms the wisdom behind traditional residential construction methods

Based on the previous analysis of the walls, roof, and windows of the dwelling, and taking into account the economic constraints in rural areas, optimizing the roof structure proves to be the most effective strategy for passively improving indoor thermal comfort in traditional Sibe ethnic dwellings through structural modifications. In this scenario, the roof structure comprises, from top to bottom, 20 mm concrete tiles, 20 mm lime mortar, 60 mm hard polyurethane foam board PUR ($\rho \geq 35$), and 20 mm templates.

Through the study of the building envelope, it is evident that even though traditional dwellings employ simple envelope structures and rudimentary materials, they provide excellent indoor insulation, effectively ensuring thermal comfort within the residence. This demonstrates the wisdom inherent in traditional construction practices. Consequently, the subsequent discussion will delve into enhancing indoor thermal comfort through the utilization of traditional construction-based active heating methods.

5. Discussion: Swastika Kang Heating Effect

5.1. Surface Temperature Impact

Figure 8 illustrates the location of the kang surface references in the experimental program. The blue area is the upper surface of the kang. Figure 9 illustrates the variation in temperature distribution at a height of 1.2 m above the floor as the upper surface temperature of the "Swastika kang" increases. Considering the placement of the Swastika kang in the eastern and western sections of the residence, which are the primary activity areas, our discussion primarily focuses on the impact of the Swastika kang on these two rooms, specifically emphasizing the temperature and PMV changes at a height of 1.2 m above the ground.

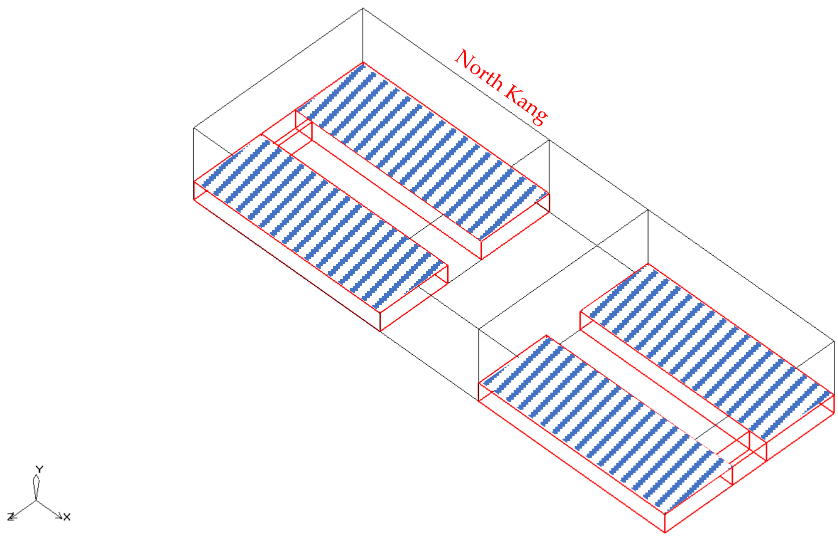

Figure 8. Schematic diagram of the upper surface of the kang.

Figure 9 shows the simulation of the temperature distribution in the plane at 1.2 m in the room under different kang surface temperature conditions, which clearly indicates the distribution of the temperature in the plane and provides support for exploring the temperature trend in Figure 10.

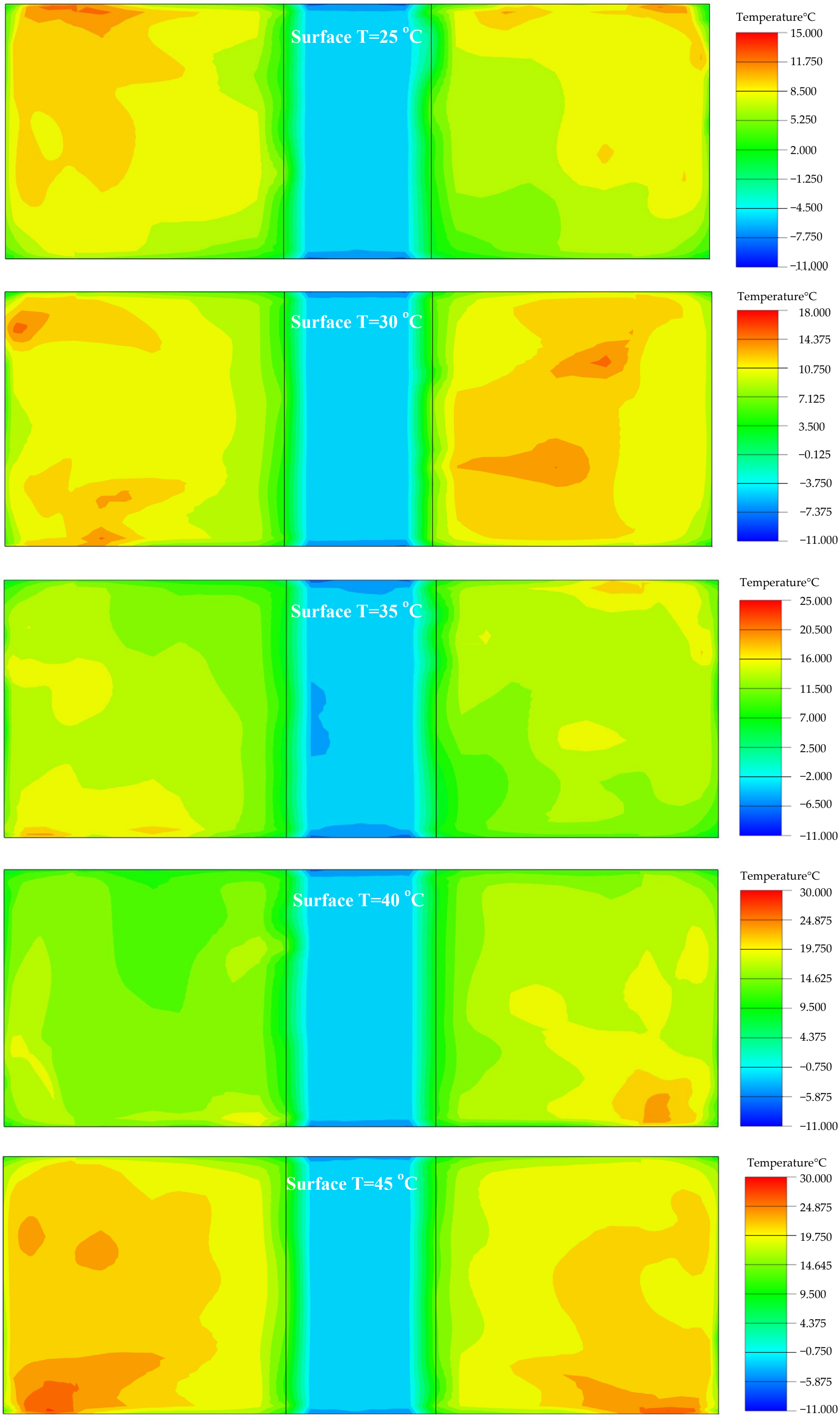

Figure 9. The influence of the surface temperature of the "Swastika kang" on the temperature distribution at a height of 1.2 m.

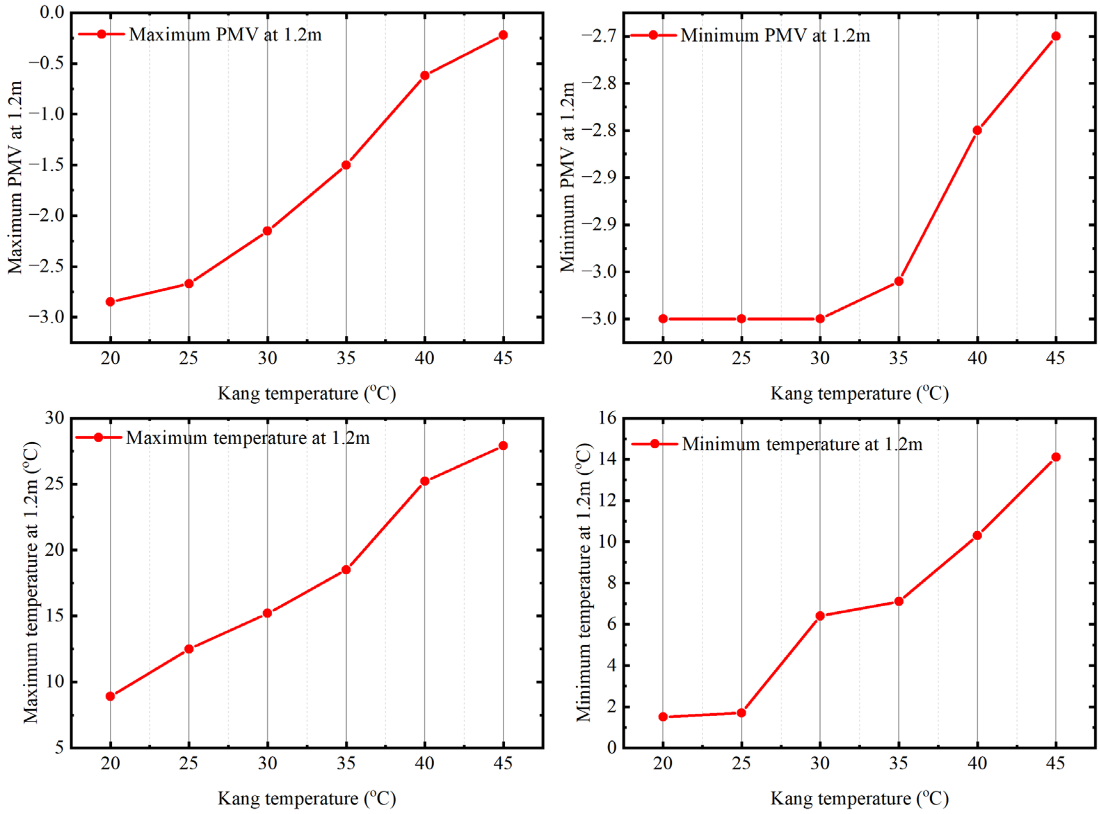

Figure 10. The influence of the upper surface temperature of the kang on the temperature distribution and PMV variations at a height of 1.2 m.

Initially, as the temperature increases, both the maximum and minimum indoor temperatures and PMV values demonstrate an upward trend. At a height of 1.2 m, the maximum temperature increases by 19 °C, rising from 8.9 °C to 27.9 °C, while the minimum temperature increases from 1.5 °C to 14.1 °C, marking a rise of 12.6 °C. The temperature variation between the maximum and minimum values amounts to 6.4 °C. Additionally, within the temperature range of 35 °C to 40 °C, there is a noticeable increase in the slope of both the maximum and minimum temperature values, whereas between 40 °C to 45 °C, the slope decelerates or remains stable, further confirming the conclusion that 40 °C serves as the optimal temperature for the Swastika kang surface.

Furthermore, concerning the indoor PMV, the trends in the maximum and minimum values at 1.2 m align closely with the temperature variations, displaying an upward trend. The maximum PMV at 1.2 m rises from −2.85 to −0.22, an increase of 2.63. Conversely, the minimum PMV within this plane increases marginally from −3 to −2.7, representing a rise of 0.3. In summary, with the elevation of the Swastika kang surface temperature, both the maximum temperature and PMV at a height of 1.2 m show a notable increase, whereas the rise in the minimum temperature and PMV remains relatively gradual.

5.2. Heating Area Impact

Considering that the main components of the "Swastika kang" include the north-south main kang and the west kang, this section separately discusses the impact of the areas of the north-south kang and the west kang on the indoor thermal environment, as shown in Figure 11.

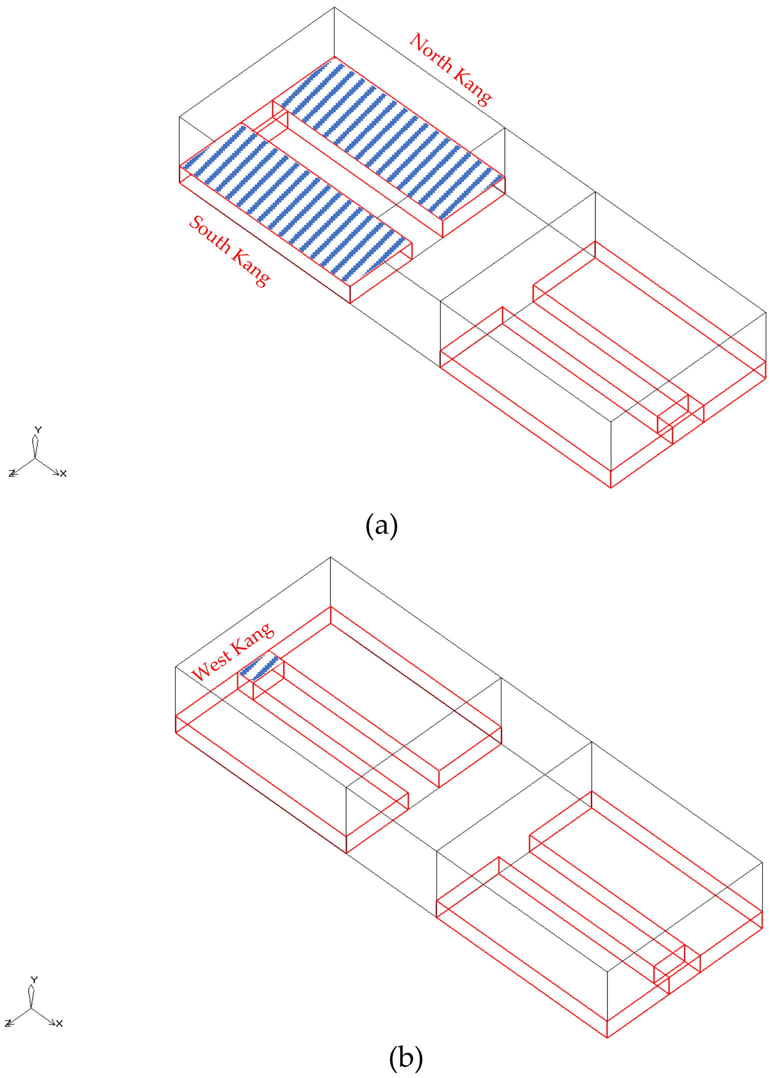

Figure 11. Schematic of the simulation strategy. (**a**) North-south kang. (**b**) West kang.

Figure 12a illustrates the impact of the surface area of the main north-south bed (the primary part of the Swastika kang) on the thermal comfort within the indoor space, focusing specifically on the temperature and PMV (Predicted Mean Vote) changes at a height of 1.2 m in the east-west rooms. As depicted in the graph, an increase in the bed's surface area results in an ascending trend in both the maximum and minimum temperatures at the 1.2-m height plane. The maximum temperature rises from 25.2 °C to 27.5 °C, marking a 2.3 °C increase, while the minimum temperature increases from 10.3 °C to 14 °C, representing a 3.7 °C rise. The range of change in the minimum temperature is 1.4 °C higher than that of the maximum temperature.

Regarding the PMV values at a height of 1.2-m, both the maximum and minimum PMV values also display an upward trend. The maximum PMV value elevates from −0.62 to −0.26, a rise of 0.36, while the minimum PMV value climbs from −2.8 to −2.2, showing a 0.6 increase. It is apparent from Figure 12a that the variations in temperature and PMV values at the 1.2-m height plane exhibit a relatively gradual trend. Therefore, the conclusion drawn is that enlarging the surface area of the main north-south bed contributes to improving indoor thermal comfort. However, the enhancement in thermal comfort within the indoor space due to the expanded bed area does not appear significant in comparison to the reduction in the available space for indoor activities.

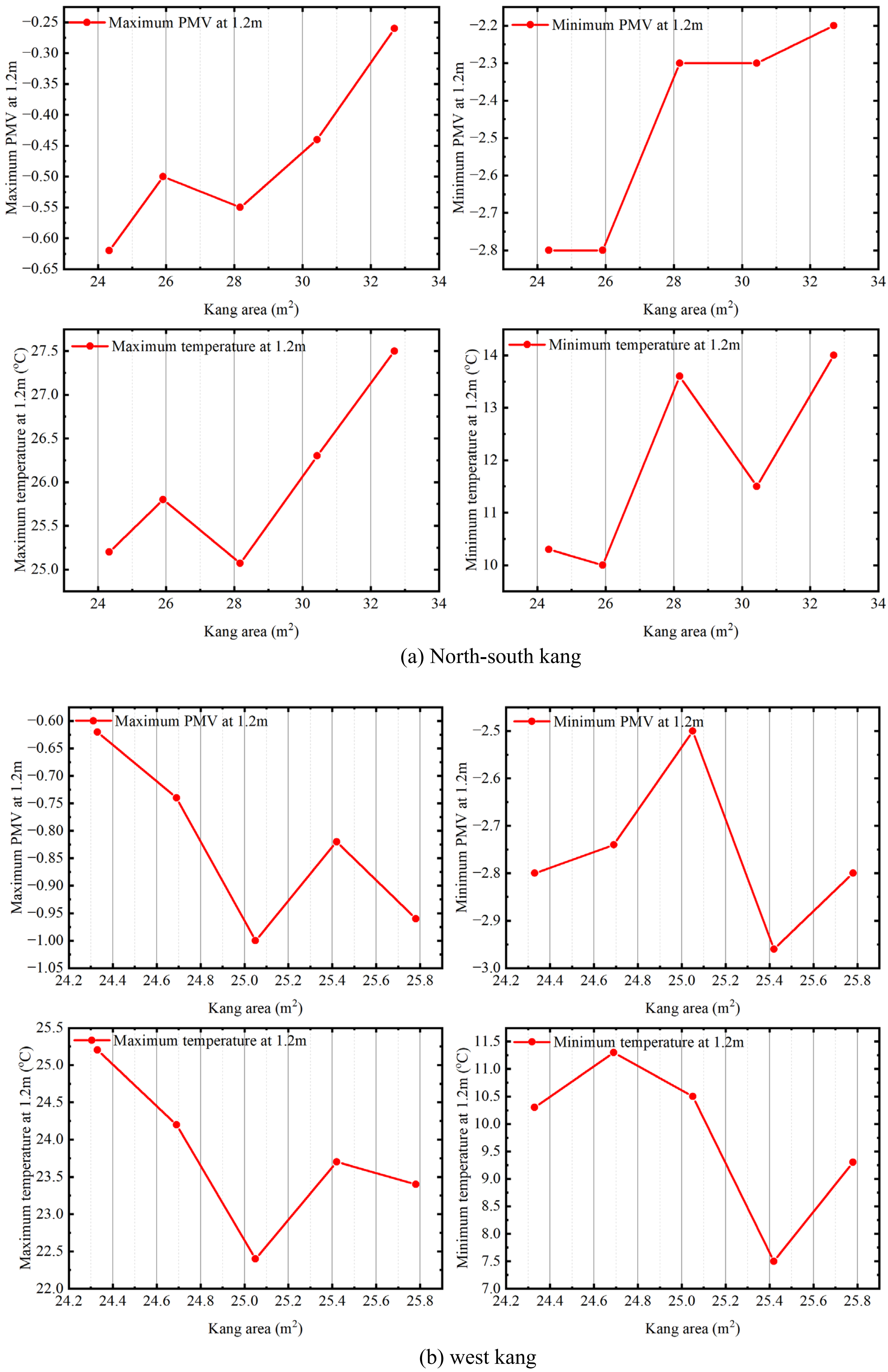

Figure 12. The influence of changes in the upper surface area at different locations of the kang on the changes in temperature and PMV at a height of 1.2 m.

When increasing the surface area of the west kang, Figure 12b illustrates the variation in indoor thermal comfort, considering the temperature and PMV changes at a height of 1.2 m of the east-west two-room configuration. As depicted in the graph, an increase in the surface area of the west kang leads to an unstable and relatively minor fluctuation in both the maximum and minimum values of temperature and PMV at a height of 1.2 m. Given the initially small size of the west kang, its impact on indoor thermal comfort appears relatively modest. Considering the traditional cultural context of the Sibe ethnic group, it can be inferred that the necessity of increasing the surface area of the west kang is not significantly substantial. It is clear that compared to the effect of changing the kang temperature on indoor thermal comfort, the effect of changing the kang area on indoor thermal comfort is smaller, so for the active heating device with traditional construction wisdom of the Sibe dwellings, the indoor thermal comfort can be further improved by raising the kang surface temperature.

6. Conclusions

Indoor thermal comfort and living environments have become increasingly prominent topics of concern. Scholars are dedicating more effort to enhancing indoor thermal comfort and proposing various methods and suggestions across different fields to improve living conditions. However, for traditional rural dwellings, advanced improvement methods are not always applicable due to factors like economic conditions and cultural traditions.

In the case of Sibe ethnic dwellings, economic factors significantly limit the enhancement of indoor thermal comfort. Through investigations, it was found that the Sibe employ passive strategy methods by reinforcing the thermal performance of structural enclosures. Additionally, they utilize traditional construction techniques to install active heating devices—known as “kang”—to combat harsh cold weather conditions. The introduction of these structural enclosures and “kang” has notably improved the indoor thermal comfort of their dwellings. Over time, “kang” has evolved into an indispensable heating facility in Sibe homes. This study focuses on two methods within Sibe dwellings—passive strategy and active heating—to enhance indoor thermal comfort, aiming to affirm traditional construction techniques while laying the groundwork for future research. The main conclusions of this paper are as follows:

1. Simulations of residential structural enclosures revealed that enhancing roof insulation had the most pronounced effect on indoor thermal comfort compared to improving wall or window insulation. However, simulations also indicated that despite continuous enhancements, the effectiveness of passive strategy methods on indoor thermal comfort within structural enclosures is limited and less applicable to Sibe dwellings.
2. The configuration of the traditional “kang” combined with the architectural layout of the Sibe residence is better suited for space heating
3. Regarding the simulation research on the active heating device—”kang”—it was found that raising “kang” temperature significantly improves indoor thermal comfort, while increasing the “kang” area has a comparatively small effect. Therefore, future improvement measures could emphasize temperature-related factors.

By analyzing the structural enclosures and active heating devices of traditional Sibe dwellings, this study explicitly acknowledges the traditional construction techniques of the Sibe, guiding the direction for enhancing indoor thermal comfort in Sibe dwellings. Moreover, the methods and approaches used in this research offer insights into addressing thermal comfort issues in traditional rural dwellings in other regions. However, this study specifically focuses on a particular type of dwelling influenced by geographical and cultural factors, gradually forming its present style. Other regions and distinctive rural dwellings are influenced by varying geographical and cultural factors, resulting in different construction techniques. Therefore, when studying traditional dwellings in other regions, these diverse influences need consideration. Additionally, this study only conducts preliminary research on structural enclosures and active heating devices without further extensive improvements. Hence, future research could start by enhancing active heating devices to better improve the indoor thermal environment of Sibe dwellings.

Author Contributions: Conceptualization, M.Z.; methodology, Z.S.; software, K.L.; writing—original draft preparation, M.Z.; writing—review and editing, K.X.; supervision, K.X.; funding acquisition, K.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was Supported by Sichuan Science and Technology Program, grant number 2025ZNSFSC1302 and Scientific research startup fund subsidy project for talent introduction, Southwest Minzu University, grant number RQD2022030.

Data Availability Statement: The raw climate data provided in the study are available on the XIHE-ENERGY.COM at https://www.xihe-energy.com, accessed on 25 February 2025. The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The authors declare no conflicts of interest.

Nomenclature

Nomenclature	**Definition**
Heat storage coefficient (S) W/(m^2·K)	The ability of a material to store heat is defined as its thermal capacity. The greater this value, the better the thermal stability of the material.
Heat transfer coefficient W/(m^2·K)	Under steady-state heat transfer conditions, it refers to the amount of heat transferred per unit time through a unit area of a building envelope when there is a temperature difference of 1 degree (K or °C) between the air on either side.
Kang	In northern China, a kang is a sleeping platform constructed from bricks or adobe, featuring hollow spaces underneath that are connected to a chimney. It can be heated by burning fuel, providing warmth for sleeping and living areas.
Resistance (R) (m^2·K/W)	When heat is transferred through an object, the ratio between the temperature difference across the object and the power of the heat source is defined as the thermal resistance.
"Swastika kang"	In the bedroom, a continuous kang is built along the north and south walls, with a narrower kang constructed on the west side. In some cases, the west kang is of the same width as the south and north kangs, connecting with them to form a "π"-shaped structure. The chimney extends through the wall to the outside.
Thermal conductivity (λ) W/(m·K)	The measure of a material's ability to conduct heat.
Thermal inertia	The thermal inertia index is a measure of how quickly temperature fluctuations on one side of an object's surface attenuate within the object when subjected to periodic thermal effects.

References

1. Zhao, H.; Jiang, Y. Research on Strategies for Improving Rural Human Settlements in the Context of Rural Revitalization—A Case Study of Zhejiang Province. *Small Town Constr.* **2019**, *37*, 9–14+93. (In Chinese)
2. Ma, B. Research on Energy-Saving Design Solutions for Rural Houses in Northern China from the Perspective of Rural Revitalization. Master's Thesis, North China University of Science and Technology, Tangshan, China, 2021. (In Chinese)
3. Bao, C.; Zhang, C.; Bi, L. Research on Optimization Strategies for Indoor Thermal Comfort in Rural Houses in Severe Cold Regions. *Archit. Cult.* **2023**, 26–27. (In Chinese) [CrossRef]
4. Hou, J. Research on Optimization of Indoor Thermal Environment in Traditional Tibetan Dwellings on the Northwest Sichuan Plateau during Winter. Master's Thesis, Sichuan Agricultural University, Ya'an, China, 2019. (In Chinese)
5. Kaynakli, O.; Kilic, M. Investigation of Indoor Thermal Comfort under Transient Conditions. *Build. Environ.* **2005**, *40*, 165–174. [CrossRef]
6. Cheng, C.; Deng, X.; Zhao, X.; Xiong, Y.; Zhang, Y. Multi-Occupant Dynamic Thermal Comfort Monitoring Robot System. *Build. Environ.* **2023**, *234*, 110137. [CrossRef]
7. Ma, K.; Yu, Y.; Yang, B.; Yang, J. Demand-Side Energy Management Considering Price Oscillations for Residential Building Heating and Ventilation Systems. *IEEE Trans. Ind. Inform.* **2019**, *15*, 4742–4752. [CrossRef]
8. Deng, X.; Zhang, Y.; Zhang, Y.; Qi, H. Toward Smart Multizone HVAC Control by Combining Context-Aware System and Deep Reinforcement Learning. *IEEE Internet Things J.* **2022**, *9*, 21010–21024. [CrossRef]
9. Wang, X.; Mai, X.; Lei, B.; Bi, H.; Zhao, B.; Mao, G. Collaborative Optimization between Passive Design Measures and Active Heating Systems for Building Heating in Qinghai-Tibet Plateau of China. *Renew. Energy* **2020**, *147*, 683–694. [CrossRef]
10. Li, X.; Shen, C.; Yu, C.W.F. Building Energy Efficiency: Passive Technology or Active Technology? *Indoor Built Environ.* **2017**, *26*, 729–732. [CrossRef]
11. Imbabi, M.S.-E. A Passive–Active Dynamic Insulation System for All Climates. *Int. J. Sustain. Built Environ.* **2012**, *1*, 247–258. [CrossRef]
12. Liu, J. Research on Optimization Strategies for Traditional Dwellings in Jia County Based on Thermal Comfort Improvement. Master's Thesis, Zhengzhou University, Zhengzhou, China, 2022. (In Chinese)
13. Wei, D.; Zhao, G.; Liu, S.; Yang, L. Indoor Thermal Comfort in a Rural Dwelling in Southwest China. *Front. Public Health* **2022**, *10*, 1029390. [CrossRef]
14. Wang, Y.; Dong, Q.; Guo, H.; Yin, L.; Gao, W.; Yao, W.; Sun, L. Indoor Thermal Comfort Evaluation of Traditional Dwellings in Cold Region of China: A Case Study in Guangfu Ancient City. *Energy Build.* **2023**, *288*, 113028. [CrossRef]
15. He, Q.; Liu, D.; Zhu, X.; Yang, L.; Liu, J. Field Study on Indoor Thermal Environment of Tibetan Dwellings in the Western Sichuan Plateau. *J. Xi'an Univ. Archit. Technol. Nat. Sci. Ed.* **2015**, *47*, 402–406. (In Chinese) [CrossRef]
16. Zhang, C.; Pomianowski, M.; Heiselberg, P.K.; Yu, T. A Review of Integrated Radiant Heating/Cooling with Ventilation Systems-Thermal Comfort and Indoor Air Quality. *Energy Build.* **2020**, *223*, 110094. [CrossRef]
17. Minglu, Q.; Liang, X.; Deng, S.; Yiqiang, J. Improved Indoor Thermal Comfort during Defrost with a Novel Reverse-Cycle Defrosting Method for Air Source Heat Pumps. *Build. Environ.* **2010**, *45*, 2354–2361. [CrossRef]
18. Myhren, J.A.; Holmberg, S. Flow Patterns and Thermal Comfort in a Room with Panel, Floor and Wall Heating. *Energy Build.* **2008**, *40*, 524–536. [CrossRef]
19. Zhuang, Z.; Li, Y.; Chen, B.; Guo, J. Chinese Kang as a Domestic Heating System in Rural Northern China—A Review. *Energy Build.* **2009**, *41*, 111–119. [CrossRef]
20. Yu, K.; Tan, Y.; Zhang, T.; Zhang, J.; Wang, X. The Traditional Chinese Kang and Its Improvement: A Review. *Energy Build.* **2020**, *218*, 110051. [CrossRef]
21. Wei, L. Research on the Cultural Value of the Manchu "Swastika Kang". Master's Thesis, Jilin University of Arts, Changchun, China, 2022. (In Chinese)
22. Zhang, Q. Simulation Analysis of Flow and Heat Transfer of Flue Gas in Traditional Kang of Northeast China. Master's Thesis, Harbin Institute of Technology, Harbin, China, 2017. (In Chinese)
23. Liu, Y.; Gu, Y.; Li, Y. Comparative Analysis of Energy-Saving Design between Ground Kang and Elevated Kang in Rural Houses in Northeast China. *J. Anhui Agric. Sci.* **2014**, *42*, 4326–4328. (In Chinese) [CrossRef]
24. *GB 50352-2019*; Uniform Standard for Design of Civil Buildings. Ministry of Housing and Urban-Rural Development of the People's Republic of China: Beijing, China, 2019. (In Chinese)
25. Xiao, H.; Jiang, N. Investigation and Conservation Strategies for the Living Environment of Traditional Xibo Ethnic Villages—A Case Study of Shifosi Village, Shenbei New District, Shenyang, Liaoning Province. *Urban Hous.* **2020**, *27*, 98–102. (In Chinese)
26. Lin, H.; Wang, J.-B.; Zhang, X.; Hu, F.; Liu, J.; Hong, X.-C. Historical Sensing: The Spatial Pattern of Soundscape Occurrences Recorded in Poems between the Tang and the Qing Dynasties amid Urbanization. *Humanit. Soc. Sci. Commun.* **2024**, *11*, 730. [CrossRef]

27. *GB 50176-2016*; Code for Thermal Design of Civil Buildings. Ministry of Housing and Urban-Rural Development of the People's Republic of China: Beijing, China, 2016. (In Chinese)
28. Wang, Y.; Zhang, X.; Zhang, H. Thermal Comfort Analysis of Loader Cab Based on PMV-PPD. *J. Taiyuan Univ. Sci. Technol.* **2024**, *45*, 38–43. (In Chinese)
29. *GB/T 50785-2012*; Evaluation Standard for Indoor Thermal Environment in Civil Buildings. Ministry of Housing and Urban-Rural Development of the People's Republic of China: Beijing, China, 2012. (In Chinese)
30. Yao, R.; Li, B.; Liu, J. A Theoretical Adaptive Model of Thermal Comfort—Adaptive Predicted Mean Vote (aPMV). *Build. Environ.* **2009**, *44*, 2089–2096. [CrossRef]
31. Shi, J. Research on the Interpretation of the Character "Kang" and the Development Process and Origin of Kang. *Pop. Art Lit.* **2016**, *266*. (In Chinese)