DOCTORAL DISSERTATION

Research on winter energy-saving design of traditional residential buildings in southern Shaanxi of China

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Abstract

As one of the most common sources of energy in today's society, solar energy has the advantages of being green, renewable, and energy efficient. The combination of solar energy and buildings can greatly save energy, and a great deal of practical and theoretical research has been conducted on solar buildings around the world. Rural areas in southern Shaanxi, China, have wet and cold winters. The average room temperature is 4°C and below 2°C at night, which greatly exceeds the range of thermal comfort that the human body can tolerate. In response to a series of problems such as backward heating methods and low heating efficiency in southern Shaanxi, two fully passive heating methods are proposed for traditional houses in the region. the first one is a rooftop solar heating and thermal storage system, which works by transforming the opaque roof of traditional houses into a transparent glass roof and installing thermal insulation and heat storage material HDPE on the attic floor. the system works by increasing the amount of indoor solar radiation and thus increasing the indoor temperature and extending the indoor heating time by using the thermal insulation property of the thermal storage material. The heat transfer process, heat transfer mode, and temperature change of the system are analyzed by software simulation, and the energy-saving effect of the system is analyzed. The system can effectively improve indoor temperature and has good energy-saving performance. The indoor temperature is increased by 5.8℃, and the annual heat load of the building is reduced by 1361.92kWh, with a reduced rate of 25.02%. The second type is the thermal storage wall heating system (TSWHS). The specific method is to set up heat storage walls outside the exterior walls of the east, west, and south sides of the residential building. The body is equipped with air exchange ports, and there is no glass on the outside of the doors and windows, which does not affect the normal application. The principle is that after the thermal storage wall receives solar radiation, the temperature of the air inside the internal HDPE (high-density polyethylene) and cavity rises, and through a heat transfer and the air exchange port inside the thermal storage wall, the indoor temperature rises. The hot air in and inside the heat storage wall achieves the heating purpose. Finally, the practicality of the new system is confirmed by comparison with OHS. Through experimental simulations, the system can raise the indoor temperature by an average of 5.3°C in winter and save energy by about 1726.43 kWh, accounting for 27.24% of energy savings.

Keywords: Hot-summer and cold-winter regions; Residential buildings; Thermal storage roof pool heating system; Thermal storage wall heating system (TSWHS); HDPE; Energy efficiency

Contents

List of Figures

List of Tables

List of Nomenclature

1. Window-to-Wall Ratio (WWR)
2. Hot Summer and Cold Winter Regions (HSCW)
3. Expanded Polystyrene Board (EPS)
4. Extruded Polystyrene Board (XPS)
5. Tons of Standard Coal Equivalent (TCE)
6. Predicted Mean Vote (PMV)
7. Predicted Percentage of Dissatisfied People (PPD)
8. Design of Experiments (DOE)
9. Phase Change Materials (PCMs)
10. High-Density Polyethylene (HDPE)
11. Wall Solar Radiation (WSR)
12. Thermal Storage Wall (TSW)
13. Thermal Storage Wall Heating System (TSWHS)
14. Original Heating System (OHS)

Chapter 1. Introduction

1.1 Research Background

The building is an important carrier of social and economic development and an important place for human production and life. The process of human construction, use, and demolition of buildings will consume a large amount of energy and resources, especially in recent years, the total economic volume of China continues to increase, people's living standards gradually improve, the proportion of building energy consumption in the total consumption of energy in China shows a trend of increasing year by year [1]. Although China has huge reserves and stocks of energy and resources, the large population base has led to insufficient per capita possession, and for the construction industry, the crude way of producing construction works cannot adapt to the national situation of insufficient resources per capita, so dealing with the relationship between construction works and resource and energy consumption has become the primary task of industry development. The rapid development of China's economy after more than 30 years has brought about compressed and compound environmental problems that are becoming more and more serious, such as the complete combustion of coal in fossil fuels into CO_2 into the atmosphere leading to the intensification of the greenhouse effect [3]. At present, vigorously developing renewable energy is one of the important measures to enhance energy security, reduce greenhouse gas emissions, adjust energy structure, improve the ecological environment, and narrow the gap between the rich and the poor in urban and rural areas [4]. Therefore, the state strongly advocates the development of new energy and the development of clean new energy is an effective way to mitigate the socioeconomic development and energy crisis. As China's modernization and urban scale continue to expand, the proportion of energy consumption in buildings is also increasing, and high energy-consuming buildings account for more than 90% of all buildings, and the energy consumption per unit area for heating is more than three times that of developed countries [5]. The problem of building energy consumption in new rural areas is becoming more and more significant in China's urbanization process, which has intensified the trend of energy demand tension, and the research and promotion of building energy efficiency are mainly concentrated in urban areas, and the application of building energy efficiency technology in rural areas has not been properly promoted, according to the survey, the population in rural areas of China is mostly, the area of rural houses is much larger than the area of houses in urban areas, and the area of rural houses in the whole building accounts for This has led to large energy consumption in rural areas in China [6]. In the building, energy consumption structure, heating, and heating energy use account for about 45%, so reducing heat loss in heating and heating systems and improving the heat utilization rate of solar heating systems have become key issues for research. Solar energy is a kind of renewable energy, solar energy has the characteristics of being clean and non-polluting, inexhaustible, China has abundant solar energy resources, the annual sunshine hours exceed 2200h, 2/3 of the total annual solar radiation is greater than 5020 MJ, according to the size of solar radiation can be divided into five categories of China's solar energy resources, especially in the northwest in the solar energy resources rich in a class of areas and In particular, the northwest region is in the first and second class areas rich in solar energy resources, solar energy has great potential and research value (Figure1-1).

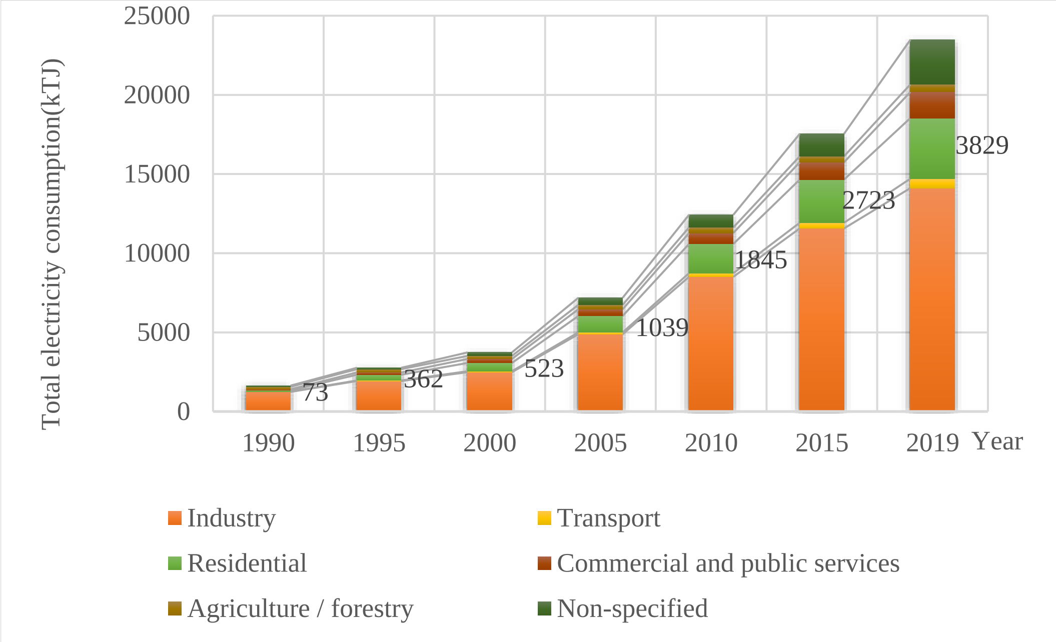

Figure 1-1. Electricity consumption by industry in China from 1990 to 2019

The climate of Northwest China is characterized by long winters, low temperatures, large temperature differences between day and night, and long heating periods in winter. The traditional heating method in rural areas of Northwest China is mainly coal, and the large consumption of coal resources causes serious environmental pollution. This makes the heating in the region face great difficulties, so it is especially important to improve the living conditions in the new rural areas and solve the problem of energy consumption while improving the living standards of the residents and developing clean energy. We can make use of the abundant solar energy resources in Northwest China to popularize and promote the application of solar energy in new rural areas, using solar energy and other energy sources for heating. Based on the preliminary research, a solar heating system for a single building is constructed based on the climatic conditions of the northwest region, and through a comparative analysis of solar low-temperature radiant floor heating and radiator heating, it is concluded that solar low-temperature radiant floor heating has certain superiority, and the heat utilization status of the solar low-temperature radiant floor heating system is analyzed, and optimization measures are proposed to optimize the system. The economics of the system after optimization is analyzed. It is of positive significance to improve the energy utilization rate, improve the energy consumption structure of new rural buildings, solve the problems of energy scarcity and environmental pollution, and improve the living environment of residents (Figure 1-2).

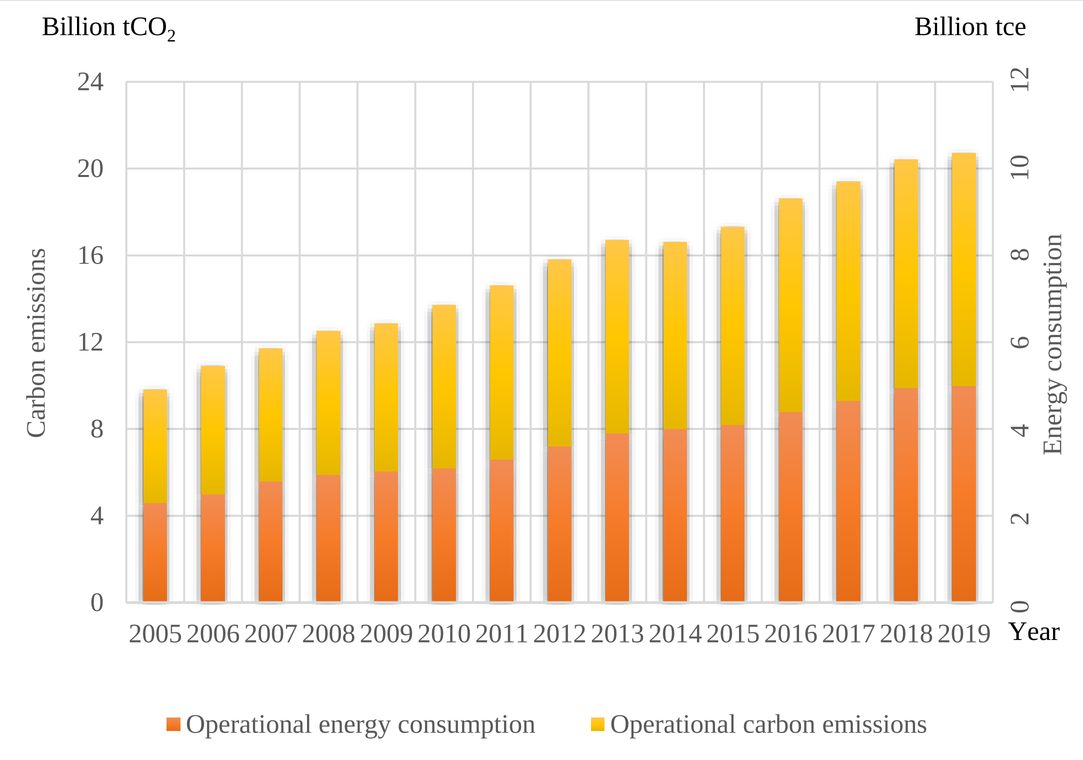

Figure 1-2. The proportion of energy consumption for different building types

At present, under the promotion of the top-level design of national green development and energy-saving technology standards, energy-saving technology is developing rapidly, and the concept of green development has gradually become popular, and energy-saving buildings have become a trend. In today's energy problems and increasingly severe environmental situations, solar energy, as a clean energy source, provides a new idea for green development in the building industry. The western region of China, living deep in the interior of the country, has a relatively fragile ecological environment, relatively harsh climatic conditions, and relatively lagging economic development, and in terms of building characteristics, the rural building envelope in this region has poor thermal performance, high heating energy consumption, and low indoor thermal environment quality [2]. With the introduction of the concept of new urbanization and the deepening of the concept of ecological architecture, the study of solar architecture in the western region has become one of the hot issues of concern for experts and scholars in the academic field. From the perspective of geographical factors, the region accounts for more than 70% of China's land area, while the population accounts for less than 30%, which is typical of "vast land and sparse people"; from the perspective of resource factors, the region has sufficient solar energy resources, long sunshine hours throughout the year, and large solar radiation. The development of passive solar heating buildings in the region by local conditions will play a positive role in solving the contradiction between the poor indoor thermal environment of buildings in the region and between heating energy use and ecological protection. With the deepening of climate change research, all countries in the world are actively reducing carbon emissions. As the second largest economy in the world, China is responsible for a huge CO_2 reduction task every year according to the international climate change convention, and construction activities are one of the main human activities that cause the increase of CO_2 concentration in the atmosphere. The IPCC report calculated that the construction industry consumes 40% of the global energy and emits 36% of CO_2 [3]. In the past decades, the annual growth rate of carbon emissions from construction projects has been almost the same as the global carbon emissions growth rate, which is about 2%, with 2.7% for commercial buildings and 1.7% for residential buildings; in terms of the global growth rate of commercial buildings, the fastest annual growth rate of carbon emissions is for commercial buildings in developing countries, reaching about 30%, followed by North America and APEC countries.

1.2 Literature Review

Many scholars around the world have conducted many theoretical studies and social practices on building energy efficiency, and have achieved many fruitful results, which also promote the rapid development of the industry. The overall research is broadly divided into three areas, solar energy, passive heating, and energy-efficient building design.

First, the study on solar energy is shown below. Zhoujun Wang has conducted a novel study on the coupling of solar and thermal energy. Here, the definition and principle of solar-thermal energy coupling are clarified, and the reduction of CO_2 emissions by coupling solar and thermal energy [1]. M. Mofijur presented the application of PCM for solar energy use and storage for power generation, water heating, drying, etc. [2]. Rebecca R. Hernandez examines the strategic engineering of solar technologies and provides a conceptual model and framework to describe 16 solar Tess and describes 20 potential technology-ecology synergy outcomes for their use [3]. Amir Shahsavari suggests that the use of solar energy as an energy source can reduce the world's use of fossil fuels and reduce CO_2 emissions, noting that it is particularly important in developing countries [4].Wei Li investigated the core-shell structured titanium dioxide nanomaterials for solar energy utilization and confirmed that they can save energy and reduce emissions and have good prospects for use [5]. Guruprasad Alva has studied the application of thermal energy storage (TES) facilities in the field of solar energy and concluded that they can be used for power generation and home space heating needs [6]. Derong Liu investigates variable weather solar residential energy scheduling and proposes an action-based heuristic dynamic planning (ADHDP) approach to solve the problem, and simulation results show that the scheduling approach effectively reduces the total cost of electricity and improves the load balancing process. Ammar H. Elsheikh investigates artificial neural networks (ANN) as an action-based intelligent system approach to optimize and predict the performance of different SE devices is applied and presents important conclusions and recommendations for future research [7].Huawei Chan presents a miniature CCHP system based on solar energy and high-temperature proton exchange membrane fuel cells. The performance analysis of the model shows that the current density and solar radiation intensity can significantly affect thermal, economic, and environmental performance, while the operating temperature and ambient temperature only have a significant effect on thermal performance [8]. Xiuqiang Li proposed a dual-mode device with electrostatically controlled thermal contact conductivity, and building energy simulations showed that our dual-mode device could save 19.2% of heating and cooling energy if deployed widely in the United States [9]. Gorazd Krese takes a look at thermochemical thermal storage technologies and systems, focusing on systems involved in solar energy utilization in buildings. These studies are based on the storage materials used, system configurations, and models reviewed to predict and optimize system performance [10]. Janar Kalder presents a solution for storing solar thermal energy in summer and a thermal energy balance calculation for such a storage system. The calculations are based on solar radiation measurements and heating demand data from sample houses. Seasonal storage of solar thermal energy can increase the use of solar thermal energy and reduce the working time of heat pumps [11]. NS Suresh presents a method to estimate the potential for solar collector integration for process heating. The method uses the process operating temperature to select the type of solar collector [12]. Raimonda Soloha has studied the use of solar energy in district heating systems using buildings in Latvia as a case study. It was concluded that the seasonal use of TES tanks also allows the solar fraction to increase to 50% or more [13]. A. Jamar discusses the latest developments and advances in solar water heating based on the three basic components that may affect the thermal performance of the system. Among the non-concentrating and concentrating collectors, the parabolic reflector collector has the best overall performance [14]. Abdulrahman Dahash has studied the progress of seasonal thermal storage technology for solar district heating applications, analyzed by large-scale TES modeling, and proposed modifications for large hot water tanks and pit thermal storage systems [15]. Man Wang proposed a multi-objective optimization of solar-driven combined cooling, heating, and power (CCHP) systems. The results show that multi-objective optimization provides a more comprehensive set of solutions so that the best performance can be achieved according to the different requirements of the system [16]. Enrico and Carpaneto studied the optimal integration of solar energy in district heating networks, concluding that the implementation can highlight the advantages of solar inputs, especially in mid-season and summer to reduce management costs [17]. Bram van der Heijde investigates the cross-comparison of genetic design optimization algorithms for solar district heating systems with seasonal thermal energy storage, using different representative days. An additional optimization problem chooses the set of representative days and then optimizes the ordering of the representative days in order to reorder the set to a full year as well [18]. Fatih Ünal conducted an experimental analysis of a solar-assisted VGSHP system designed to meet the heating needs of a laboratory during the heating season. The energy efficiency, fire use efficiency and fire use economy factors for the whole system were 67.36%, 27.40% and 60.51%, respectively [19]. ManolisSouliotis' study of two innovative solar water heating systems integrated into the facades and roofs of social housing buildings. The results of the study showed that the building's energy demand for space heating and cooling was reduced by about 10%, while hot water and electricity demand reached 80% and 50%, respectively [20]. Victor Tulus presents a systematic approach to optimizing these systems according to economic and environmental criteria. The results show that the CSHPSS plant offers significant environmental and economic improvements compared to the use of conventional natural gas heating systems [21]. Claes G. Granqvist examines solar thermal converters, transparent insulators, and devices for radiative cooling through exposure to clear skies, providing a map of applications for various materials that are increasingly important [22]. Benoît Stutz studied different types of solar thermal energy storage for low temperature (40-120°C) and medium to high temperature (120-1000°C) applications, ultimately proposing energy saving measures [23].

There are some studies on passive heating around the world as follows. Benjamin Duraković discusses the classification and working principles of passive heating/cooling technologies, the need to select the right passive heating/cooling technology, the need to consider the different factors discussed in the previous paragraphs, and a summary of recent research advances [24]. Evangelos Bellos proposed an innovative Trombe wall with an additional window in the huge wall. The results show that the new Trombe wall is the most suitable technique to create a warmer interior silhouette than in other cases, especially between midday and afternoon hours [25]. Biao Sun developed a methodology combining stochastic dynamic programming (DP) and rollout techniques within a price-based coordination framework to obtain an efficient and integrated strategy for energy use promptly. Simulation results show that these strategies are scalable and can be effective in reducing energy costs and improving human comfort [26]. Ayyoob Sharifi reviews the literature on the use of rooftop pools for passive heating and cooling of buildings. The main objective is to provide a detailed understanding of different rooftop pool configurations and their performance, ultimately suggesting that future research should provide more detailed knowledge on the performance of all rooftop pool variants and further explore the applicability of rooftop pools relative to other passive design measures [27]. Marwa Dabaieh describes a design solution for an advanced passive refugee house with a suitable climate for Sweden. Preliminary feasibility costing shows a payback period of 7.4 years over the 25-year recommended service life using these three passive solutions [28]. Xiaoliang Wang proposes a collaborative optimal design method (CODM) to optimize the heating cost and energy consumption throughout the building life cycle. The results show that the optimal total heating cost and total heating energy consumption of building heating can be reduced by 1948 Yuan/m^2 and 2292 kW h/m^2 compared to the initial design [29]. Anh-Tuan Nguyen investigated the potential for improving thermal comfort through passive strategies in the Vietnamese climate. Simulations show that natural ventilation is an effective cooling solution, as the increase in thermal comfort varies with climate zone, from 24.8% in Hanoi and 22.1% in Da Nang to 32.0% in Ho Chi Minh City [30]. Zhijian Liu analyzed the effect of building envelope performance on indoor air temperature based on IES-VE numerical simulation. The results show that the building retrofit can reduce coal consumption by 97 kg/week during the heating period and increase the average indoor temperature of two bedrooms by 4.8℃ and 1.7℃, respectively [31]. Ivan Oropeza-Perez studied a home in Mexico City with the thermal simulation program EnergyPlus and showed that the correct use of these driving characteristics may achieve significant temperature drops in cooling and significant room temperature increases in heating [32]. Z.Y. Zeng summarized the advanced technologies in ATB and presented the future vision of space heating applications. A passive solar heating system with day and night operation, zero power consumption, and controllable thermal comfort is conceived [33]. Bumsoo Park designs and validates model-free data-driven reinforcement learning methods by comparing table Q-learning and policy gradient algorithms for passive heating and cooling. The strategy reduces the load by 13-64% compared to traditional rule-based control [34]. Fang'aiChi's proposed passive system can operate in sunny and rainy weather conditions without an energy supply through air movement driven by a solar chimney and hydraulically driven ventilators. (According to numerical simulations, the total annual energy saving of the new building is 5523.42 kWh compared to the base case) [35]. Weishu Wang proposed a novel passive heating design approach, On-top Sunspace, to solve the rural heating problem in the harsh cold regions of northern China. The results show that the lowest building energy consumption can be achieved when the roof angle is 28° and the glass-to-roof ratios of the front and rear roofs are 0.5 and 0.6, respectively [36]. Yanfeng Liu compares the effectiveness of indoor thermal environments and the ability to reduce thermal loads of different passive solar technologies by modeling between direct gain windows, Trombe walls, and attached sunlit spaces. The analysis shows that residential buildings have higher Trombe wall-to-wall ratio limits and more significant energy savings potential than office buildings [37]. Giacomo Cillari provides a comprehensive understanding of the elements that influence passive solar systems by analyzing the theoretical background and the synergistic design of the various solutions available. The case study shows that nearly 20% of a building's energy needs can be saved by passive solar systems [38]. Neha Gupta analyzed the passive solar heating and cooling concepts and their impact on the thermal management performance of buildings, according to the study, direct heating through double-glazed windows can maximize the savings of conventional fuel for winter heating [39]. Paula Marin has researched phase change materials, which figure to support the application of PCM technology in lightweight portable buildings as a passive alternative for energy savings in varying weather conditions [40]. Ran Wang developed a model for predicting the passive performance of future buildings considering multidimensional variables, including climate change, building design, and operational characteristics. For similar buildings located in the same climate zone, the thermal design solution determines the growth rate of cooling demand [41]. J. Balcomb investigates the passive solar heating experience, particularly in the United States. Design approaches are reviewed and examples are shown. Los Alamo's procedures for performance simulation and evaluation are described, and a simplified approach to performance estimation is outlined [42]. Yanfeng Liu investigated the indoor temperatures of three different passive solar technologies. The operating modes and functional requirements are different in the schools analyzed and allow the use of validated models to determine the best type of passive solar technology [43]. Luka Pajek investigated the relevance of selected passive design measures for heating and cooling energy use in single-family detached buildings in five European locations. Statistical analysis shows that the importance of passive design measures will change under the expected global warming impact [44]. Alexandra R. Rempel's study of passive heating that reduces the thermal load of space heating in buildings reveals the scale of passive space conditioning resources in this energy-intensive region and demonstrates the power of simple, effective operational strategies in achieving substantial energy savings [45]. Waqas Ahmed Mahar conducted a global sensitivity analysis of the effect of passive design parameters on adaptive comfort in a cold semi-arid climate. This study provides evidence-based and informed design recommendations that can be used for architects and homeowners to integrate passive design measures at the earliest conceptual design stage for cold semi-arid climates [46]. Shambalid Ahady modeled and simulated building energy to evaluate the effect of different shading and orientation on energy performance. The study highlights the broad scope of research to customize building design to Afghan climatic conditions and other developing countries, thereby contributing to building sustainability [47]. Lazaros Aresti , P. Christodoulides studied the use of foundation concrete as a storage material in a new building and the results showed that the chosen system provides comfort for the occupants in winter under the regional climatic conditions considered here [48]. Muhammad Wasim Anwar studied two scenarios of passive climate change adaptation measures (PCAM) used individually or in combination to analyze their impact on the energy efficiency of residential buildings in Pakistan [49]. Sahar Zahiri conducted a series of field studies and building simulation analyses to improve the thermal performance of a female secondary school building in Tehran, Iran, during winter using passive design strategies. The simulation results show that building fabrics and thermal performance, as well as glazing and orientation, have a significant impact on indoor air temperature and thermal comfort [50]. Alexandra Rempel investigates the application of passive solar heating, shading and natural ventilation in old renovation projects, where passive solar collection and storage can meet more than half of the heating needs through optimal control [51]. M. Krzaczek implemented a new fuzzy hybrid gain scheduling strategy based on the idea of the local modal fuzzy mixing weighting of the values of certain automatically designed control parameters. Experiments show that the proposed HVAC has an excellent performance and effective control system [52]. Aylin Ozkan develops a methodology to assess the relative impact of passive measures on building system performance. Throughout a building's life cycle, its use and occupancy may change significantly when the building is repurposed [53]. Magnar Berge's study of the significant reduction in the heat load required for passive house construction leading to a process of post-heating through the supply air suggests that additional heat sources should always be used in the bathroom to supplement the air heating and that it should be possible to regulate the air supply temperature in the bedroom independently of the other rooms [54]. Maria-Mar Fernandez-Antolin discusses energy efficiency and optimized building design for residential buildings located in different climate zones in Spain. These measures help to meet the energy demand thresholds set by the Passivhaus standard in all climatic zones [55]. Sandra Carolina Camacho-Montano synthesizes different building types, the impact of potential measures on future conditions, and their costs. It also provides specific guidance on the most appropriate measures to improve indoor thermal comfort in classrooms in Karlsruhe, Germany [56]. Amir Baniassadi used whole-building energy simulations to compare indoor air temperatures in a typical single-family home without air conditioning in eight U.S. cities at the turn of the century and mid-century. The analysis suggests that summer overheating times could increase by as much as 25% by mid-century [57]. Giacomo Chiesa introduces a coding method for dynamic energy simulation through this study of generic offices located in northern countries and temperate/Mediterranean regions, and the results show that it is necessary to include a larger set of variables from early design configurations to optimize the expected energy demand according to different aspects [58]. Jalil Shaeri investigates the impact of a prototype model in an office building on annual energy consumption for cooling, heating, and daylight loads. Finally, in terms of natural light gain, the linear form has the most natural daylighting of all the studied cases in the three cities [59]. Xiaoliang Wang proposed a hybrid heat collection façade (HHCF). To analyze the thermal performance of the HHCF, a heat transfer model based on the heat balance method was developed and verified by experimental results. The results show that the thermal performance of the HHCF mainly depends on the window operation time, the width and absorption rate of the heat collecting wall and the thermal performance of the inner double glazed window [60]. Meng Zhen investigated the independent and combined effectiveness of nine passive design strategies and showed that passive solar heat gain was the most important passive design strategy, with an average contribution of 14.64% and 28.38% in both heating and non-heating seasons, respectively [61]. Dongjun Suh proposes an evaluation energy model for estimating the energy efficiency of architects' and engineers' design choices in the early design phase. This study provides valuable guidance for developing energy-efficient homes in Korea and will help architects consider appropriate design options [62]. Farah Mehdaoui discusses the energy performance of a solar heating prototype (SHP) designed by the lab to meet the air heating needs of Tunisian homes. The results show that for a total annual solar insolation of about 6493.37 MJ m^{-2}, the average solar fraction obtained is about 84% [63]. Farhad Amirifard provides a technical review of passive measures in buildings and provides a classification of passive energy measures, which shows that although they excel in reducing energy consumption, the implementation of the most effective combination of these passive technologies remains a great challenge for building designers/managers in terms of the characteristics of the building [64]. P. Fazil Hassan telah mempelajari dinding Trombe yang dirancang dan dikembangkan oleh Rural Energy Centre (REC). Hasilnya menunjukkan bahwa dinding Trombe dapat memainkan peran penting dalam mengubah udara di dalam Gedung [65]. Yeweon Kim proposes a methodology and process to establish a reactive level of building energy policy development in Korea. Finally, four insulation standards for representative areas are proposed to derive a measure to minimize energy loss from building facades or windows [66]. A. I. Ismail critically reviews and analyzes the various passive cooling technologies that can be employed in tropical climates to achieve desired thermal comfort in buildings and the factors that influence their selection; to contribute to the development of guidelines on how to mitigate the effects of climate change [67]. In order to reduce the heating demand and the risk of overheating in the cold and warm seasons respectively, Sören Eikemeier used a simulation-supported optimization strategy, which resulted in an improved rating for the mandatory Austrian Energy Certificate [68]. Adeel Waqas utilizes solar energy and nighttime ambient cool temperatures as a passive means of heating and cooling buildings. And the performance of an air-based PCM storage unit that uses solar energy to comfortably heat the building in dry cold and climate was evaluated [69]. Maria Elena Menconi analyzed the performance of a typical farmhouse in central Italy in terms of thermal comfort and energy efficiency. Sensitivity analysis showed that the component with the greatest impact on thermal comfort is the roof insulation [70]. E Darling explores the potential of two different clay-based interior surface coatings to passively reduce indoor ozone. The results suggest that clay-based coatings may be effective as passive removal materials, with relatively low by-product emission rates that can decay rapidly within 2 months [71].

The progress of domestic research on building energy efficiency is as follows. Fu Xiao researched artificial intelligence (AI) control tools to build a framework for implementing AI in building energy efficiency. Before implementation, annual energy costs reached $1,004,339. in 2018, the AI implementation framework was introduced to deploy AI in on-site systems. in total, 47.5%, 37%, and 36.9% of energy were saved at the equipment, facility, and building-wide levels; a maximum savings of $385,203 [72]. Li proposed a new triple-glazed vacuum-water flow window that combines the advantages of aqueous media windows and vacuum glass. The thermal performance was numerically analyzed under various climatic conditions with double-glazed water flow windows. The application of the vacuum gap proved to be very effective in reducing the heat flow through the window [73]. Song Mengjie briefly reviewed the research trends in building and energy efficiency, using air-source heat pumps as a representative. The results show the importance of both fundamental mechanistic research and applied technological solutions. Research trends in this field are moving toward intelligent, multi-dimensional, and interdisciplinary directions [74]. Tohid Jafarinejad proposed a two-layer energy-efficient occupancy profile optimization method using a meta-heuristic algorithm combined with a demand-driven control strategy for dynamic setpoint temperature adjustment to optimize energy consumption within a university department building. Finally, the demand-driven control scheme is combined with an optimized course schedule, resulting in improved controller performance and achieving a savings potential of up to 18.97% [75]. YabinGuo proposes a new method for fault diagnosis of building energy efficiency based on the deep learning method of deep belief network and discusses its potential application in the field of air conditioning fault diagnosis. The results show that fault diagnosis of variable flow refrigerant systems may not require very deep models [76]. Jaqueline Litardo modeled the building's baseline and presented an independently evaluated energy savings scenario. the SPVS output power converter provides a total of 66,590 kWh of electricity per year, of which 48,497 kWh is provided to the building, while the remaining power is injected into the grid [77]. Yanyi Sun describes the key types of TIM and their properties in terms of thermal and optical behavior, as well as the benefits that may be achieved by applying them to buildings. Finally, this review provides a workflow that can be used to evaluate and analyze the benefits of applying TIM to buildings for energy efficiency and daylight comfort in buildings subject to different climatic conditions [78]. JingfuCao studied the changes in meteorological parameters in five major climate zones in China, Harbin, Tianjin, Kunming, Shanghai, and Guangzhou, and analyzed the effects of climate change on meteorological parameters for them. The results showed that the outdoor design temperature for heating or air conditioning increased significantly in all five climate zones [79]. Zhaoran Liu conducted a study on multi-objective energy efficient design of buildings based on the application of green building materials. Finally, the experimental results give the scores of green rating and environmental impact factors of several candidates for green building materials, which validate the effectiveness of the proposed algorithm [80]. SAA Shazmin is developing a property tax assessment incentive model by evaluating its impact on local tax revenues and the amount of property taxes levied on taxpayers. Through the tax abatement model, local authorities do see an increase of $4 to $9 in existing tax revenue. For taxpayers, the annual energy savings from the green envelope component compensates them for the tax increment [81]. Huang focuses on energy efficiency policies in the building sector by conducting a comparative study of Japan and China. The analysis shows that BES policies have promoted building energy efficiency in both Japan and China. A comparison of barriers shows that there are many obstacles in Japan and China, including high transaction costs and a lack of applicable methodologies [82]. Jinsung Byun proposes an adaptive intelligence system for providing building control and energy-saving services in buildings. The results show that the autonomous energy savings using our system are about 16-24% depending on the number of SIS [83]. Silvia Soutullo developed a new digital Geographic Information System (GIS) platform to quantify the energy savings obtained through the implementation of residential building renovation measures. Buildings built before the implementation of the 2006 Spanish Technical Building Code have achieved high rehabilitation potential, with isolated houses having a higher rehabilitation potential than collective buildings [84]. Chen-FuChien developed an energy efficiency assessment model for Fabs in the semiconductor industry based on the SMART decision analysis structure, and the results showed that Fabs must additionally evaluate energy-efficient designs when expanding, specifying energy efficiency and energy management [85]. Yunqing Fan presented a simulated demand-controlled ventilation (DCV) system combining BES and CFD with CO_2. Optimizing ventilation rates based on a CO_2 DCV system with appropriate airflow patterns helps create and maintain a healthy, comfortable environment in addition to saving energy[86]. Enzo Zanchini analyzes the energy savings achieved by combining a commercial M-Cycle evaporative cooling system with a conventional refrigeration cycle for the air conditioning of an office building in northern Italy. The results show that the second application of the M cycle provided the best performance: it reduced the energy extracted by the refrigeration cycle by 37.6%, the thermal energy by 76% and the total electricity use by 38% [87]. AM Gladkih considers the main aspects of green buildings, energy efficiency standards, international certifications of LEED and BREEAM, and the legislation of the Russian Federation in this field. The analysis of enterprises and office buildings in the Russian Federation with international certificates is presented. The reasons for the lack of development of green buildings in Russia, especially in Siberia, are evaluated. The criteria needed to develop this direction are revealed [88]. Hang Tan verifies and analyzes the energy-saving potential of BIGP in the hot-summer and cold-winter regions of China through comparative experiments in vertical greening chambers and references chambers [89]. Paula van den Brom examined nearly 90,000 renovated homes in the Netherlands, including actual and calculated energy consumption data before and after renovation [90]. Handing Guo discusses the basic features of government incentives, energy service company (ESCO) technology innovation, ESCO revenues, and homeowner awareness that have contributed to the development of the existing building energy retrofit market. The results of the study provide a theoretical basis and guidance for the Chinese government to develop policies to support energy efficiency retrofits in existing buildings[91]. Qudama Al-Yasiri discusses the main techniques employed in this context to identify modern and effective methods with a special focus on PCM. The main findings of PCM thermal performance have been described, considering cooling/heat load reduction, energy savings, and thermal comfort as well as several research interruptions for future studies [92]. Dongliang Zhao introduced a new roof-integrated radiant air cooling system. The system combines sky radiant cooling with attic ventilation to reduce attic temperatures. The results show that for a single-family home, attic temperatures can attic insulation levels vary and attic temperatures can be significantly reduced by 15.5 to 21.0°C [93]. Yixue Zhang investigated the cooling performance and energy efficiency of four types of roofs under simulated daylight. The experimental results showed that all the other three roofs reduced the temperature fluctuation in the room and reduced the heat flow into the room compared to the normal roof [94]. Hyuk Ju Kwon is providing preliminary data for an optimal control study by integrating various input variables to control the slat angle of slatted blinds. By comparing and analyzing the building energy performance under each condition, energy savings of up to 20.7% were achieved during the cooling period and up to 12.3% during the heating period [95]. Yawen He has developed a modular 3D printed vertical concrete green wall system, known as 3D-VtGW. results show that buildings with 3D-VtGW show significant potential for energy savings and improved thermal comfort. the integrated greening system in 3D-VtGW works through a combination of plant shading, evapotranspiration The integrated greening system in 3D-VtGW has a combined effect through plant shading and evaporation [96]. Hom B. Rijal conducted thermal measurements and thermal comfort surveys in order to quantify seasonal differences in comfort temperatures and to develop a domestic adaptive model for highly insulated Japanese homes. The results show that residents are highly adaptive to the thermal environment of their homes and that comfort temperatures have seasonal variations [97]. Sultan Kenzhekhanov quantified the thermal performance and energy efficiency of residential buildings with nine PCMs (PCM19 to PCM27) integrated into different subarctic climate cities. The results show that residential buildings integrated with PCMs exhibit better performance in terms of ATFR, especially during the warm season [98]. Benedetta Pioppi examined the potential benefit strategies of human-centered energy retrofits and showed that eliminating energy waste behaviors could involve reducing building energy demand by as much as 17 percent [98]. Zhanbo Xu studied the total energy consumed during building operation and the relationship between building energy efficiency and total demand and showed that significant energy savings can be achieved by exploring the soft comfort needs of occupants [99]. Morshed Alam evaluated the energy performance of an active PCM system installed in an 11-story building in Melbourne. The results showed that the active PCM system reduced the chiller cooling load by 12-37% in the colder months only, but remained dormant during the summer months [100]. Saeed Esbati uses residential buildings as a case study for energy optimization. After validating the software data, the insulation is simulated in the software and the results of using this insulator are studied to reduce energy consumption [101].

1.3 Aim of the Study

The thermal comfort of Traditional Houses in southern Shaanxi is poor in winter. The existing heating methods have some disadvantages, such as low efficiency, high energy consumption, and high carbon. This study proposes a roof solar heating storage system to improve the indoor heating effect using the principle of solar heating technology. Chi et al. [14] confirmed that the ANSYS simulation results agree with the measured data by comparison. Therefore, this study uses software for simulation to verify the effectiveness of roof solar heating storage system heating. The research objectives are as follows:

(1) Measure the indoor temperature of the current residential house and calculate the heating time as well as energy consumption.

(2) Study the heat storage performance and heating efficiency of phase change materials.

(3) Simulate and calculate the heating time, equilibrium temperature, and heating efficiency of the new system

(4) Evaluate the appropriate time for the new system to be used throughout the year, and calculate the annual heat load reduction and energy savings when using the new system through comparative analysis.

(5) Optimization and application of the new system.

1.4 Scientific Originality

Affected by the monsoon climate in southern Shaanxi, the indoor environment of traditional houses is generally wet and cold in winter. The existing heating methods are mainly grouped into two types: the traditional heating method is mainly heating by burning charcoal, and the modern heating method is mainly local heating with small electrical appliances. These two heating methods only heat part of the indoor space, and the energy consumption is high. This study proposes a roof solar heat storage heating system, which adds a roof skylight to the roof of traditional houses and adds the high-density polyethylene heat storage and insulation material to the roof attic plate so that the polyethylene material on the attic plate can absorb the heat radiation of the sun and improve the overall indoor temperature using the heat transfer principle of heat convection and heat radiation. This heating system is different from the previous solar glass roof heating system. The roof attic plate is made of the solar panel heat storage material—HDPE. This material has been proven to be a promising phase change material with many advantages, such as small volume change, high thermal efficiency, no corrosion, light under cooling, and so on [34,35]. To increase the efficiency of absorbing solar heat radiation, the traditional opaque roof in southern Shaanxi is transformed into a push-pull transparent glass roof. In winter, the thermal insulation roller shutter is closed to ensure that the solar panel heat storage material absorbs more heat radiation from solar radiation. In summer, opening the thermal insulation roller shutter can effectively reduce the indoor temperature. The whole heating process completely depends on passive solar heating without any power equipment support. It is a complete passive heating technology.

The thermal environment of building interiors is influenced by a variety of factors, including heating sources, insulation properties of envelope materials and practices, and building design practices. These influences can be improved to achieve energy savings and optimize the indoor thermal environment. However, the composition of the building is complex, containing a variety of materials and multiple space combinations, and the research on indoor thermal engineering is currently more about using solar collectors to assist in heating, or about improving the insulation performance of the building envelope, which can be interpreted as an inside-out insulation approach. In this approach, the building has a limited contact area for sunlight and the utilization rate of solar energy is low.

(1) In this study, the traditional residence is partially retrofitted with solar energy for heating design, and HDPE thermal storage material is added as wall insulation material. This design method is a novel approach for traditional Chinese houses, which is effective for energy saving and indoor thermal environment enhancement of traditional houses.

(2) Previous studies on winter indoor thermal work of traditional houses mainly include, using the greenhouse effect to design sunrooms, firewalls, sunrooms, etc. In this study, a new approach is adopted to open skylights on the roof of traditional houses to obtain more solar energy by increasing the light area. This approach only removes the existing tiles and installs skylights, which also makes the roof load of the building reduced, also increases the indoor lighting.

(3) This study uses solar energy and uses the greenhouse effect to increase the air temperature inside the glass layer on the outside of the building's exterior walls and opens vents in the walls to make the hot air inside the glass layer exchange with the cold indoor air, thus improving the indoor thermal environment. The purpose of energy saving is achieved.

1.5 Research Contents

By investigating and studying the information related to the layout, house type, exterior wall, structure, material, and height of the building, we provide the basis for subsequent optimization of thermal comfort.

(1) The current situation of heating in traditional houses

Through research and data aggregation and analysis, the heating method, heating equipment, and heating efficiency of traditional houses are derived.

(2) The current situation of indoor thermal comfort of traditional houses

Through research and instrument testing, combined with residents' feelings, as well as consulting relevant codes and standards, evaluate whether the indoor thermal comfort meets the specifications.

(3) Energy consumption of traditional houses

Through research, understand the consumption of household appliances or other energy sources in traditional houses, and propose corresponding energy-saving measures.

(4) Propose a solar passive heating system

Through the research on the current situation of heating, indoor thermal comfort, and energy consumption, we propose a solar passive heating system to improve indoor thermal comfort in winter.

(5) Thermal comfort and energy saving of the new system

Through modeling and software simulation, we analyze the thermal comfort and energy saving of the new system and compare it with the current heating method to find out the advantages of the new system.

(6) Optimization and application of the new system

Optimize the key factors affecting the thermal comfort and energy consumption of the new system and compare it with the new system to find a better way to further improve the applicability and energy-saving capability of the new system.

1.6 Research Methodology

Through research and testing of residential houses in hot-summer and cold-winter regions, and comparing and analyzing with the normative theory, we find the problems of residential houses in winter indoor thermal environment village and propose the solution strategies. And the software simulation is used to verify the effectiveness of the strategies. The research methods used in this paper include the survey method, literature research and data compilation, comparative analysis and deductive reasoning, software simulation method, and statistical analysis method. The details are as follows.

(1) Survey method

This research activity takes the natural environment of the hot summer and cold winter region as the background, investigates the residential houses in the region and the indoor thermal environment, draws out its problems, analyzes the causes and influencing factors of the problems, and based on the research, analyzes the problems of the traditional residential houses in the winter indoor thermal environment by combining the relevant theories, standards, and norms, and proposes the solution strategies.

1) Field research method

By observing and experiencing the natural environment, geographical conditions, and architectural information of the township in the field, first-hand information is obtained using photos or on-site records. This research method is easy to carry out and is the most basic, which must be contingent to conduct research, and does not apply to large samples of observation.

2) Questionnaire method

The purpose of the study is achieved through indirectly written interviews. The questionnaire method can break through the constraints of time and space, the scope of the survey is wide, and can be conducted on many respondents at the same time. Change the survey method of the respondents should have a basic understanding of the text and a certain ability to express themselves in writing.

3) Interview survey method

Through face-to-face conversations with respondents, relevant questions are asked, and the interview is recorded on-site. Compared with the physical observation method, this research method can obtain further and more valuable information.

(2) Literature research and data organization

Relevant research literature in the subject area was systematically collected and studied, the progress and depth of research were analyzed, and research gaps were pointed out to clarify the direction for this paper and thus determine the focus of the research.

(3) Comparative Analysis and Deductive Reasoning

A comparative analysis of foreign passive design standards, passive ultra-low energy building standards of other countries, and passive ultra-low energy building standards of China are conducted; a horizontal analysis of existing energy-saving design methods is conducted to summarize their general laws and provide a logical basis for constructing a framework of passive ultra-low energy building design auxiliary decision-making methods.

(4) Simulation method

Software simulation is a quantitative research method for determining the target value of energy consumption and conducting sensitivity analysis. Establishing a typical model and conducting an energy consumption simulation is a common method to study the energy consumption of specific types of buildings. In this paper, energy consumption simulation software is used to simulate the energy consumption of typical models to provide a direct data basis for the derivation of energy consumption target values, establishment of regression equations, and sensitivity analysis.

(5) Statistical analysis method

The statistical analysis method is a quantitative research method used to process and analyze energy consumption simulation results. It includes methods such as the abnormal data exclusion method, data testing method, data validation method, and regression analysis method. The introduction of relevant methods from other disciplines both enriches the research tools and improves the scientific nature of the study. Finally, the constructed design-aided decision-making method is applied in combination with specific design cases to reflect its role in optimizing the design and aiding the decision-making of solar thermal storage heating systems.

1.7 Chapter Summary

This chapter mainly introduces the research background, research purpose, and research innovation. This paper reviews the application of passive heating in architecture, passive heating, energy-saving design, and passive additional sunlight. Through the analysis of the references, the passive heating technology is summarized. Combined with research methods and research objectives, this paper tries to solve the passive winter heating of traditional houses in southern Shaanxi. It is found that there are some problems with heating and energy saving in traditional houses, and the rational application of passive heating technology in traditional houses in southern Shaanxi is explored.

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Chapter 2. Research on the Current Situation of Traditional Houses in Southern Shaanxi

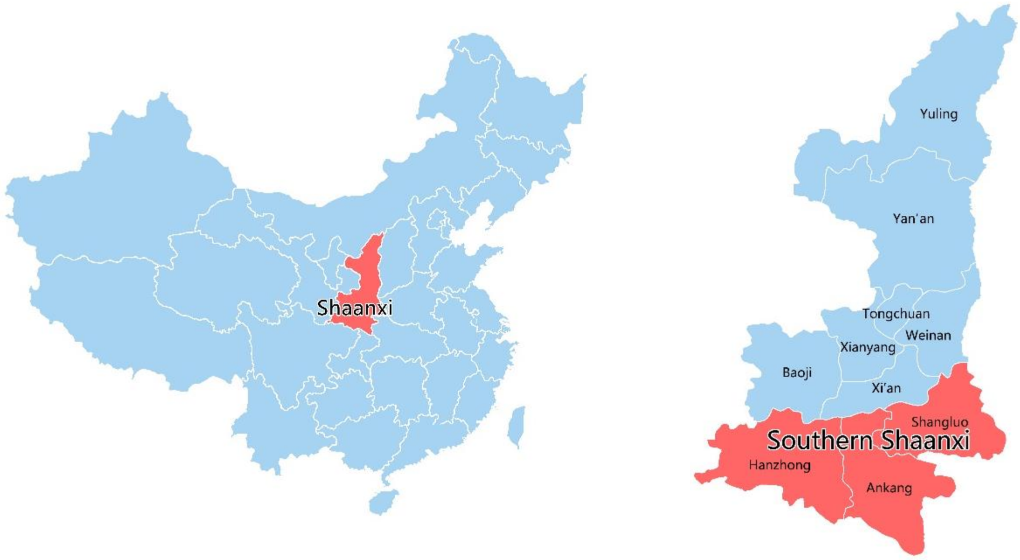
2.1 Investigation Overview

2.1.1 Investigation Scope

The study site of this paper is Southern Shaanxi, which is located in the south of Shaanxi Province, China, including Hanzhong, Shaanxi, and Shangluo from west to east [1], The location is shown in Figure 2-1. The southern part of Shaanxi Province is located in the Qinba Mountain Range, which has a very different natural and geographical environment compared with the Guanzhong and northern parts of Shaanxi [2]. The Qinba Mountains are the birthplace and cultural cradle of the Chinese nation, the central cultural lineage of Chinese civilization, and the cultural temple [3]. This region is an important biodiversity and water-conserving ecological function area in China, with well-developed water systems and abundant runoff resources; it is also the central green lung of China and the convergence of forest carbon sinks [4]. The Qinling Mountains in the north, the Ba Mountains in the south, and the Han River in the middle are the core of the Qinba Mountain region [5]. Its geomorphological pattern of "two mountains sandwiched by one river", the humid monsoon climate of the north subtropical continent, vertical zonal geographical differentiation, and rich water resources have distinctive regional characteristics [6].

The resource constraints, farming conditions, and environmental capacity of the natural environment are the decisive factors influencing the characteristics of traditional architecture in southern Shaanxi. The climatic conditions and resource conditions of the regions where the natural landform types are located determine the spatial combination and association of the habitat environment in southern Shaanxi, and the traditional habitat activities form the differences in the distribution of settlements under the cultural consciousness of conforming to nature [7]. The ancient towns and villages in the Qinba Mountains and the Shangfu docks along the Han and Dan rivers show the settlement pattern of southern Shaanxi, which is integrated with the landscape pattern, the free and simple dwelling types, the simple and practical spatial combinations, the localized material construction, the flourishing hall architecture, and the eclectic decorative styles.

Cultural exchange and integration are important factors influencing the characteristics of traditional architecture in southern Shaanxi. The economic development of the southern Shaanxi region is not developed enough, the depth of the region is small, and the resource-carrying capacity is limited. It belongs to the regional sub-cultural circle, and the economic and social life is influenced by the radiation of the central cultural circle; the migration into the region has contributed to the intermingling of northern and southern cultures, making the southern Shaanxi region a place where the diverse cultures of Ba Shu, Jing Chu, and Qin Long converge [8].



a. Location of Shaanxi in China

b. Location of Southern Shaanxi in Shaanxi

Figure 2-1. Location analysis map

Combined with the topic of the paper, a large number of researches were conducted on the villages within the scope of Hanzhong, Shaanxi, and Shangluo cities in southern Shaanxi. During the doctoral period, there were three surveys in total [9]. Based on the problems existing in the thermal comfort of traditional houses in winter, typical villages and towns were selected to focus on their basic conditions, spatial functions, physical environment, etc.

2.1.2 Investigation Route

From 2020 to 2021, we conducted several studies on traditional houses in several towns in southern Shaanxi. The towns in Hanzhong City include Qingmuchuan Town, Anlehe Town, Yanzibian town, Yangpingguan Town, Daijiaba Town, and Da’an Town. The townships in Shaanxi City include Xianhe Township, Shuhe Township, Liu Liu Township, Yingfeng Township, Zigou Township, and Tanba Township. Townships in Shangluo City include Deihua Township, Jingziguan Township, Zhaochuan Township, Manchuanguan Township, Xiaoling Township, and Phoenix Township. The statistical table of this research township is shown in Table 2-1.

Table 2-1 Statistics of the township survey list

Research time	City	Township
2020.1	Hanzhong City	Qingmuchuan Town, Anlehe Town, Yanzibian town, Yangpingguan Town, Daijiaba Town and Da’an Town.
2020.12	Shaanxi City	Tanba Township, Xuanwo Township, Yundou Township,

		Xihe Township, Houliu Township, and Shuhe Township.
2021.2	Shangluo City	Deihua Township, Jingziguan Township, Zhaochuan Township, Manchuanguan Township, Xiaoling Township, Phoenix Township.

2.2 Investigation of Towns

2.2.1 Survey Contents of Towns

(1) Introduction to the township

The research and review of information provided insight into the basic conditions of the township, including its geography, climatic conditions, and economic development. This gave us a clear understanding of the environment in which the homes in the area are located.

(2) Information on traditional houses

Information about the courtyard form, building dimensions, floor plan, building materials, and construction methods of traditional houses. This is very important for passive design and building renovation.

(3) Analysis of heating methods

Understanding the heating methods of residents, the heating effect of heating equipment, and energy consumption, is to determine whether this heating method can meet the needs of heating use and whether energy-saving needs.

(4) Indoor thermal comfort survey

The residents' demands for indoor thermal comfort and satisfaction are understood through questionnaire discussions. At the same time, the indoor thermal environment is measured by using a temperature and humidity meter and thermal imager, and the 24-hour data changes are counted, and whether the indoor thermal comfort meets the needs of the human body is derived by comparing with the specification. This leads to the research question.

2.2.2 Detailed Information About the Towns

(1) Qingmuchuan town

1) Introduction to the township

Qingmuchuan ancient town is a national AAAA tourist attraction. It is located at the junction of Shaanxi, Gansu, and Sichuan, with Qingchuan County in Sichuan Province to the west and Wudou District and Kang County in Longnan City, Gansu Province to the north. It is the westernmost town in Shaanxi Province, 108 km from the county capital and 197 km from Hanzhong City. The town has superior natural conditions, good ecological vegetation, rich historical and humanistic resources, traditional old neighborhoods, ancient folk customs, folklore, folk customs, and traditional life, production appliances, have a unique style of painting; ancient buildings, ancient cliffs, ancient ancestral halls, ancient temples, ancient inscriptions, etc., to show the town's long history and deep cultural heritage.

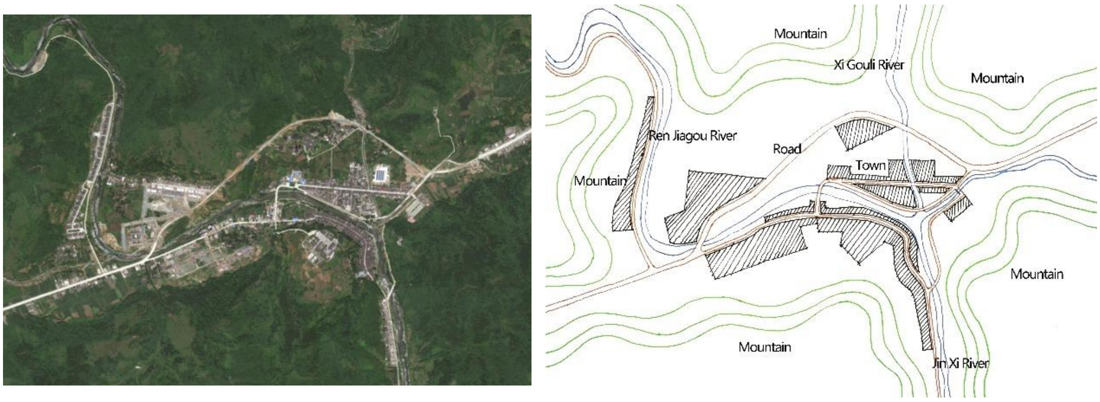


Figure 2-2. Township plan of Qingmuchuan township

2) Information on traditional houses

Now preserved quaint and unique, with carved beams and elegant style, more than 260 houses of ancient architecture, is a non-renewable historical and cultural heritage, the ancient architectural complex is to Wei Fu Tang's new, old mansions, Hulongchang old street to foreign houses, Fu You She, boat-shaped house as the main body of all the Qing Dynasty and the Republic of China buildings and Fu Ren Middle School auditorium. Ancient town of the existing ancient street Huilongchang, Ming Dynasty, built during the Chenghua period, east and west of more than 800 meters long, more than 50 meters wide, a street width of 4 meters, a total area of more than 40,000 square meters. The houses of nearly 100 families on the ancient street are all quadrangles, with a two-story structure of two in and two out, preserved to 80%.

The most complete preservation of the ancient town is the Wei's House, built by Wei Fu Tang, a well-known gentleman in the Republic of China. There are two Wei's houses, five commercial houses, and one middle school, with a total area of 10,000 square meters, which is 85% preserved. Nearby, 8 km away, there are ancestral halls of the Qu, Wei, Zhao, and Tu clans from the Ming and Qing dynasties, and there are inscribed monuments, with a preservation rate of 70%. With the popular broadcast of the TV series "A Generation of Lords" based on Ye Guangqin's novel "Qingmuche", the town of Ningqiang Qingmuche, the original site of Fenglei Town in the drama, has become a tourist hotspot with widespread attention.

3) Analysis of heating methods

The town's traditional residential heating methods as well as heating equipment were investigated. Since the town is small in area, the number of residents is small, and most of them live in scattered houses, so the conditions for centralized heating are not available, and the heating methods in rural areas include active heating and passive heating, with active heating being air conditioning and other heating equipment. Passive heating is mainly the traditional Chinese charcoal heating, mainly with charcoal, including fire pots, fire pits, and fire roasting tables.

4) Indoor Thermal Comfort Survey

Most of the results showed that it was very cold and unbearable in winter, and the charcoal heating could only partially heat the room, and it would be very cold again if we left the heating source. However, the use of household appliances for heating consumes a lot of electricity and makes it difficult to pay high electricity bills. A 24-hour test of several households was chosen for the winter season around January, using temperature and humidity testing instruments. Based on the measurements, the indoor temperature and humidity were unsuitable for human habitation and exceeded the minimum temperature that the human body can tolerate. Therefore, it can be concluded that the thermal comfort of the site continues to improve in winter, while energy saving and emission reduction need to be considered.

(2) Daijiaba town

1) Introduction to the township

Daijiaba Town belongs to Ningqiang County, Hanzhong City, Shaanxi Province. It is located in the north of Ningqiang County, the southern foot of the mountain, bordering Da’an Town in the east, connected with Yangpingguan Town in the south, adjoining Jutting Town in the west and Gongjiahe Town in the north. The total area is 265.24 m^2. The township is scattered, surrounded by mountains on three sides, the Zhangjiaba River passes through the western side of the township, the Baocheng Railway crosses from the eastern side of the township, the township is divided into three parts, the transit road 309 County Road and the Ditmiao Road intersect in the township, the township is developed along two transit roads, in a "T" shape. Daijiaba Township is located in the hinterland of Qinling Ba Mountain, with Mountain Mountain in the north and Wuting Mountain in the south, and the terrain is low around the high school. The highest point in the territory is located in northwestern Xuehua Taiping Mountain, 1,776 meters above sea level; the lowest point is located in the village of Gangzigou, 550 meters above sea level. The climate of Daijiaba Town is a warm temperate humid monsoon climate, which is characterized by four distinct seasons and abundant light. The average temperature for many years is 13.5°C. The annual average sunshine hours is 1619 hours, and the annual average frost-free period is 220 days. The average annual precipitation is 950 mm, and the rainfall is mainly concentrated from June to September every year. The rivers in Daijiaba town belong to the Jialing River system in the Yangtze River basin. The main rivers are Nansha River and Donghuang Ditch, two of which originate in Xiejiagou Village, Hanyuan Town, from the south to the north, incorporating Qiaogou and Ringshuigou Creek in Jiamin Village into the Blackwater River; Donghuang Ditch originates in Shuiping Mountain Village, merges into the

Blackwater River in Fanjiaying, and flows to the exit of Baishuigou Village into Juting Town.

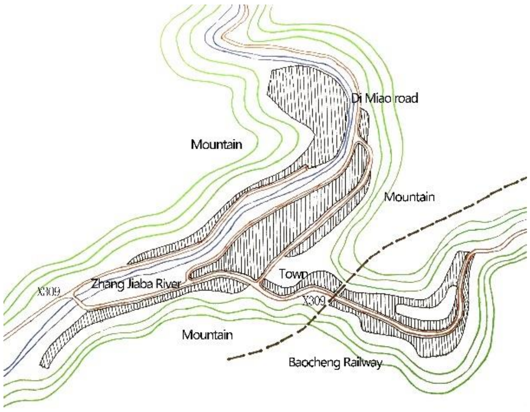


Figure 2-3. Plan of Daijiaba township

2) Information on traditional houses

According to the research statistics, the number of traditional houses in Daijiaba town is about 40%, and the rest are two-story brick buildings. Most of the traditional houses have double-sloped roofs, and most of the courtyards are linear or L-shaped, while a few of them are U-shaped. The number of floors is mostly 2, of which the first floor is for living, with a height of 3.3-3.9 meters. The second floor is a small attic for storage, with a floor height of 2.9-3.3. Generally, it has 3 openings, but some have 5 openings, and the depth is generally 5-6 meters.

3) Analysis of heating methods

The town's traditional heating methods for residents and heating equipment were investigated. Since they are in the same geographical area, the heating methods are similar and the same as the heating methods in the above-mentioned township. The heating methods are divided into active heating and passive heating, where active heating is heating equipment such as air conditioners. Passive heating is mainly the traditional Chinese charcoal heating, which mainly uses charcoal, including fire pots, fire bowls, and fire grills.

4) Indoor Thermal Comfort Survey

Based on questionnaires and interviews, villagers said that winters are very cold and unbearable, and charcoal heating is only partially warm, and if you leave the heating source, it will be very cold again. However, using household appliances for heating consumes a lot of energy and the electricity cost is expensive. During the winter, several homes were selected for 24-hour testing using temperature and humidity testing instruments. According to the measurement results, the indoor temperature was low and not sufficient for human use, exceeding the minimum temperature that the human body can tolerate. Therefore, it can be concluded that the thermal comfort of the site continues to improve in winter, while energy saving and emission reduction need to be considered.

(3) Yanzibian town

1) Introduction to the township

Yanzibian town belongs to Ningqiang County, Hanzhong City, Shaanxi Province. It is located in the west of Ningqiang County, east of Sunling Town and Yangpingguan Town, south of Yuanji Town, Chaotian District, Guangyuan City, Sichuan Province, west of Anlehe Town, and north of Yangba Town, Kang County, Gansu Province. The maximum distance between the east and west of the jurisdiction is 15 km, and the maximum distance between the north and south is 24 km, with a total area of 225.97 m^2. Yanzibian town is located in the hinterland of Qinba, the terrain is high in the north and low in the south. The terrain in the territory is mainly mountainous, with major peaks such as Head-raising Mountain, Sancang Mountain, Wangjiaya, and Bright Mountain. The highest point is 2074 meters above sea level, and the lowest point is 520 meters above sea level. The climate of Yanzibian town is a humid monsoon climate with a transition from warm temperate to subtropical. The average temperature for many years is 13℃, the extreme minimum temperature is -4℃ and the extreme maximum temperature is 38℃. The average annual frost-free period is 230 days, and the average annual precipitation is 1025 mm, with rainfall mainly concentrated from June to September each year. The rivers in Yanzibian town belong to the Jialing River system in the Yangtze River basin. The main rivers are the Jialing River, Yanzi River, Sending Knife Ditch, Mukou Ditch, etc. Among them, the Jialing River enters from Sending Knife Ditch village, with a flow length of 21 km; Yanzi River, which flows from north to south into Jialing River, with a flow length of 11 km and a watershed of 53.1 m^2; Sending Knife Ditch enters from Zhuangzi Mountain, which flows from north to south into Jialing River, with a flow length of 12 km.

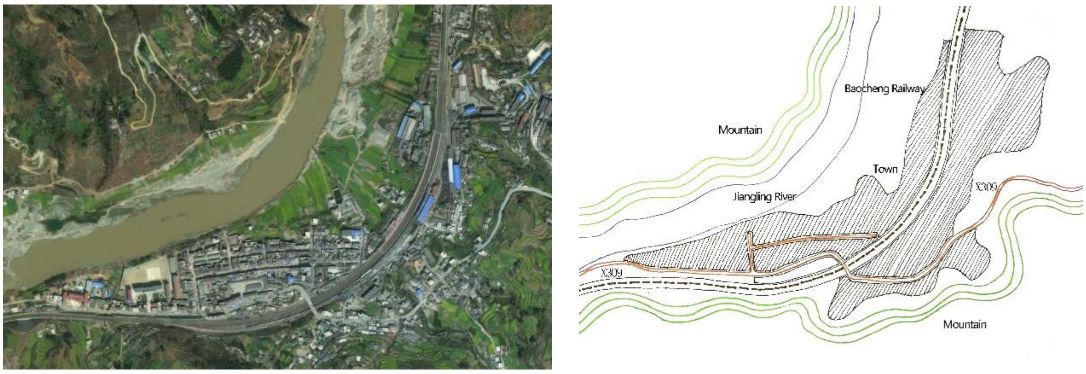


Figure 2-4. Plan of Yanzibian township

2) Information on traditional houses

According to the research statistics, the number of traditional houses in Daijiaba town accounted for about 36%, and the rest were made of brick and mortar buildings. Most of the traditional houses have double slope roofs, the courtyards are mostly linear or L-shaped, and a few are U-shaped. The number of floors is mostly 2, of which the first layer is for residential use, with a height of 3.3-3.9 meters. The second story is a small attic for storage, with a height of 2.9-3.3. Generally, it has 3 openings, but some have 5 openings and the depth is generally 5-6 meters.

3) Analysis of heating methods

The town's traditional heating methods for residents and heating equipment were investigated. Since they are in the same geographical area, the heating methods are similar and the same as the heating methods in the above-mentioned township. The heating methods are divided into active heating and passive heating, where active heating is heating equipment such as air conditioners. Passive heating is mainly the traditional Chinese charcoal heating, which mainly uses charcoal, including fire pots, fire bowls, and fire grills.

4) Indoor Thermal Comfort Survey

Based on questionnaires and interviews, villagers said that winters are very cold and unbearable, and charcoal heating is only partially warm, and if you leave the heating source, it will be very cold again. However, using household appliances for heating consumes a lot of energy and the electricity cost is expensive. During the winter, several homes were selected for 24-hour testing using temperature and humidity testing instruments. According to the measurement results, the indoor temperature was low and not sufficient for human use, exceeding the minimum temperature that the human body can tolerate. Therefore, it can be concluded that the thermal comfort of the site continues to improve in winter, while energy saving and emission reduction need to be considered.

(4) Anlehe Town

1) Introduction to the township

Anlehe Town is affiliated with Ningqiang County, Hanzhong City, Shaanxi Province. Located in the southwest corner of the county. It is adjacent to Yanzibian Town in the east, Chenjiaba Town, Chaotian District, Guangyuan City, Sichuan Province in the south, Guangping Town in the west, and Yangba Town, Kangxian County, Gansu Province in the north. The maximum distance between the east and west of the jurisdiction is 9.5 km, and the maximum distance between the north and south is 33 km. Anlehe town is located in the Qinba mountain, the terrain is high in the north and low in the south, like a trapezoid. The mountains within the rolling, gully crisscross. The highest point is located in the north of the town, Dayuanbao, 1967.1 meters above sea level; The lowest point is located at Songjiaping, 600 meters above sea level. Anle River town is a warm temperate zone to subtropical humid monsoon climate transition. The annual average temperature is 14℃, and the annual average precipitation is 1000 mm. The rainfall is mainly from June to September every year. Anle River town river is in the Yangtze River basin Jialing River system. The main river is the Anle River, which enters the country from Kainma Chang, Gansu Province, bends from north to south to the Lijia River in the southwest at Anle River Street, and flows into the Jialing River at Guangyuan North Qingfeng Gorge, with a flow length of 25.6 km and a drainage basin of 331.3 m^2. Anle River town mineral resources are mainly distributed as magnetite, marble, gold, and so on. The magnets and brown iron are mainly distributed in Jinzishan, with a reserve of 790,000 tons. Marble is mainly distributed in the Bahaihe River, with reserves of 90 million cubic meters.

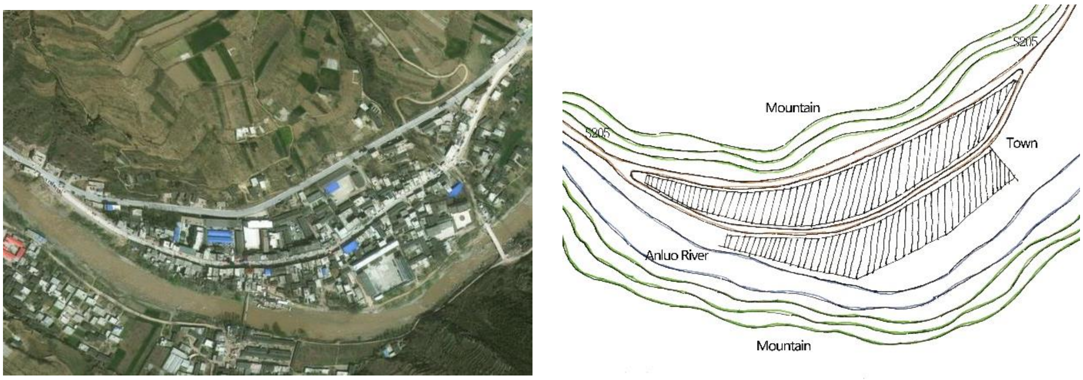


Figure 2-5. Plan of An Le River township

2) Information on traditional houses

There is a green stone paved, about 300m Ming and Qing Dynasties old street, winding, undulating long, and narrow. The street houses on both sides have different styles. One side shows the style of Bashu with a hanging mountain roof, piercing wooden frame, and wood-mounted panel wall, while the other side shows the hard mountain horse head wall, brick hollow bucket, or rammed earth wall enclosure, reflecting the influence of Jingchu culture. The "Shu style" folk houses in Laojie near the river inherited the simplicity of the folk houses in northern Sichuan. Hanging mountain green tile roof with long eaves, set asymmetrical long eaves according to local conditions, attached with clear wood through the bucket gable, small square wooden Windows, no carving and painting. Such as "house package tree" residential. It is worth noting that there are many Bashu houses in the old street, but they no longer follow the custom of rammed earth gable, but instead adopt the masonry method of masonry hollow bucket, which reflects the cultural integration, but also shows the high economic level of the local due to the prosperity of commercial culture.

3) Analysis of heating methods

The town's traditional heating methods for residents and heating equipment were investigated. Since they are in the same geographical area, the heating methods are similar and the same as the heating methods in the above-mentioned township. The heating methods are divided into active heating and passive heating, where active heating is heating equipment such as air conditioners. Passive heating is mainly the traditional Chinese charcoal heating, which mainly uses charcoal.

4) Indoor Thermal Comfort Survey

Based on questionnaires and interviews, villagers said that winters are very cold and unbearable, and charcoal heating is only partially warm, and if you leave the heating source, it will be very cold again. However, using household appliances for heating consumes a lot of energy and the electricity cost is expensive. During the winter, several homes were selected for 24-hour testing using temperature and humidity testing instruments. According to the measurement results, the indoor temperature was low and not sufficient for human use, exceeding the minimum temperature that the human body can tolerate.

(5) Yangpingguan Town

1) Introduction to the township

Yangpingguan Town belongs to Ningqiang County, Hanzhong City, Shaanxi Province. It is located in the west of Ningqiang county. It is adjacent to Daijiaba Town in the east, Shujiaba Town in the south, Yanzibian Town in the west, and Yangling Town in the north. The total area is 300.61 m^2. In August 2009, Yangpingguan Town was designated as a provincial key town by the Shaanxi Provincial government. The territory of the municipal cultural relics protection units Sanquan County site and Longmen Cave. Yangpingguan town is located in the Sichuan Road area of the Jialing River Valley, facing the Jialing River in the north and Jigong Mountain in the south. The highest point in the territory is located in Jinlongguan village, 1861 meters above sea level; The lowest point is located in the village of Laimagou, 530 meters above sea level. Yangpingguan town is a warm temperate humid monsoon climate. The annual average temperature is 13℃, and the annual average frost-free period is 240 days. The annual average precipitation is 1184 mm, and the rainfall is mainly from June to September every year. Yangpingguan Town within the river is the Yangtze River basin Jialing River system. The main rivers are the Jialing River, Sandao River, Hanjia River, Qinghe, and so on. Among them, the Jialing River enters from Yangpingguan Village, with a flow length of 12.2 km, a watershed area of 3 m^2, and an average flow of 166 cubic meters per second.

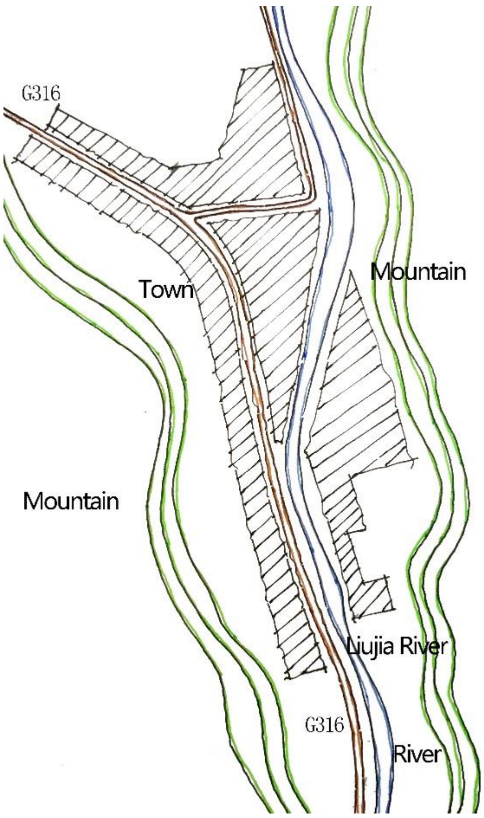


Figure 2-6. Plan of Yangpingguan town

2) Information on traditional houses

The dwellings were built by the terrain and the mountains, and the spatial layout was flexible. The entrance to the Zhongjia compound was built on a bridge across a stream. Due to limited land use, the entrance, front yard, and main axis courtyard form an L-shaped layout. The Luo family compound was built near the stream, and part of the wing room was raised by stilted wooden posts to gain more space in the limited land use. The adjacent Gengjia courtyard was built on the whole according to the mountain, with stepped passageways and horizontal courtyards located on different levels on the main axis. The space layout is compact, and it is a typical example of Taiyuan-style residential buildings. Ha Street Po Shan Hall is located in a small flat area on a hillside. Due to the limited depth of the courtyard, it is a seven-room horizontal courtyard with a winding path leading up the stairs.

3) Analysis of heating methods

The town's traditional heating methods for residents and heating equipment were investigated. Since they are in the same geographical area, the heating methods are similar and the same as the heating methods in the above-mentioned township. The heating methods are divided into active heating and passive heating, where active heating is heating equipment such as air conditioners. Passive heating is mainly the traditional Chinese charcoal heating, which mainly uses charcoal.

4) Indoor Thermal Comfort Survey

Similar to the situation in the town before, the indoor temperature is generally low in winter. The traditional heating method can not meet the needs of human thermal comfort.

(6) Da 'an Town

1) Introduction to the township

Da 'an Town is affiliated with Ningqiang County, Hanzhong City, Shaanxi Province. Ningqiang County is located in the eastern part of the city, the source of the Han River. Qingyangyi Town of Mian County borders on the east, Tiesuoguan Town to the south, Daijiaba Town to the west, and Miaoba town to the north. The total area is 341.53 m^2. Da 'an town has a long history. Before Dayu's flood control, there were ancient villages where human beings multiplied and lived here. It is the only place where the ancient Jinniu Road and Chenping Road pass through. Dayu water control, WudingKaiguan, stone cow dung gold stories spread through the ages, the territory has Xianglong cave, Dayu cave, and other cave groups. Modern times is the cradle of the Red Revolution, revolutionary martyr Chen Jinzhang once set up the first communist group here in southern Shaanxi, and spread the revolutionary truth, the Red Army Long March family story happened here.

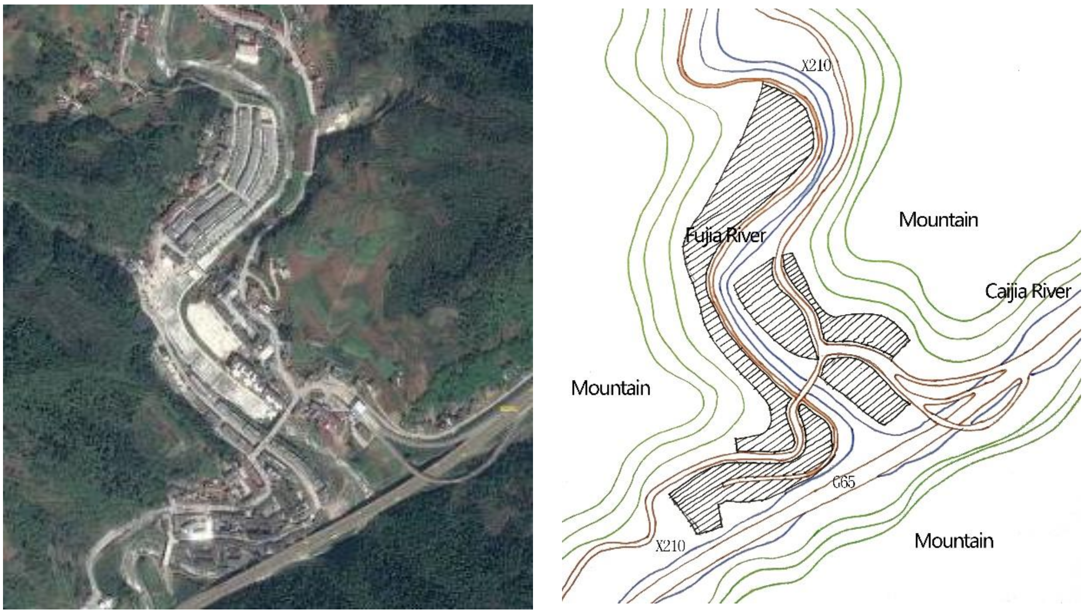


Figure 2-7. Plan of Da 'an town

2) Information on traditional houses

Due to the shortage of land resources, in order not to occupy arable land, freestanding courtyards, and dwellings are mostly built on the hills, and the depth is limited. Even large courtyards usually enter the courtyards 1-2 times, forming the regional characteristics of horizontal development with more roads and less access. Due to the trend of mountains and rivers, the layout habit of "sitting in the north facing south" cannot be completely followed. The orientation is diverse, but it still follows the basic rules of the traditional architectural layout of "middle axis symmetry", "center is respected" and "upper left and lower right".

3) Analysis of heating methods

The town's traditional heating methods for residents and heating equipment were investigated. Since they are in the same geographical area, the heating methods are similar and the same as the heating methods in the above-mentioned township. The heating methods are divided into active heating and passive heating, where active heating is heating equipment such as air conditioners. Passive heating is mainly the traditional Chinese charcoal heating, which mainly uses charcoal.

4) Indoor Thermal Comfort Survey

Similar to the situation in the town before, the indoor temperature is generally low in winter. The traditional heating method can not meet the needs of human thermal comfort.

(7) Tanba Town

1) Introduction to the township

Tanba Town, under the Shaanxi Province Shaanxi City Hanbin District. It is located in the north of the central Hanbin District, bordering Gongjin Town in the east, Wuli Town in the south, Shuangxi Town in the west, and Cigou Town in the north. The maximum distance between east and west is 25 km, and the maximum distance between north and south is 9 km, with a total area of 126.8 m^2. Tanba town is located at the end of the Qinling Mountains, the terrain is high in the northwest and low in the southeast. Within the peaks and valleys. The main mountains are Niushan Mountain and Triangle Mountain, the highest peak is Niushan main peak, 1547.6 meters above sea level; The lowest point is Huangshitan Reservoir, 387 meters above sea level. Tanba town climate is subtropical humid monsoon climate. It is characterized by cold winter less rain and snow, rainy summer and drought, a warm and dry spring, and cool and humid autumn with more continuous rain. The annual average temperature is 15%, the average temperature in January is 0°C, and the extreme minimum temperature is -8°C (December 8, 2009); The mean temperature in July was 25 °C, and the extreme maximum temperature was 42 °C (July 21, 2010). The annual average frost-free period is 240 days, the longest is 270 days, and the shortest is 210 days. The average annual sunshine duration is 1665 hours. The annual average precipitation is 930 mm, and the rainfall is mainly from July to September every year. Tanba Town within the river is the Yangtze River basin Han River system. The main rivers are the Fujia River and Tanjiaba River, among which the Fujia River has a flow length of 20 km and a watershed area of 8 km.

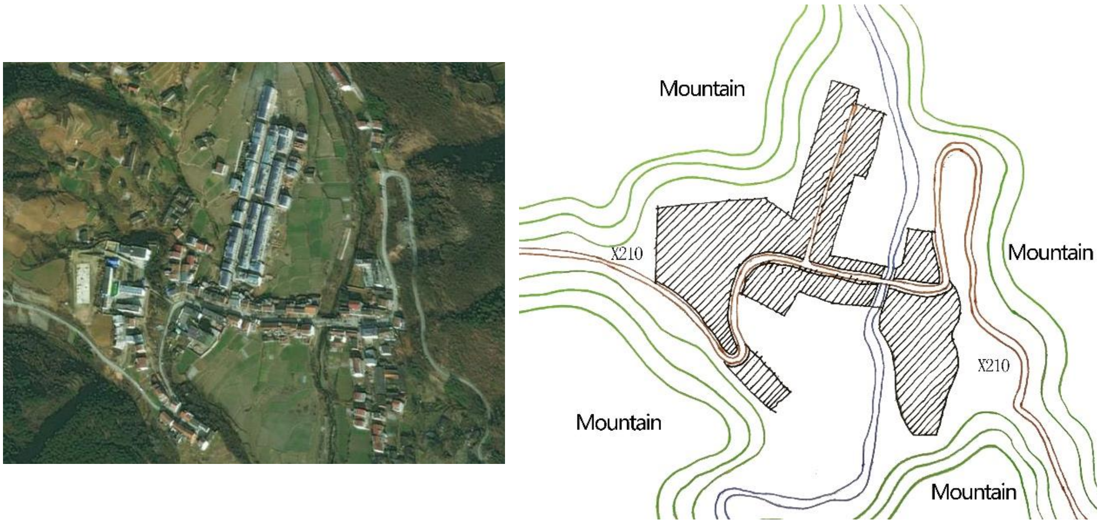


Figure 2-8. Plan of Tanba town

2) Information on traditional houses

Courtyard residential buildings are mostly enclosed by building entities, and a few of them are enclosed by high walls combined with buildings. The facade of the window is small and small, each opening is often not a large stone window and the second-floor attic open-air hole. There is no window or small stone window behind the main room, and there is no window in the side room. The defensive nature of folk dwellings in this area is related to the years of war in the Ming and Qing Dynasties. For example, the lower house of the Zhangjia courtyard does not open the window, only the second floor of the wing room with a small stone air hole, a strong sense of closure.

3) Analysis of heating methods

The heating method used is similar to other towns. Traditional heating is mainly based on wood burning to raise the temperature of the room. Modern heating relies mainly on electricity for heating.

4) Indoor Thermal Comfort Survey

Similar to the situation in the town before, the indoor temperature is generally low in winter. Traditional heating methods can not meet the needs of human thermal comfort.

(8) Xuanwo town

1) Introduction to the township

Xuanwo town, under the Shaanxi Province Shaanxi City Hanyin County. It is located in the south of Hanyin County, at the southern foot of Fenghuang Mountain, bordering Hanwang Town of Ziyang County in the east, Liangzi Town of Ba County, Hanzhong Town in the south, adjacent to Hanyang Town in the west, and bordering Chengguan Town in the north along Fenghuang Mountain [1]. The total area is 224.97 m^2. Xuanwo town is located on the southern foot of Phoenix Mountain. The terrain within the large ups and downs, shallow hilly area geomorphic features. The highest point is the main peak of Fenghuang Mountain at 2,128.3 meters above sea level. Xuanwo town climate is a subtropical humid monsoon climate. It is characterized by mild and humid, four distinct seasons, rain and heat in the same season, sufficient light, abundant heat, abundant precipitation, long frost-free period. The annual average temperature is 12°C. The annual average frost-free period is 240 days, and the annual average sunshine duration is 1742.5 hours. The average annual precipitation is 829.5 mm. Xuanwo town within the river is the Yangtze River basin Han River system. The main river is the Han River, which has a length of 4.2 km and a drainage area of 0.8 m^2. Its tributaries include the Mouzi River, Lengshui River, Lanjiang River, Pingxi Valley, Zhangfeng River, etc.

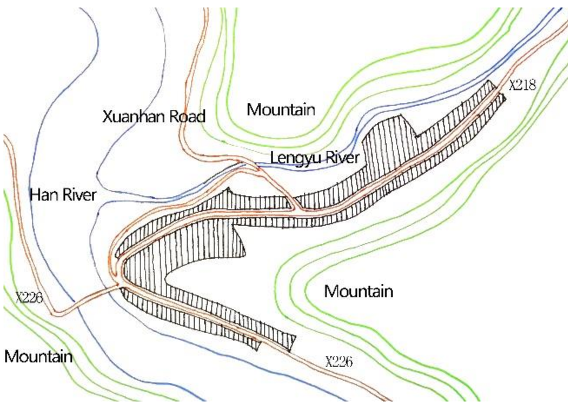


Figure 2-9. Plan of the town of Xuanwo

2) Information on traditional houses

With a total length of more than 1,000 meters, the old Street retains numerous dwellings of the

Ming and Qing dynasties. The architectural style inherits the characteristics of ancient dwellings of the Jianghan Dynasty, and vaguely shows the cultural influences of Guanzhong and Central Plains. The width of the street roof is not full of zhang, but the depth of the house is 30 or 40 meters, forming a narrow and long courtyard, with "three into three open" as the basic type and gradually rising. The spatial form of the courtyard is very close to that of the Guanzhong Narrow Courtyard (with three rooms wide and more than 20 meters or even 30 meters deep, which is divided into several courtyards). A stone rainwater collection pond is set in the courtyard, which is also used for water storage and courtyard greening. The roofs all around slope towards the courtyard, forming a pattern of " Four Rivers Returning to the Pool ".

3) Analysis of heating methods

The heating method used is similar to other towns. Traditional heating is mainly based on wood burning to raise the temperature of the room. Modern heating relies mainly on electricity for heating.

4) Indoor Thermal Comfort Survey

Similar to the situation in the town before, the indoor temperature is generally low in winter. The traditional heating method can not meet the needs of human thermal comfort.

(9) Yundou town

1) Introduction to the township

Yundou town belongs to Shiquan County, Shaanxi City, and Shaanxi Province. Is located in the southernmost Shiquan County. It borders Hanyang Town, Hanyin County in the east, Lianghekou Town, Xixiang County, Hanzhong City in the south, Gaochuan Town, Xixiang County, Hanzhong City in the west, and Houliu Town and Xihe Town in the north. Yundou town is located in the middle and low mountains of Bashan Mountain, with high terrain around and low terrain in the middle. Undulating terrain, peaks, gullies, 460-1590 meters above sea level. Yundou town climate is subtropical humid monsoon climate. It is characterized by abundant light and heat, abundant rainfall, and distinct four seasons. The annual average temperature is 14.6°C. The average annual precipitation is 967.5 mm, and the average annual precipitation days are 122 days. The rainfall is concentrated from July to September every year, with the most in September. The river in Yundou town is the Yangtze River basin Han River system. The main rivers are the Fushui River, and there is 7 large and small river gully. The total length of the river is 38 km, with a total runoff of 116,000 cubic meters. The largest river, the Fushui River, has a length of 11.6 km and a drainage area of 32.6 m^2.

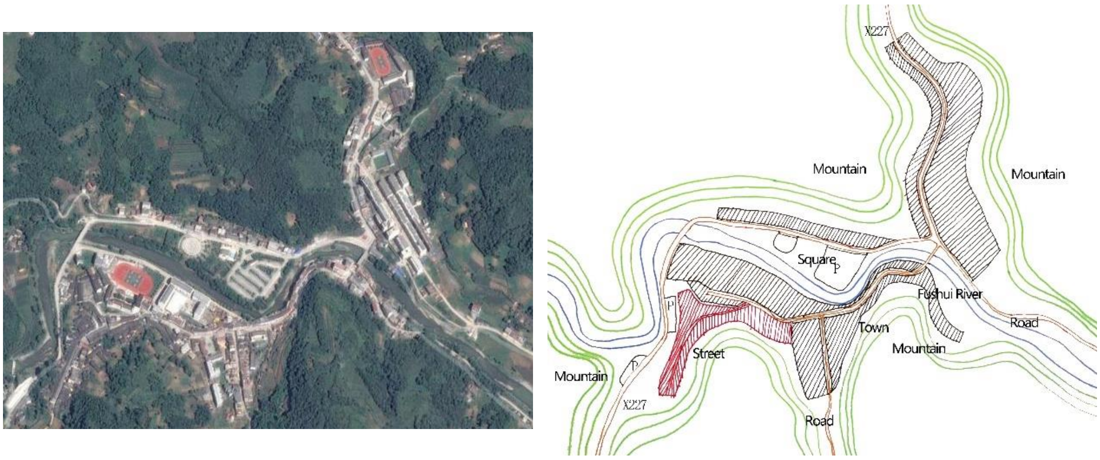


Figure 2-10. Town plan of Yundou

2) Information on traditional houses

Yundou ancient town has a history of thousands of years. It is a post town on the Chuan-Chu Ancient Road. Yundou town is built on karst rock. Most of the existing ancient streets are buildings from the Ming and Qing dynasties, especially the stilted buildings that take up more than one day to give up three feet of land. The ancient town is built near mountains and rivers, surrounded tightly by the Fushui River. Although after thousands of years of time changes, it still retains the past quiet, simple, elegant style, quite a small bridge, water, and people's poetry. With the continuous development of highway traffic, the bustling Chuanchu ancient Road for thousands of years is silent. Now, when you come to Yundou town, you can see the style of the thousand-year-old town: the blue flagstone street, wooden facade, ancient theater, Guandi Temple, the ancient trade road leading to Hanzhong and Sichuan, which have become the cultural relics that witness the rise and fall of Yundou town. With the opening of the Swallow Cave scenic area, Yundou Ancient Town will also show visitors its charm of simple vicissitudes of life, allowing people to taste and pursue the hustle and prosperity.

3) Analysis of heating methods

The town's traditional residential heating methods as well as heating equipment were investigated. Since the town is small in area, the number of residents is small, and most of them live in scattered houses, so the conditions for centralized heating are not available, and the heating methods in rural areas include active heating and passive heating, with active heating being air conditioning and other heating equipment. Passive heating is mainly the traditional Chinese charcoal heating, mainly with charcoal, including fire pots, fire pits, and fire roasting tables.

4) Indoor Thermal Comfort Survey

Most of the results showed that it was very cold and unbearable in winter, and the charcoal heating could only partially heat the room, and it would be very cold again if we left the heating source. However, the use of household appliances for heating consumes a lot of electricity and makes it difficult to pay high electricity bills. A 24-hour test of several households was chosen for the winter season around January, using temperature and humidity testing instruments. Based on the measurements, the indoor temperature and humidity were unsuitable for human habitation and exceeded the minimum temperature that the human body can tolerate. Therefore, it can be concluded that the thermal comfort of the site continues to improve in winter, while energy saving and emission reduction need to be considered.

(10) Xihe Town

1) Introduction to the township

Xihe Town belongs to Shiquan County, Shaanxi City, Shaanxi Province. Located in the southeast of Shiquan County, east across the Fenghuang Mountain in Chengguan Town, south and Hanyang Town Hanyin County border, west, and Yundou town adjacent, north and Houliu Town, Chihe town connected. The maximum distance between east and west is 19 km, and the maximum distance between north and south is 13.5 km. Xihe town is located on the Sichuan road and shallow hilly area. Within the territory of the peaks and valleys, gullies, terrain ups, and downs, divided into Zhongshan, low mountains, hills, and mountain valleys 4 types. The highest point is Dawang Mountain, 1,381 meters above sea level; The lowest point Shiquanzui, 332.8 meters above sea level, is also the lowest point in Shiquan County. The climate of Xihe town is a subtropical humid monsoon climate, which is characterized by abundant light and heat, abundant rainfall, and distinct four seasons. The annual average temperature is 14.6°C. The growing season averages 240 days per year. The annual average precipitation is 967.5 mm, and the annual average rainfall days are 122 days. The precipitation is concentrated from July to September every year, with the most in September. The river course of Xihe town is the Yangtze River basin Han River system. Nine major rivers, including Lotus River Valley, Qingshan Valley, Sichuan Valley, Wazi Valley, Daigou, Yangwu Valley, Donggou, Fenggou, and Changyang Valley, are fan-shaped into the Han River, with a total flow length of 10 km and a watershed area of 90 m^2.

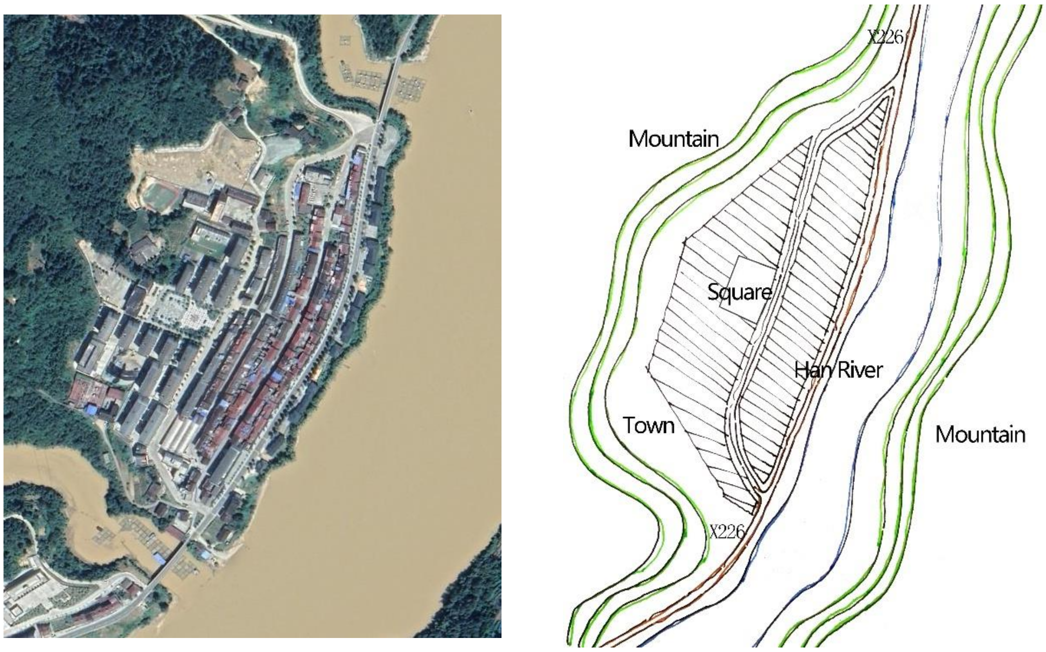


Figure 2-11. Plan of Xihe Town

2) Information on traditional houses

The complex is located in the south and north, built against the mountain, with six courtyards scattered and arranged. It integrates the northern palace and the southern garden practices and crosses the axis of the Sanqing Hall area, the main hall area, the south and north garden area, and the book granting floor area, forming a unique plane layout and spatial relationship

3) Analysis of heating methods

The heating method used is similar to other towns. Traditional heating is mainly based on wood burning to raise the temperature of the room. Modern heating relies mainly on electricity for heating.

4) Indoor Thermal Comfort Survey

Most of the results showed that it was very cold and unbearable in winter, and the charcoal heating could only partially heat the room, and it would be very cold again if we left the heating source. However, the use of household appliances for heating consumes a lot of electricity and makes it difficult to pay high electricity bills. A 24-hour test of several households was chosen for the winter season around January, using temperature and humidity testing instruments. Based on the measurements, the indoor temperature and humidity were unsuitable for human habitation and exceeded the minimum temperature that the human body can tolerate. Therefore, it can be concluded that the thermal comfort of the site continues to improve in winter, while energy saving and emission reduction need to be considered.

(11) Houliu town

1) Introduction to the township

Houliu town is located in the south of Shiquan County. It borders Chihe Town and Xihe Town in the east, Xihe Town in the south, Gaochuan Town in Xixiang County, Hanzhong City in the west, and Chengguan Town in the north. The total area is 146.63 m^2. Houyu is located along the Han River. Within the mountains and peaks, the ridges and ridges, trenches and rivers crisscross. The terrain is mainly Zhongshan, with low mountains and hills, and there are small valley flats along the Han River basin. The highest point is Muzhu Mountain at 1,503 meters above sea level. The climate of Houliu town is a subtropical humid monsoon climate, which is characterized by long winter and summer, short spring and autumn, and distinct four seasons. There is plenty of heat, plenty of rainfall, and a mild and humid climate. The annual average temperature is 14.8°C, and the annual average of the growing season is 298 days. The annual average frost-free period is 242 days. The average annual precipitation is 877.1 mm, and the average annual precipitation days are 60 days, up to 80 days. Rainfall is mainly concentrated from July to September every year, with the most in August. Houliu Town within the river is the Yangtze River basin Han River system. The largest river, the Han River, has a length of 5 km and a drainage area of 23 m^2. Other tributaries Zhongba River, Heigou river, and so on.

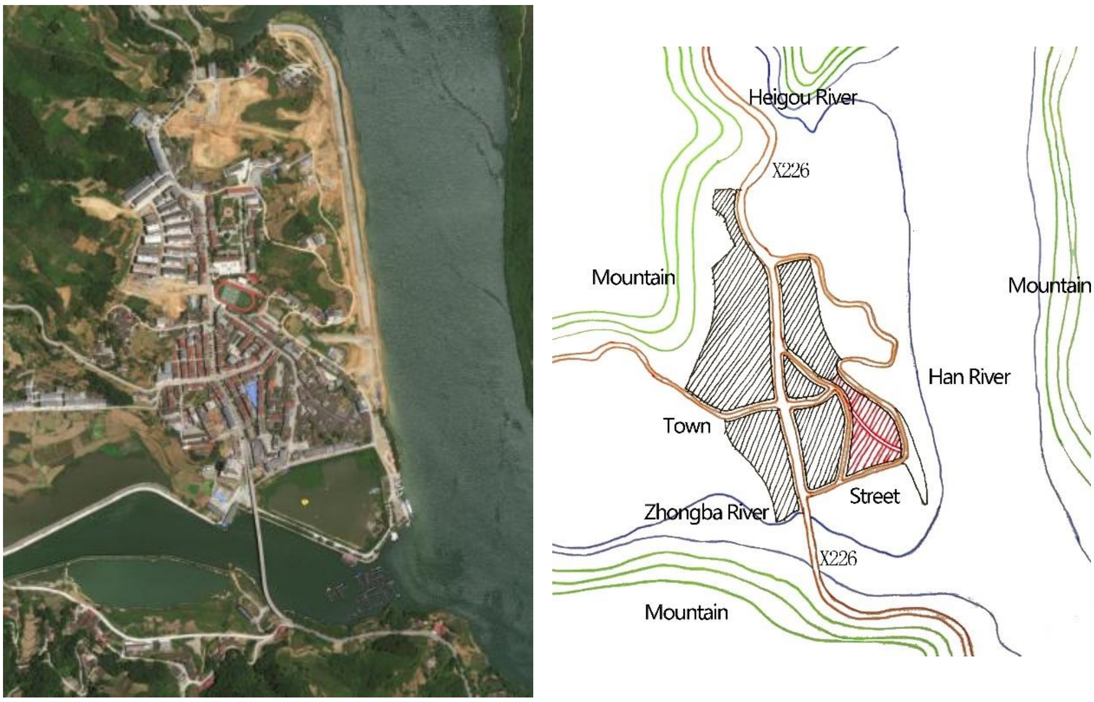


Figure 2-12. Plan of Houliu town

2) Information on traditional houses

The residential buildings in southern Shaanxi are represented by the space construction of "one-font" and stilted buildings, and the "one-font" is the basic constituent unit. Through the horizontal and vertical expansion, the residential buildings form a spatial combination mode mainly based on the use function. Through the vertical combination of terrain elements, stilted buildings conform to the trend of contour lines, forming the characteristics of space construction that combine the use of function, architectural form, and natural environment. The public building space is represented by the hall building, which combines the use function with the economic and social environmental factors and is formed by the demand of business activities. The construction materials of the building are made of local materials. Natural materials are widely used in traditional dwellings, forming a regional construction method. The construction technology reflects the comprehensive consideration of the local climate, terrain, and resource use, and is simple, easy to use and economical, and durable.

3) Analysis of heating methods

The heating method used is similar to other towns. Traditional heating is mainly based on wood burning to raise the temperature of the room. Modern heating relies mainly on electricity for heating.

4) Indoor Thermal Comfort Survey

Similar to the situation in the town before, the indoor temperature is generally low in winter. The traditional heating method can not meet the needs of human thermal comfort.

(12) Shuhe Town

1) Introduction to the township

Shuhe Town is affiliated with Xunyang City, Shaanxi City, and Shaanxi Province. It is located in the east of Xunyang County, east of Xianhe Town and Jingyang Township, Yunxi County of Hubei Province, south of Baihe County, west of Changxi Town, Guankou Town, north of Shuanghe Town. The maximum distance between east and west is 15.5km, and the maximum distance between north and south is 14.2km. Shuhe town is located in the Qinba mountain, the terrain on both sides of the high middle low. The terrain in Zhongshan and shallow hill valley. The main mountains are Daba Mountain and Nanyang Mountain. The highest peak is 1186.9 meters above sea level and the lowest point is Han River Beach. Shuhe town's climate is subtropical mountain humid monsoon climate. The annual average temperature is 15.5℃, the extreme minimum temperature is -20.2℃, and the extreme maximum temperature is 43.1℃. The annual average precipitation is 840 mm, and the rainfall is mainly concentrated from July to October every year. Shuhe town within the river belongs to the Yangtze River basin Han River system. The main river is the Han River, 8.4 km in length; Its main tributaries Shu River, a small water river, and sand ditch 3, the total length of the territory of 35.1 km.

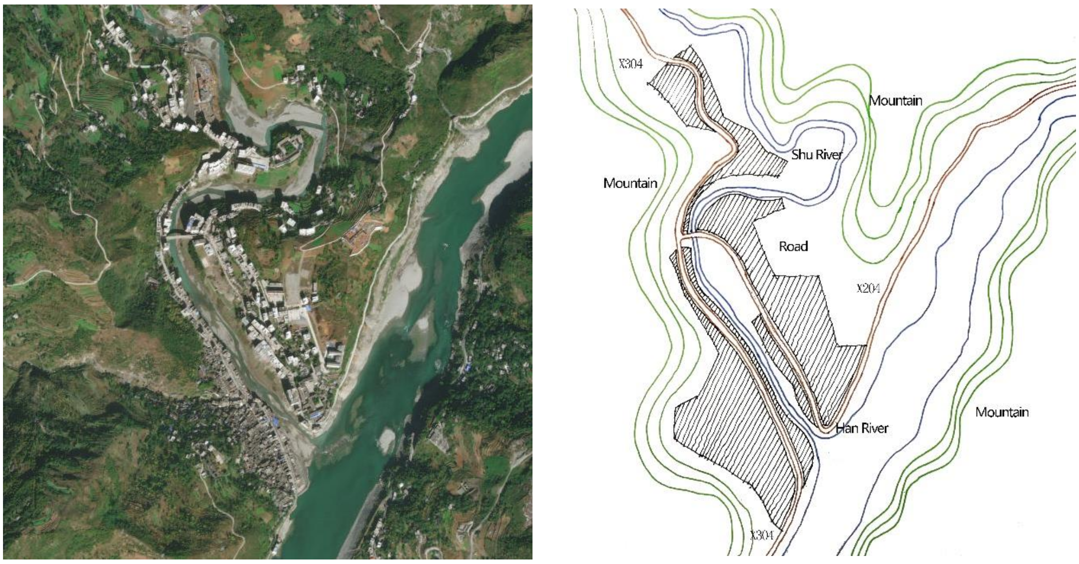


Figure 2-13. Plan of Shuhe town

2) Information on traditional houses

Located on the back slope of Shuhe Street, sitting west to east, back against the hillside, south beside the Han River, facing the Shu River, overlooking the Shuhe Old Street. From the front to the back as a step rise, respectively built the gate building, music building, worship hall, and main hall. Although the building is constructed in stages, it is based on the central axis, symmetrical, hierarchical, and uniform in style. Huangzhou Pavilion is a traditional palace structure with a strong Southern architectural style. All the buildings are brick and wood structures of the Qing Dynasty, beautiful, and do not lose solemn and generous. It was first built in the 12th year of Tongzhi in the Qing Dynasty (1874). It is located on the cliff of the ancient ferry in Shuhe Town, sitting west to east and north to the hillside. According to the remnant tablet, the temple was built no later than the Qianlong period. Although it was named Temple, it was the Ship-gang Hall, because it enshrined the first shipbuilder Yang Siye inside, so it was named "Yangsi Temple".

3) Analysis of heating methods

The heating method used is similar to other towns. Traditional heating is mainly based on wood burning to raise the temperature of the room. Modern heating relies mainly on electricity for heating.

4) Indoor Thermal Comfort Survey

Similar to the situation in the town before, the indoor temperature is generally low in winter. The traditional heating method can not meet the needs of human thermal comfort.

(13) Manchuanguan Town

1) Introduction to the township

Manchuanguan Town is affiliated with Shanyang County, Shangluo City, Shaanxi Province. Located in the southeast of Shanyang County, it is adjacent to Shifo Temple Town in the east, Shangjin Town, Yunxi County, Shiyan City, Hubei Province in the south, Nankuanping Town in the west, and Judge Town in the north. The total area is 266.4 m^2. Manchuanguan town is located in the south of the Guoling Tianzhu Mountain. The terrain is undulating, surrounded by mountains, mountains, south Yunling, east by Taiping Mountain, west the size of Tianchi, northland ridge. The lowest point is located in Xiaohekou, 294 meters above sea level, and is also the lowest point in Shanyang County. The average annual temperature in Manchuanguan town is 14.6 - 16.3℃. The extreme minimum temperature is -10.4℃ and the extreme maximum temperature is 41.5℃. The average annual precipitation is 653 - 758 mm. The annual average frost-free period is 215 - 235 days. The river in the town of Manchuanguan belongs to the Yangtze River basin Han River system. The largest river money River, 26 km in length, is in the small estuary into the Hubei border; Arrow River, within a length of 16 km, and an average width of 15 meters.

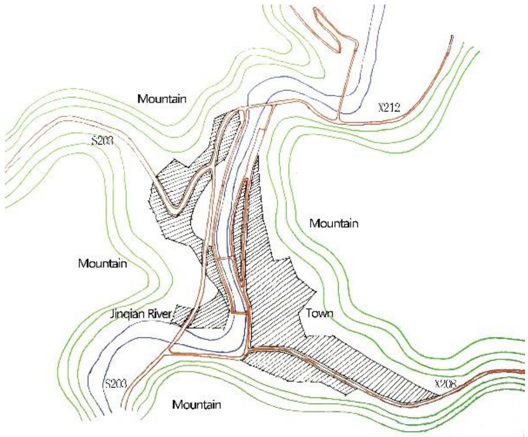


Figure 2-14. Plan of Manchuanguan town

2) Information on traditional houses

In traditional settlements, rivers and contour lines are used as the basis points for the formation of spatial structure, and the spatial form unfolds linearly, while large settlements are formed in clusters and dispersed freely. The hierarchical order is not prominent in the architectural space combination. Typical residential buildings are based on or prototype of the plane pattern of "one-word three connected rooms", forming the plane shape system of "one light and two dark" or "one room and two inside", and evolving various plane space combination forms according to the terrain, with simple and simple architectural style.

3) Analysis of heating methods

The town's traditional residential heating methods as well as heating equipment were investigated. Since the town is small in area, the number of residents is small, and most of them live in scattered houses, so the conditions for centralized heating are not available, and the heating methods in rural areas include active heating and passive heating, with active heating being air conditioning and other heating equipment. Passive heating is mainly the traditional Chinese charcoal heating, mainly with charcoal, including fire pots, fire pits, and fire roasting tables.

4) Indoor Thermal Comfort Survey

Most of the results showed that it was very cold and unbearable in winter, and the charcoal heating could only partially heat the room, and it would be very cold again if we left the heating source. However, the use of household appliances for heating consumes a lot of electricity and makes it difficult to pay high electricity bills. A 24-hour test of several households was chosen for the winter season around January, using temperature and humidity testing instruments. Based on the measurements, the indoor temperature and humidity were unsuitable for human habitation and exceeded the minimum temperature that the human body can tolerate. Therefore, it can be concluded that the thermal comfort of the site continues to improve in winter, while energy saving and emission reduction need to be considered.

(14) Fenghuang Town

1) Introduction to the township

Fenghuang Town belongs to Zhashui County, Shangluo City, Shaanxi Province. Located in the southeast of Zhashui County, it is connected to Wafangkou Town and Xingping Town in the east, bordering Zhen 'an County in the south, adjacent to Xiaoling Town and Caiyuyao Town in the west, and adjacent to Caoping Town in the north. The maximum distance between east and west is 18 km, and the maximum distance between north and south is 23 km. The total area is 167.1 m^2. Fenghuang Town is located on the southern foot of the Qinling Mountains Qinba Mountains. The terrain is mainly mountainous, high in the west and low in the east, with an average elevation of 709 meters. The annual average temperature of Fenghuang Town is 12.8°C. The rainfall is mainly concentrated from June to October and most from August to September. The river course of Phoenix Town belongs to the Yangtze River basin Han River system. There are mainly three rivers, such as Shechuan River, the Zaohe River, and the Shuigou River.

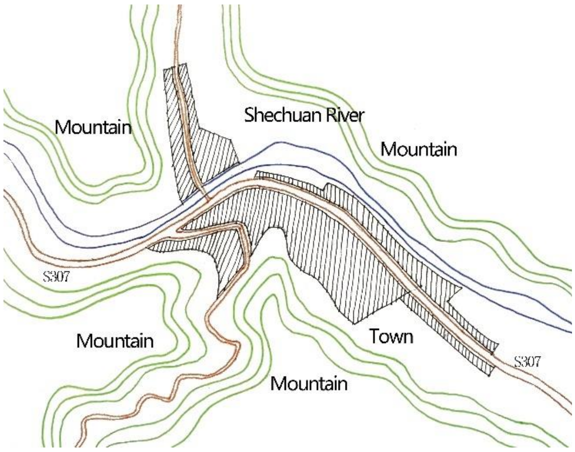


Figure 2-15. Plan of Phoenix township

2) Information on traditional houses

The winding streets and old houses of the Ming and Qing dynasties on both sides of Fenghuang

Town's old street are the biggest features here, where the traditional handmade paper-making and forging still follow the pattern of the past. More than 60 dwellings from the Ming and Qing dynasties are still well preserved in this ancient town, which is more than 2,000 meters long from east to west. A flagstone-covered stream runs along the main street, and another runs perpendicular to it through the town, forming a cross-shaped water system.

The old street is full of shops on both sides of the street, and behind the shops are residential. The street front door is generally made of strong wear-resistant walnut wood or lacquered wood, dyed with soil lacquer oil, bright and bright; The door pier is carved with stone flowers. The width of the shop is not full feet, but the depth of the house is 30 or 40 meters. It is said that the number of storefronts and the depth of the house represent the richness of the owner at that time. The wooden dwellings in Fenghuang Town are small and exquisite, with exquisite and reasonable design and good rain, moisture, moisture, and fire resistance. Compared with the traditional dwellings in the north, they have many features of the southern dwellings.

Now Phoenix town is relatively small, the town is mainly a simple single old street, people come and go on the street, suitable for idle wandering, do not have to expect too much, easy to experience the local traditional life and market is a good choice. There are many silk presses in Fenghuang Town. The silk goods here are made of the local special presses of silk, which are more durable than the presses of mulberry silk. The women here still draw, dye, and spin their silk, but the output is very small. There are also the remains of an old shanzhai on a nearby hill. The old trade of blacksmithy is still alive. You can stay at night in the town. At night, you can stand on the east hill overlooking the town. The network of streets is lit, and the brightest place is the central street of the "S" shaped old street.

3) Analysis of heating methods

The town's traditional residential heating methods as well as heating equipment were investigated. Since the town is small in area, the number of residents is small, and most of them live in scattered houses, so the conditions for centralized heating are not available, and the heating methods in rural areas include active heating and passive heating, with active heating being air conditioning and other heating equipment. Passive heating is mainly the traditional Chinese charcoal heating, mainly with charcoal, including fire pots, fire pits, and fire roasting tables.

4) Indoor Thermal Comfort Survey

Most of the results showed that it was very cold and unbearable in winter, and the charcoal heating could only partially heat the room, and it would be very cold again if we left the heating source. However, the use of household appliances for heating consumes a lot of electricity and makes it difficult to pay high electricity bills. A 24-hour test of several households was chosen for the winter season around January, using temperature and humidity testing instruments. Based on the measurements, the indoor temperature and humidity were unsuitable for human habitation and exceeded the minimum temperature that the human body can tolerate. Therefore, it can be concluded that the thermal comfort of the site continues to improve in winter, while energy saving and emission reduction need to be considered.

(15) Qingtongguan Town

1) Introduction to the township

Qingtongguan Town belongs to Zhen 'an County, Shangluo City, Shaanxi Province. It is located in the south of Zhen 'an County, on the Qianyou River, adjacent to Xikou Town in the east, Xiaohe Town in Xunyang City, Shaanxi City in the south, Chaiping Town in the west, Yongle Street in the north, and Gaofeng Town in the northeast. The maximum distance between east and west is 22 km, and the maximum distance between north and south is 24 km, with a total area of 277.52 m^2. Qingtongguan Town is inside a steep terrain, gully crisscrossed, mainly mountainous. The main mountains are Tayun Mountain and Beiyang Mountain, with the highest point at 1920.5 meters above sea level. The lowest point is located in Shijiagou, Shizhe Village, 344 meters above sea level, is also the lowest point in Zhen 'an County. The annual average temperature of Qingtongguan Town is 14.6°C. The annual average sunshine duration is 1947.8 hours, and the annual average frost-free period is 220 days. The annual average precipitation is 812.4 mm, and the rainfall is mainly concentrated from July to October, with the most in October. Qingtongguan Town is in the Yangtze River basin Han River system. The main river, the Qianyou River, runs from north to south through 8 villages, including Fengshou, Dongping, Lengshui, Zhangjiaping, Tongguan, Qianwan, Xiangzhong, and Qingmei, with a length of 20.5 km.

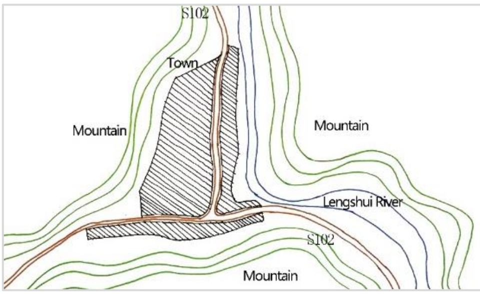


Figure 2-16. Plan of Qingtongguan town

2) Information on traditional houses

The old street along the river layout, with the river bend and curve, plane arc. With a total length of more than 532 meters, the layout of street houses on both sides of the street is complete and the style is well preserved. Unlike the quadrangle courtyard organized by deep and narrow patios of similar street houses in Shaanxi and Shangluo, the layout is flexible according to the terrain, resulting in different proportions of widths and widths and various combinations of horizontal and vertical patios. The space is relatively slow and open, and the main courtyard, side courtyard, front and back yard, and cross yard are common. The entrance is also not central, combined with function or terrain on one side of the case is very common. At the same time, due to the terrain fluctuation and land tension, residential buildings are often organized in combination with the terrain and height difference, and the front and side rooms of each yard are often not in the same contour line.

3) Analysis of heating methods

The heating method used is similar to other towns. Traditional heating is mainly based on wood burning to raise the temperature of the room. Modern heating relies mainly on electricity for heating.

4) Indoor Thermal Comfort Survey

Similar to the situation in the town before, the indoor temperature is generally low in winter. The traditional heating method can not meet the needs of human thermal comfort.

(16) Yungaisi Town

1) Introduction to the township

Yungaisi Town belongs to Zhen 'an County, Shangluo City, Shaanxi Province. Located in the west of Zhen 'a County, it is connected with Yongle Street and Huilong Town in the east, Dongchuan Town in the west, Miaogou Town in the south, and Qianyou Town in Zhashui County in the north. The maximum distance between east and west is 14.6 km, and the maximum distance between north and south is 24.4 km. The total area is 210.51 m^2. Yungai Temple town is high in the northwest and low in the southeast. The territory is mainly mountainous, the main mountains have the wind convex ridge, Kowloon top mountain, and Zi bridge valley mountain. The highest point is located in Heiyaogou Village, with an altitude of 2,428.2 meters; The lowest point is located at the mouth of Getiaogou, 705.6 meters above sea level. The annual average temperature of Yungaisi town is 12.5℃. The annual average sunshine duration is 1947.3 hours, the annual average frost-free period is 212 days, and the annual average precipitation is 869 mm. Yungai Temple town is in the Yangtze River basin Han River system. The main river county River, Qianyou River tributaries, originated from the Black Yaogou labyrinth and Xiaomuling and flows through Yunzhen village, Yanwan village, and county city, with a flow length of 33 km.

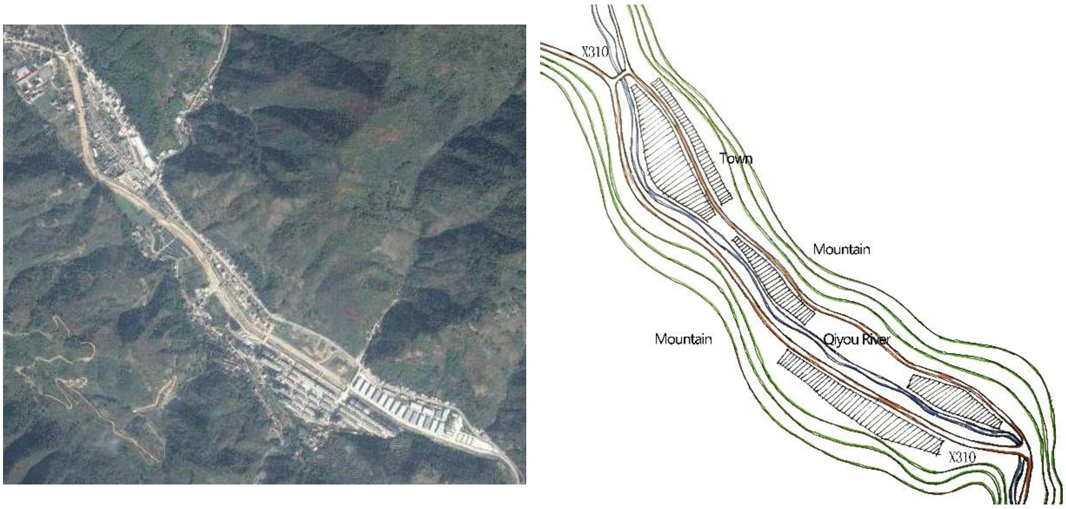


Figure 2-17. Plan of Yungaisi town

2) Information on traditional houses

The ancient town is formed by the water, which varies according to the mountain and the place, and is flexible and diverse. Trade set up a town, Jia city, and live (Old Street), Zifang Village was built against the risk, according to the potential of the city, its unique architectural style and pattern have gone through thousands of years. Years are more valuable after. According to the landscape analysis hierarchy, the local ancient architecture space landscape is according to macro. The analysis is carried out at the level of view, meso, and micro.

3) Analysis of heating methods

The town's traditional residential heating methods as well as heating equipment were investigated. Since the town is small in area, the number of residents is small, and most of them live in scattered houses, so the conditions for centralized heating are not available, and the heating methods in rural areas include active heating and passive heating, with active heating being air conditioning and other heating equipment. Passive heating is mainly the traditional Chinese charcoal heating, mainly with charcoal, including fire pots, fire pits, and fire roasting tables.

4) Indoor Thermal Comfort Survey

Similar to the situation in the town before, the indoor temperature is generally low in winter. The traditional heating method can not meet the needs of human thermal comfort.

(17) Zhaochuan Town

1) Introduction to the township

Zhaochuan Town belongs to Shangnan County, Shangluo City, Shaanxi Province. It is located in the south of Shangnan County, the middle and lower reaches of Taohe River Basin, bordering Yunxian County and Yunxi County of the Shiyan City of Hubei Province in the east, south, and west, adjacent to Weijiatai Town in the north and northeast, and connected to Shiliping Town in the northwest. The total area is 317.21 m^2. Zhaochuanzhen landform to low hills, high north low terrain. The main mountains are Yuhuangding, and Zhonggu Mountain, the highest peak in the territory Yuhuangding, 1030 meters above sea level. Zhaochuan town within the river is the Yangtze River basin Danjiang River system. The territory of the largest river Tao River, through the territory of the village after Chuan, Qianchuan village, stone dam River village, old house Bay village, and silt Bay village, flow length of 25 km. Zhao Chuanzhen has been proven to have underground mineral resources barite, marble, iron, topaz, and so on. The existing initial production of 1 iron ore, 1 barite ore, marble, and xanthite ore spot 2. Agricultural farmland covers an area of 28,000 mu and woodland covers an area of 176,000 mu.

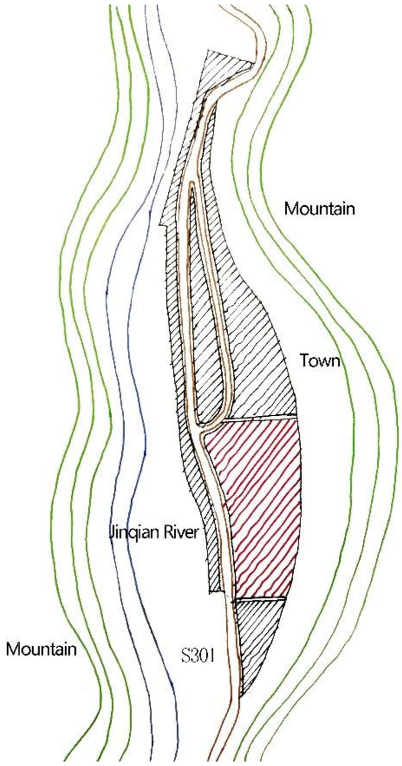


Figure 2-18. Plan of Zhaochuan town

2) Information on traditional houses

As a whole, the mountain from the foot of the mountain with the height of the gentle slope and gradually rising, the whole ancient. The town was built here along the winding river. According to the change of terrain, the flat land is built housing, some in the relatively flat area at the foot of the mountain, or the open area in the valley, made the forms of the dwellings different. Because of the obvious changes in the terrain, there is an obvious "S" shape in the overall pattern of the street. To vary, etc. Based on the high line, the buildings also vary. The scale of the dwellings near the mountain is smaller and the density is increasing, whereas the scale is on the other side. Large and low-density, some courtyards appear on both sides of the road. Therefore, a bird 's-eye view of the whole town is formed Phoenix-like, close to the foot of the phoenix mouth, land constraints will appear clustered state. And it's perpendicular to space. The main body is the roof. The curve of the firewall makes the whole vertical height of the building change obviously, and because of the local people. The house is built in conjunction with the mountain, which allows the original curved skyline to blend into the vertical morphology of the landscape. If viewed from the top of the mountain, the alleys, and old streets will be connected with the ups and downs of the roof, forming a whole, every piece of the sky reflected by the roof makes all the courtyards feel comfortable and quiet. Looking down from above, the whole of phoenix towns has a kind of kinetic beauty.

3) Analysis of heating methods

The town's traditional residential heating methods as well as heating equipment were investigated. Since the town is small in area, the number of residents is small, and most of them live in scattered houses, so the conditions for centralized heating are not available, and the heating methods in rural areas include active heating and passive heating, with active heating being air conditioning and other heating equipment. Passive heating is mainly the traditional Chinese charcoal heating, mainly with charcoal, including fire pots, fire pits, and fire roasting tables.

4) Indoor Thermal Comfort Survey

Most of the results showed that it was very cold and unbearable in winter, and the charcoal heating could only partially heat the room, and it would be very cold again if we left the heating source. However, the use of household appliances for heating consumes a lot of electricity and makes it difficult to pay high electricity bills. A 24-hour test of several households was chosen for the winter season around January, using temperature and humidity testing instruments. Based on the measurements, the indoor temperature and humidity were unsuitable for human habitation and exceeded the minimum temperature that the human body can tolerate. Therefore, it can be concluded that the thermal comfort of the site continues to improve in winter, while energy saving and emission reduction need to be considered.

(18) Xiaoling Town

1) Introduction to the township

Xiaoling Town belongs to Zhashui County, Shangluo City, Shaanxi Province. Located in the middle of Zhashui County, it is connected with Fenghuang Town in the east, Huilong Town in Zhen 'an County in the south, Shiweng Town in the west, and Caiyuyao Town in the north. The maximum distance between east and west is 15 km, and the maximum distance between north and south is 13 km, with a total area of 115.06 m^2. Xiaoling town is located in the hinterland of the Qinling Mountains, the terrain is high in the northwest and low in the southeast. The terrain is divided into two parts: the west is surrounded by mountains, and the east is the Sichuan landform. The main mountains are Guangdong Mountain, 2062 meters above sea level; The lowest point is located in Mulberry Street, Changwan Village, 730 meters above sea level. The annual average temperature in Xiaoling Town is 12.5°C. The average temperature in January was 0.3 °C and the extreme minimum temperature was -15 °C (10 January 1991); The mean temperature in July was 23.6 °C and the extreme maximum temperature was 37.8 °C (12 July 2003). The annual average is 220 days in the growing season and 209 days in the frost-free season. The annual average precipitation is 750 mm, and the rainfall is mainly concentrated from July to September every year. Xiaoling Town within the river belongs to the Yangtze River basin Han River system. The main river has the Shechuan River, its tributaries have Che shed ditch, Lingfeng River, Zhenggou River, and so on 10.

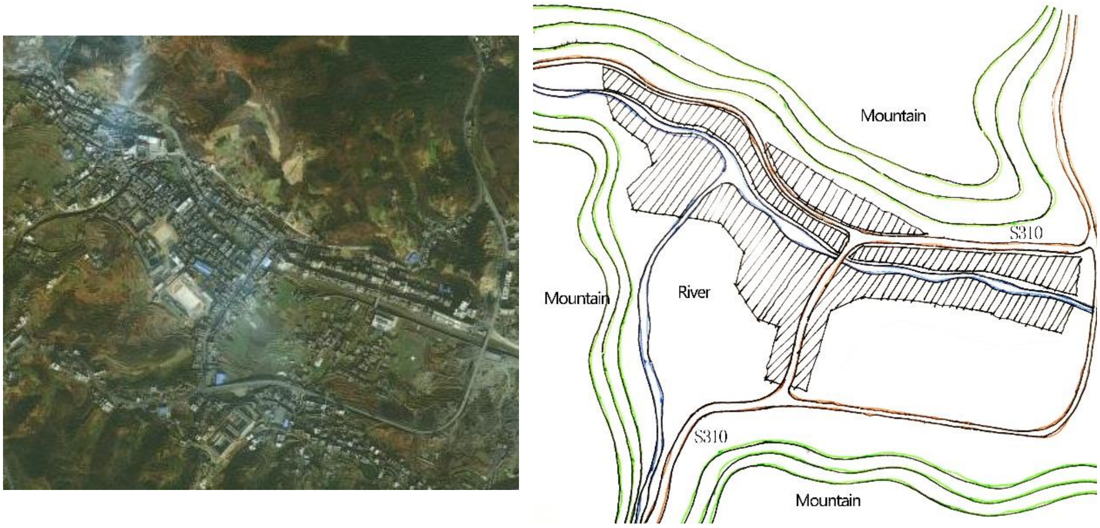


Figure 2-19. Town plan of Xiaoling town

2) Information on traditional houses

A continuous linear layout along the water; The road is fishbone, the street is parallel to the river; The building layout follows the direction of the river; Some areas use the "backwater" layout; The building is mostly one layer, the cornice is about 3.4m high, the street width is 3 ~ 5m, the street width-height ratio D/H=l, with a balanced, stable sense of scale, friendly but not closed. Surrounded by shops or houses on both sides, the ratio of street width to building height on both sides is generally about 1, which is pleasant, while the ratio of roadway width to building height as a neighborhood passage is mostly less than 1, which gives people a stable and friendly feeling. Based on the two-slope roof, it often forms a rich skyline and street landscape through the changes in the height and retreat of the building, the changes in the gable form, and the changes in the facade.

3) Analysis of heating methods

The town's traditional residential heating methods as well as heating equipment were investigated. Since the town is small in area, the number of residents is small, and most of them live in scattered houses, so the conditions for centralized heating are not available, and the heating methods in rural areas include active heating and passive heating, with active heating being air conditioning and other heating equipment. Passive heating is mainly the traditional Chinese charcoal heating, mainly with charcoal, including fire pots, fire pits, and fire roasting tables.

4) Indoor Thermal Comfort Survey

Most of the results showed that it was very cold and unbearable in winter, and the charcoal heating could only partially heat the room, and it would be very cold again if we left the heating source. However, the use of household appliances for heating consumes a lot of electricity and makes it difficult to pay high electricity bills. A 24-hour test of several households was chosen for the winter season around January, using temperature and humidity testing instruments. Based on the measurements, the indoor temperature and humidity were unsuitable for human habitation and exceeded the minimum temperature that the human body can tolerate. Therefore, it can be concluded that the thermal comfort of the site continues to improve in winter, while energy saving and emission reduction need to be considered.

2.3 Study of the Function and Construction Techniques of Residences

2.3.1 Spatial Functions of Traditional houses

(1) Line style

Line style is generally composed of open space, secondary space, and tip space. In Shaanxi folk houses, the "one-word" flat houses are mainly distributed in rural areas. This kind of house is known locally as "a lock". These dwellings are usually three rooms, usually with an open room as a hall and two rooms as a bedroom [14]. The kitchen is usually placed at the side of the building, against the gable. This kind of residential general front yard is relatively small, built on the second floor of the attic for storage. In addition, part of the "one-word" residential houses adopt five rooms.

(2) “L” style

"L" shaped courtyard, the plane figure of the building is composed of two separate monomers, one horizontal and one vertical, which are perpendicular to each other. The plane overlooking is like the letter "L", that is, it is composed of the main house and a house on one side. Since the main house is generally north and south [15], the vertical house is called "East House" or "West House" according to the location of its construction.

Generally, the house is perpendicular to the main house, and the two houses do not intersect, leaving walkway space. But according to the production and living needs of the villagers, the main house and the house will be built around the corner of the low room, mostly used for the kitchen or storage room. According to the economic strength of the residents choose to add walls or open courtyard space.

(3) “U” style

The building plan of the siheyuan is "concave" with one square and two horizontal and vertical, which means two houses are built vertically in the same direction as the main house. Due to the enclosure on three sides, the center automatically forms a sub-space. The main room is usually still three or more rooms, mostly singular. The houses on both sides are slightly smaller, mostly two or three. The main room is not connected to the two sides of the mansion, leaving enough aisle space, or left for clutter. Residents generally choose whether to build walls according to their economic strength. Generally, the siheyuan is enough to enclose all the land of the residents and will not be further enclosed. However, some residents with better economic strength will further enclose the courtyard to form independent courtyard space for their safety and other living needs.

(4) Courtyard style

A courtyard style is an important form of traditional residential architecture. The model of a compound courtyard building in north China is Beijing Siheyuan. The typical characteristic of traditional dwellings in southern China is the patio courtyard. The courtyard space of the Shaanxi area is the typical courtyard. Its prominent feature is that the roof is connected with the roof, and the space formed in the middle is the "courtyard". The drainage of the courtyard roof can be divided into organized drainage and unorganized drainage. The courtyard with organized drainage usually uses a "sky bucket" to cover the "courtyard". The water is first drained to the roof on all sides of the courtyard, and then the water can be used to drain down the water mouth at the intersection of the eaves through the water from the high eaves, so there is no drainage ditch in the yard. Unorganized drainage is the direct discharge of water from the eaves into the yard gutters [16]. The courtyard space in the Shaanxi area mainly includes "one courtyard" and "two courtyards". "One into the courtyard" is called "one bite in" by locals. The plane of the "one into the courtyard" is usually composed of the gatehouse, the side room, and the main room, while the "two into the courtyard" is usually composed of the gatehouse, the side room, the nave, the main hall, and the ear room.

Generally, the main room is five rooms, and the side room is three rooms. The two-enter courtyard residential buildings cover an area of about 600-700 square meters. Generally, three-room one-entry courtyard residential buildings cover an area of about 240-250 square meters. The three-bedroom building covers an area of about 300-400 square meters.

2.3.2 Construction Technology of Traditional houses

China has a vast territory and a long history. Over a long time, people have created and developed a structural system with wood structure, which represents the eastern architectural system, based on their resources, unique historical conditions, cultural literacy, and aesthetic taste, that is, what we call the wood architectural framework or wood framework. For thousands of years, the wood frame has been widely used and improved from palace buildings to folk houses [17]. In this kind of wooden frame system building, the exterior wall is only the maintenance structure, and the wooden frame bears the load of the whole building. Therefore, the study of ancient Chinese architecture is focused on the wooden frame. There are two main types of Chinese wooden frames: one is the beam type frame and the other is the piercing type, also known as the piercing type frame. Due to the strict production of beam lifting frame, strict materials, and strict system, the ancient palace, temple, and large memorial buildings usually used in some areas of folk architecture is also commonly used in the simple beam lifting frame form. The characteristics of the perforated wood frame are that it is directly supported on the columns, and several layers of perforated poplars are connected between the columns to form a group of shelves. The shelves are connected with braces and other components to strengthen the stiffness, to form the frame system of the wood frame space. Because of the simple production of this structure, flexible arrangement, and ease of change and decoration, local folk craftsmen in practice develop it in various shapes and forms, full of vitality.

The perforated bucket structure is the most common structural system in traditional residential houses in the Hanzhong area. It is relatively simple in structure, compact and stable, and does not need tall wood like the beam structure. It is easy to source materials, easy to construct, and relatively easy to repair and adjust [18].

The perforated frame, also known as the perforated frame, is an important form of ancient Chinese wooden architecture. Its main feature is that the upper beam frame is supported by dense columns, and the eraser of the roof rafters and the switchboard are directly placed on the capitals. There are no girders and overlapping beams on the capitals, and only some perforated beams are used between the columns to ensure the transverse connection between the columns.

In the perforated structure, the columns are arranged in rows according to the depth of the house, and Rinko is erected on the top of each row of columns so that the roof load on the Rinko is directly transferred to the columns. Each row of columns is connected with poplars that can penetrate the column body, forming a complete structural frame similar to the shelving in modern structures. To form a spatial structure that can cover a room. Luoyang is used between the eave column in the direction of the room, and the pull is used between the inner column, which is somewhat similar to the function of the forehead square or the inner forehead in the beam structure [19].

There are some more commonly used forms of the structure, such as three scraping three pillars one wear, five in five columns two wear, eleven in eleven columns five wear, and other structural forms. Because the columns of the perforated structure are thinner and the spacing between them is smaller, to prevent the columns from being too dense and affecting the use of the room, the frame is sometimes changed to every other column landing according to each column.

2.4 Study on Indoor Thermal Comfort of Traditional Traditional Houses

2.4.1 Indoor Thermal Comfort Test

To thoroughly study the indoor thermal comfort of residential houses in southern Shaanxi in winter, a residence was selected and its indoor temperature, humidity, and wind speed were tested for three days using a temperature and humidity meter and an anemometer with a temperature sampling interval of one hour. The sampling locations and the test results are shown in Figure 2-20, Figure 2-21, Figure 2-22, Figure 2-23.

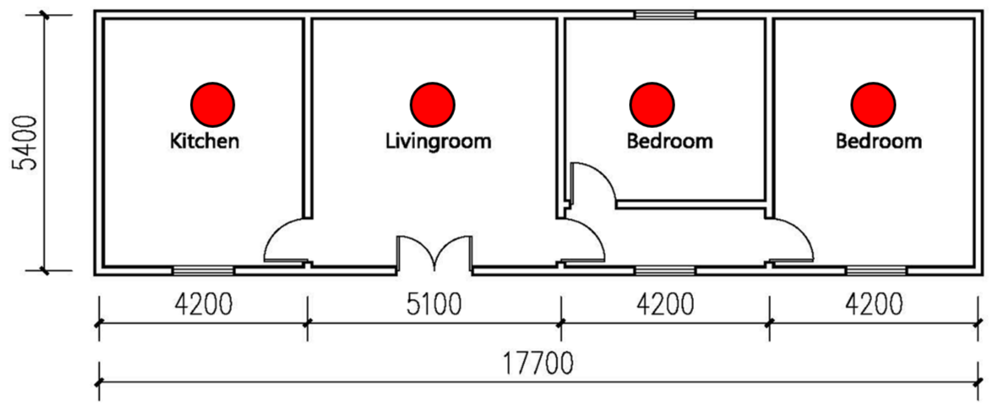


Figure 2-20. Distribution of test points

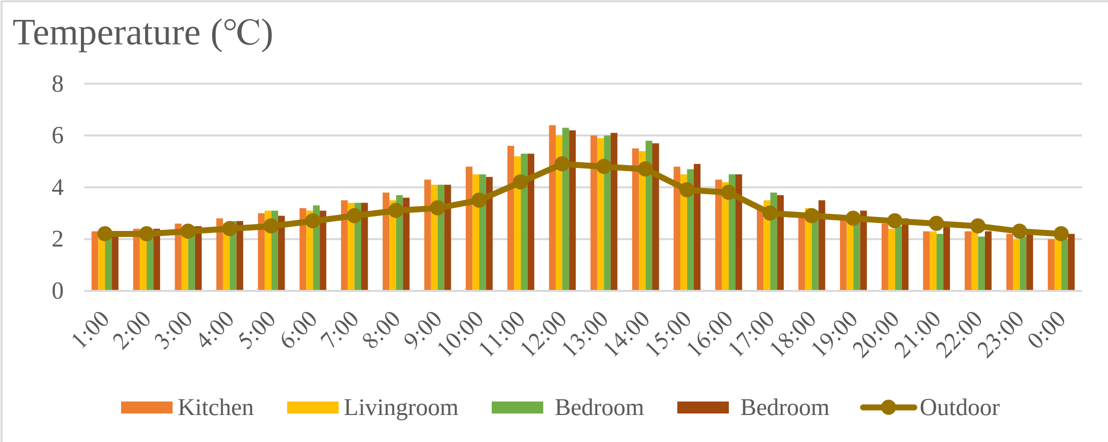


Figure 2-21. Indoor temperature variation

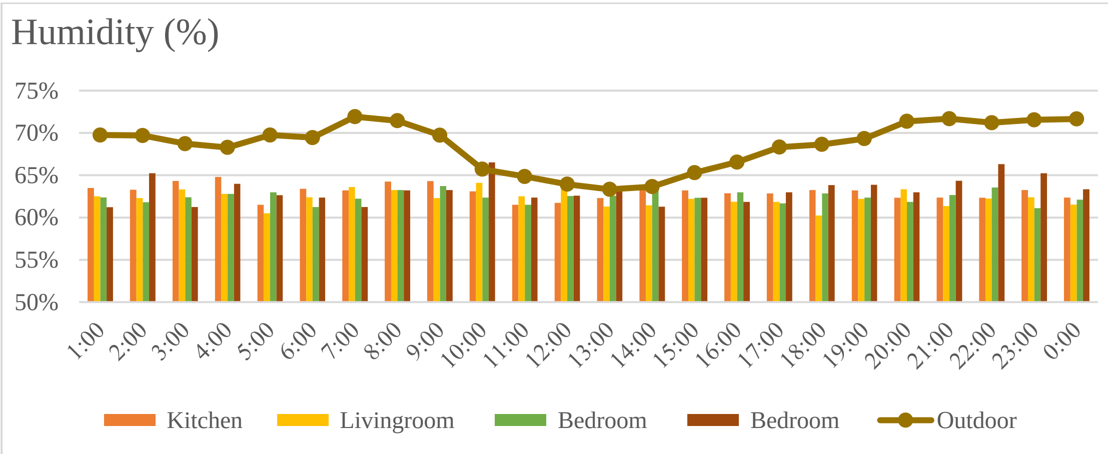


Figure 2-22. Indoor humidity variation

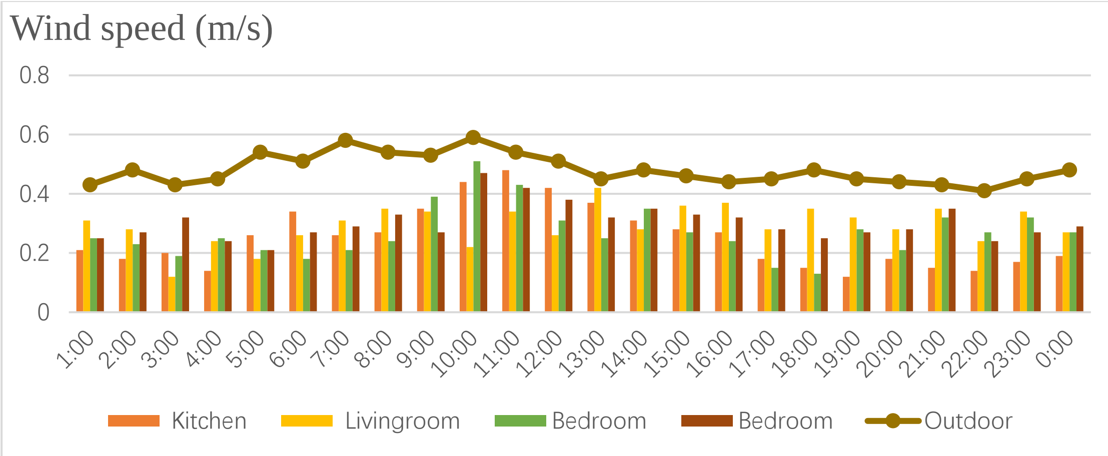


Figure 2-23. Indoor wind speed variation

By comparing the test values with the specifications and through questionnaires, it was concluded that the indoor thermal comfort values of traditional dwellings in southern Shaanxi do not meet human needs and are very cold in winter, and a study is needed to propose a reasonable method to solve this problem.

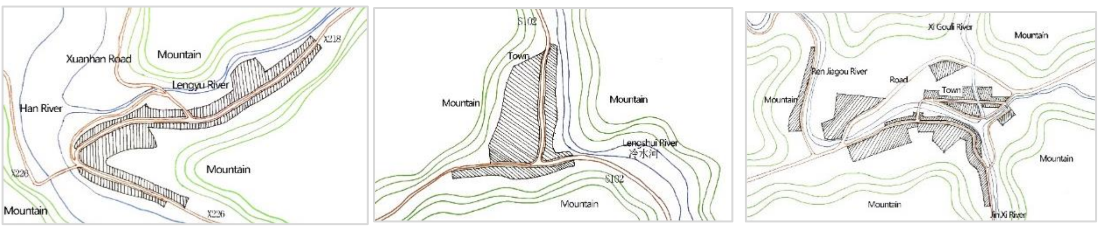
2.4.2 Indoor Thermal Comfort Study

Through the above analysis, it can be seen that the indoor temperature of traditional dwellings in southern Shaanxi is low in winter, which can not meet the needs of human thermal comfort. The reasons for this are various, such as the low efficiency of heating equipment, the poor thermal performance of building materials, and the high ventilation rate of buildings.

2.5 Investigation Summary Analysis

Through the above research and analysis, the situation of the townships in southern Shaanxi is as follows.

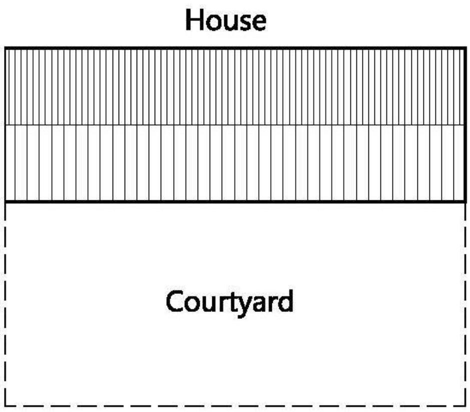
1. Township forms are mainly ribbon type, centralized type, and scattered type, with ribbon type being the main type, accounting for 50%.



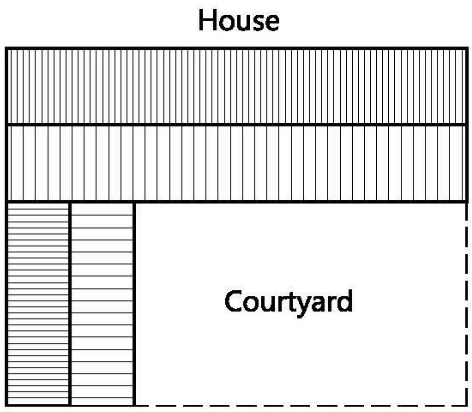
(a). Ribbon type **(b). Centralized type** **(c) Scattered type**

Figure 2-24. Township spatial form

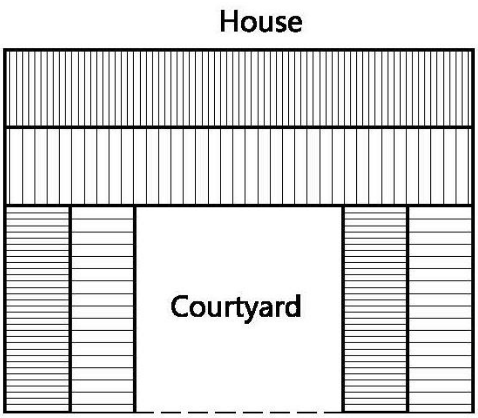
2. The courtyard form of traditional residential houses includes Line type, “L” type, “U” type, and Patio type, with Line type being the majority.



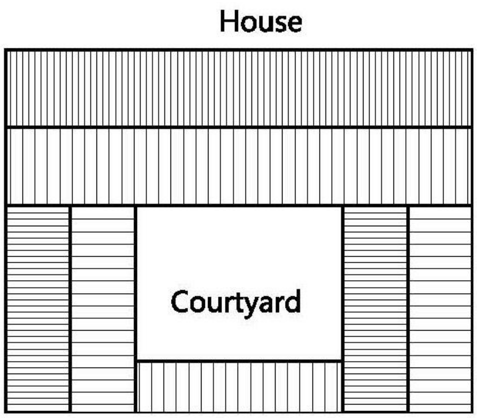
(a). Line type



(b). “L” type



(c). “U” type



(d). Patio type

Figure 2-25. Courtyard layout form

3. There are two main ways to heat the room in winter, household appliances as well as firewood for heating.

Figure 2-26. Current heating method

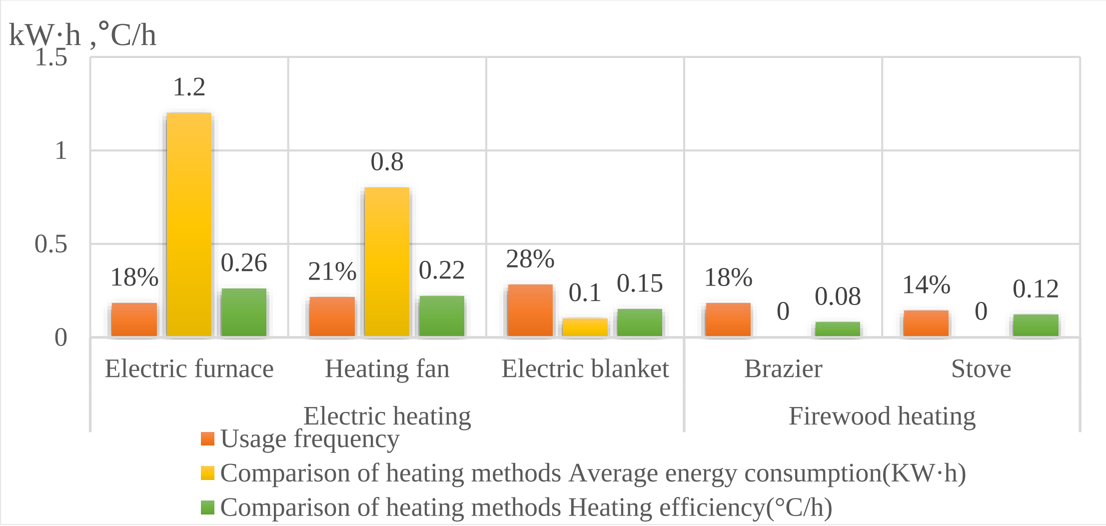


Figure 2-27. Comparative analysis of current heating methods

4. The materials used for traditional residential construction in southern Shaanxi include clay, wood, brick, tile, and stone. Most of the houses are self-built, so the envelope structure is less considered for insulation design.

Figure 2-28. Building materials of traditional houses

5. Taking the layout form of a linear traditional house as an example, its unit plan and section are shown in the Figure The functions mainly include the kitchen, living room, and bedroom. Generally, the house has two floors, and the second floor is an attic for storage.

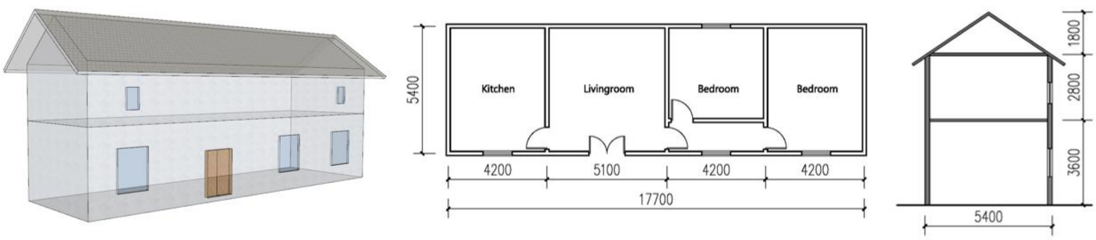


Figure 2-29. Unit plan and sectional view of traditional houses

2.6 Research Question

As traditional residential houses are mostly self-built, when they are built, they lack thermal environment consideration and lack insulation and dehumidification of the building, resulting in not meeting the needs of the human body. Through research and indoor thermal environment testing, and by comparing residential indoor thermal comfort norms, a comprehensive analysis has led to the following research problems.

(1) Indoor thermal comfort does not meet the needs of human use

The indoor thermal comfort of traditional residential houses cannot meet the needs of the human body, and even if the existing heating methods are used, they cannot meet the winter indoor temperature requirements needed by the human body.

(2) Low heating efficiency of Xi'an's heating methods

The existing firewood heating method is more commonly used, but its heating efficiency is low, and the heating range is also limited, more than a certain range of fire sources, the indoor temperature has not been significantly improved.

(3) Heating equipment energy consumption is too large

To maintain the temperature demand, the continuous burning of a large amount of firewood will also cause a large energy consumption, but also increase carbon emissions. The use of electrical heating methods, and excessive energy consumption, will also cause large energy consumption.

(4) The envelope structure lacks thermal insulation design methods

The lack of thermal insulation design measures for the building envelope directly leads to excessive energy consumption.

2.7 Chapter Summary

This section mainly focuses on the investigation of 18 villages and summarizes the space, functions, building technology, and heating methods of traditional dwellings in southern Shaanxi. It can be seen from the analysis that the indoor temperature of traditional dwellings in southern Shaanxi is low in winter, which does not meet the requirements of human thermal comfort.

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Chapter 3. Characteristics and Types of Traditional Houses in Southern Shaanxi

3.1 Natural Conditions

3.1.1 Physical Geography

1. Topography

Southern Shaanxi is one of the three natural regions in Shaanxi Province[1]. It is adjacent to Sanmenxia and Nanyang in Henan Province to the east, Chongqing, Guangyuan, Bazhong, and Wanyuan in Sichuan Province and Shiyan in Hubei Province to the south, Longnan in Gansu Province to the west, and Xi'an, Baoji and Weinan across the Qinling Mountains to the north (Table 3-1). Southern Shaanxi belongs to the Qinba Mountain region of China in terms of geographical unit type, and the landscape is mainly mountainous [2]. The Qinling Mountains in the north, the Ba Mountains in the south, and the Han River in the middle form a landscape pattern of "two mountains sandwiching one river" (Table 3-1).

Table 3-1. Geography of Southern Shaanxi

Terrain topography		Elevation	Overview	Remarks (Region)
Two Mountains	Qinling Mountains	2000～2500m	A huge mountain system extending east-west in the center, the middle section of the Qinling Mountains in Shaanxi, stretching 400-500km from east to west and 100-150km wide from north to south, with high and steep slopes.	Luyang, Liuba, Foping, Ningxia, Zhen'an, Zhushui, Luonan, Shangxian, Shanyang, etc.
	Bashan Mountains	2060～2500m	The mountains rise from the valley of the Jialing River in the west and tower between Shaanxi, Sichuan, and Hubei provinces, with a length of 600km in Shaanxi Province.	Zhenba, Nanzheng, Zhenping, Langao, Ziyang, Pingli, etc.
One river	Hilly basins and valleys along the Han River	170～800m	About 400km long from east to west and 3 to 60km wide from north to south, the Han River flows through the central part, forming several basin areas mainly in the Hanzhong Basin (Figure 4-1-2) and the Shiquan-Shaanxi Basin.	Hanzhong, Shiquan, Shaanxi, Xixiang, Xunyang, etc.

2. Climate Characteristics

Historically, the climate of southern Shaanxi has undergone four periods of warm and cold changes and alternating wet and dry periods [3]. The fourth cold period, which lasted from the 15th century to the present, was a period of significant temperature fluctuations, producing four colder periods and three warming periods (Table 3-2). This has been one of the influencing factors for population migration and its scale changes in the historical period in southern Shaanxi [4]. In the Tang Dynasty, it was recorded that the climate caused a drought: "From Longxi to Baoxia and Liang, thousands of miles within the territory of hyper-yang, people were scattered" [5]. In the Ming Dynasty, it was also recorded that in the fourth and fifth years of Zhengde, "many people were left behind" due to drought [6]. Natural disasters in southern Shaanxi are linked, i.e., one kind of disaster can trigger another kind of disaster or transform into another kind of disaster, mainly in the form of landslides caused by heavy rains or mudslides and landslides caused by floods caused by heavy rains. Landslides and mudslides are more frequent in the Qinling, Bashan, and lower hilly areas, and less frequent in the Hanzhong, Shiquan-Shaanxi, and Shangzhou-Danfeng basins. In the 2134 years from the third year after Han Gao (185 BC) to the 38th year of the Republic of China (1949), there were 72 disasters caused by heavy rainfall in the Hanzhong area. 580 years from around the 15th century to 1983, there were 17 catastrophic floods in Shaanxi, and more than 50 floods were recorded in Shangluo from the Tang Dynasty to the 1990s. According to statistics, from the beginning of the Western Han Dynasty (189BC) to 2012, floods occurred more than 140 times in the upper Han River. Floods occurred mostly in the summer and secondarily in the fall, resulting in a significant reduction in autumn grain production and the destruction of a large number of residential buildings. The largest flood in southern Shaanxi in recent years occurred in 2002, when short-lived heavy rainfall occurred in Foping, Yangxian, Xixiang, Ningxia, and Zhen'an, causing flash floods, landslides, mudslides, and other disasters, resulting in a once-in-a-thousand-year flood on the Ziwu and Xun rivers, which caused heavy damage.

Table 3-2. Climatic conditions in southern Shaanxi.

Region	Annual mean temperature (°C)	Average annual sunshine hours (H)	Mean annual precipitation (mm)	Altitude (m)
Hanzhong	10.6-19.2	1273-2031	598-1463	371.2-2610
Shaanxi	12-15.7	1495-1840	700-1280	170-2964.6
Shangluo	11-14	1874-2124	706-845	215.4-2802.1

Shaanxi Province is divided into three climatic zones from south to north: the northern subtropical zone, the warm temperate zone, and the middle temperate zone, each of which is divided into humid, semi-humid, semi-arid, and arid climates [7]. The climate of southern Shaanxi province belongs to the northern subtropical zone and the southern warm temperate zone, among which, the northern subtropical zone is divided into the Hanzhong-Shaanxi Hanjiang River Valley Basin humid climate zone and the Micang Mountain-Daba Mountain over-humid climate zone; the southern warm temperate zone is divided into the Qinling Mountain humid climate zone and the Shangluo Danjiang River Valley Basin semi-humid climate zone (Figure 3-1).

The distribution of sunshine hours is less in the south and more in the north. The average annual total solar radiation is influenced by the cloudiness and sunshine hours of each region, and it gradually increases from south to north, with the lowest 3.69×109J/M^2 in the south and the highest 5.02×109J/M^2 in the north.

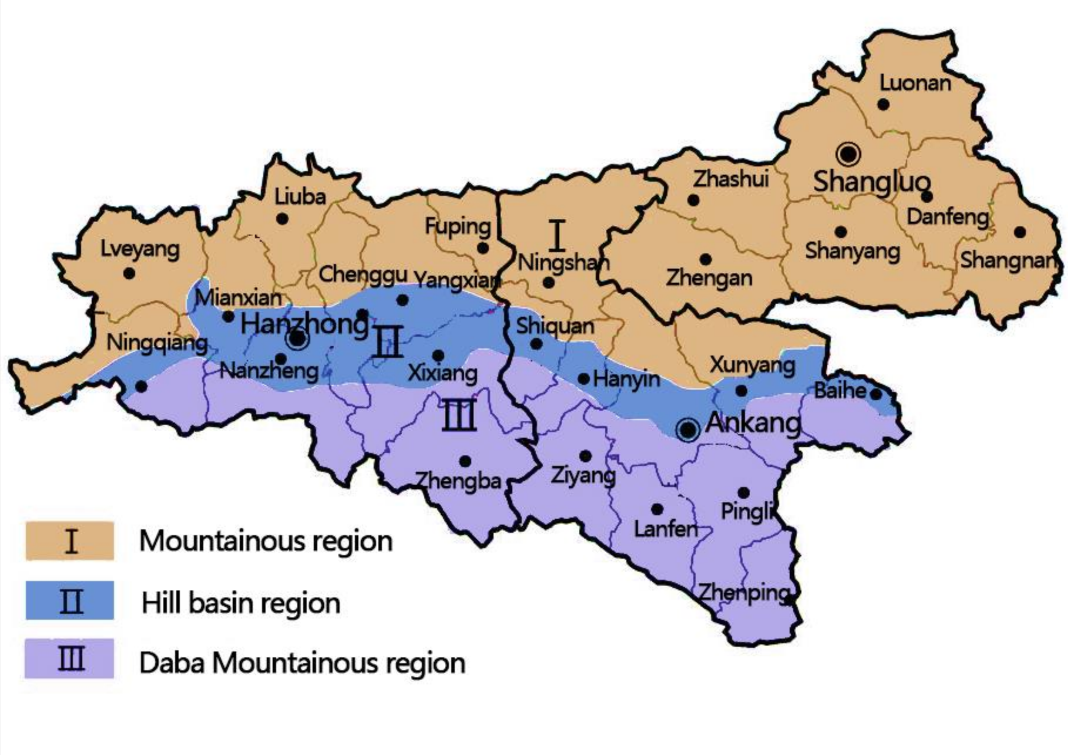


Figure 3-1. Geography of Southern Shaanxi

3. Hydrogeology

Precipitation is abundant in the southern part of Shaanxi. The average annual precipitation on the southern slope of the Qinling Mountains ranges from 600 to 800 mm, and the largest annual precipitation, up to 1400 mm or more, falls in the Micang Mountain area on the northern slope of the Ba Mountain, which is the center of precipitation in southern Shaanxi [8]. This decreases to the east, west, and north. While precipitation creates good conditions for agricultural production, it also becomes a major factor in inducing geological disasters, especially in summer and autumn, when there are many continuous spots of rain and heavy rains, which are very destructive and often cause flash floods, mudslides, and landslides.

Southern Shaanxi has a diverse climate and is the meeting zone of North China, Mengxin, West China, and Central China flora, with an average temperature of 13~15℃, an average temperature of -1~2℃ in January, and 25~27℃ in July, creating good temperature conditions for agriculture and forestry growth, with complex plant species and rich resources [9]. According to statistics, there are more than 4,250 species of higher plants in the region, which play an important role in developing the economy, maintaining ecological balance, and providing a good environment for residents to live in (in Figure 3-2).

Figure 3-2. Climate conditions

The cumulative temperature is higher in the basin and hilly areas of southern Shaanxi and lower in the mountainous areas on both sides. The basin and hilly areas below 800-900m in elevation in Hanzhong and Shaanxi and 700-800m in elevation at the southern foot of the Qinling Mountains in Shangluo are the main farming areas in southern Shaanxi, and 90% of the population in southern Shaanxi lives in this area [10].

The soil types in southern Shaanxi are complex. In the low mountains and shallow hills below 1200m on the southern slopes of the Qinling Mountains and the mountains between 800 and 2200m in the Daba Mountains, the zonal soil is mountain yellow-brown loam; in the shallow hills below 800m in the Qinling Mountains and below 800m in the Ba Mountains, the zonal soil is mainly yellow-brown loam, which is the dry soil of southern Shaanxi and the production base of grain and oil crops and subtropical economic forestry; in the Hanzhong Basin and the bottom of the Shaanxi basin are rice soils, with water and dry crop rotation and rice and wheat maturity, and this area is the largest area of agricultural production in southern Shaanxi.

The landscape of southern Shaanxi is mainly mountainous, with the Qinling Mountains in the north, the Ba Mountains in the south, and the Han River running through the center, forming a geomorphological pattern of "two mountains sandwiched by a river"; its climate is a north subtropical monsoon climate, with vertical zonation; its precipitation is rich, and rivers are dense, with feather-like and dendritic water patterns. According to the topography, climate, and hydrological conditions, most of the settlements in southern Shaanxi are located in the river valley basin area, while a few settlements are located on the sunny slope of the mountainous area.

3.1.2 Socio-human Background

1. History

The history of the southern Shaanxi region is relatively long, and the establishment test period can be traced back to the Qin Dynasty. The establishment of each period (Figure 4-1-6) is shown.

Hanzhong County was established in the Qin Dynasty, including the western and central parts of southern Shaanxi. In the 22nd year of Duke Xiao of Qin, Wei Yang captured Wei Gongzi Mao and defeated the Wei army [12]. The area became the best area for the change of law, leaving the remains of the ancient city, Shang Yang Yi. From the Three Kingdoms, the Jin Dynasty, and the North and South Dynasties to the Sui Dynasty, there were numerous wars and administrative settings were unpredictable. After several name changes, Hanzhong County was renamed Hanchuan County, Loyal County was established in central Shaanxi, and the western part was renamed Shangzhou. During this period, ancient sites related to warfare, such as the Baishengtai, were preserved. In the first year of Tianbao of the Tang Dynasty, three counties of Hanzhong, Yangchuan, and Shunzheng were established, while Shaanxi County was established in central Shaanxi, and Shangluo County was abolished in the east [13]. In the Ming Dynasty, Hanzhong Prefecture was established, including the western and central parts of southern Shaanxi, while the eastern part of southern Shaanxi belonged to Xi'an Prefecture. After the abolition of Hanzhong Prefecture in 2 years of the Republic of China, Hanzhong Road was established, Xi'an Prefecture was abolished and Guanzhong Road was established; in 17 years [14], the Road was abolished and put under the jurisdiction of the province, and in 24 years, the western part of Shaananxi was established as the 5th administrative inspection district, the central part as the 6th administrative inspection district, and the western part as the 4th administrative inspection district. After the liberation in 1949, the eastern, central, and western parts of Shaananxi were established as Shaananxi South Administrative Region, Shaanxi South Administrative Region Shaanxi Division, and Shaanxi South Administrative Region Shangluo Division, respectively [15].

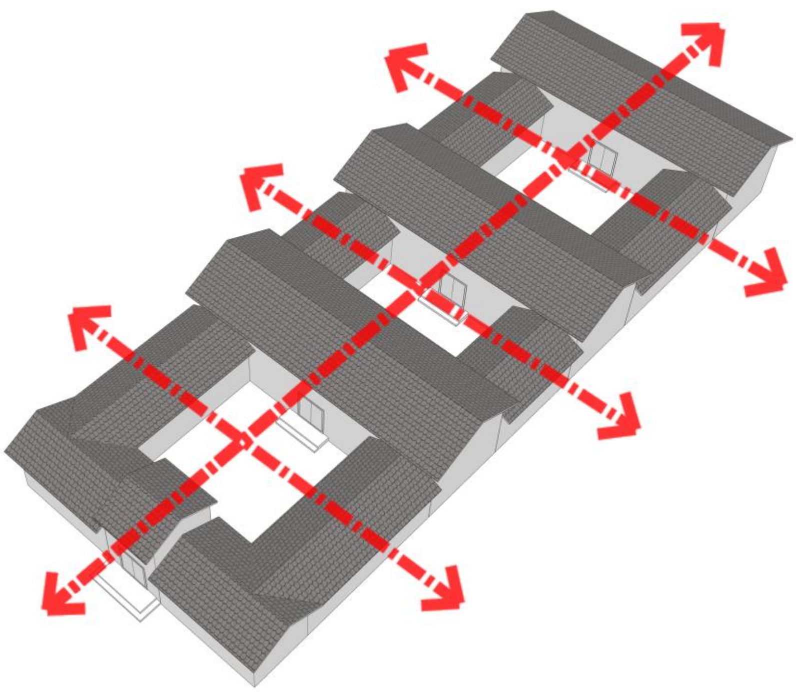
The most important feature of the culture of southern Shaanxi is the intermingling of north and south and cultural diversity. At the same time, the fishing and hunting culture is an important symbol of cultural differentiation between southern Shaanxi and other regions of Shaanxi. The southern Shaanxi region can be divided into three parts, namely the eastern, central, and western parts represented by Shangluo, Shaanxi, and Hanzhong, which have both commonalities and differences in culture.

2. Cultural commonalities in southern Shaanxi

The geographical location of southern Shaanxi is at the boundary between the north and the south, and it is a transportation hub with a large and complex population, which brings different cultural customs [16]. For example, from the time of King Hui Wen of Qin to the time of Emperor Shi Huang of Qin, criminals, wealthy mainlanders, and ordinary people were moved into Ba Shu, and some of the inhabitants of the Chengdu Plain and the Guanzhong Plain were integrated into the indigenous population of southern Shaanxi [17]. During the Three Kingdoms period, Zhuge Liang moved more than a thousand families from Xixian County (south of Tianshui City, Gansu Province) to Hanzhong to build a water conservancy. In the late Ming and early Qing dynasties, most of the indigenous people in southern Shaanxi died or fled due to war, and natural disasters and famine in neighboring provinces led to the inward migration of foreign residents, resulting in a situation in which "nine out of ten families were guests, and there were no indigenous people for a hundred years," which had a huge impact on the local culture. The culture of Southern Shaanxi is a blend of North and South and is characterized by a wide range of characteristics. Its commonality can be summarized as the following characteristics.

(1) Belief in nature and Confucian ritual culture

The landscape has given the people of southern Shaanxi the character traits of loving freedom, yearning for freedom, and admiring nature. The people of southern Shaanxi believe in Confucianism, and traces of the roots of Buddhism can be seen in Buddhist monasteries such as Zhiguo Temple and Lingyan Temple, which were built in the Tang Dynasty. At the same time, the people of southern Shaanxi also highly esteem Taoist culture. One of the earliest Taoist sects, the Wudoumido, developed and grew in the Hanzhong Basin and established a regime of unity between church and state. The spread and development of Taoist culture had a profound and lasting impact on the lives, production methods, values, and settlement patterns of the people of southern Shaanxi. It was also influenced by the Confucian ritual culture, with buildings mostly symmetrical in the central axis and buildings and spaces arranged in a sequence. (Figure -3-3).



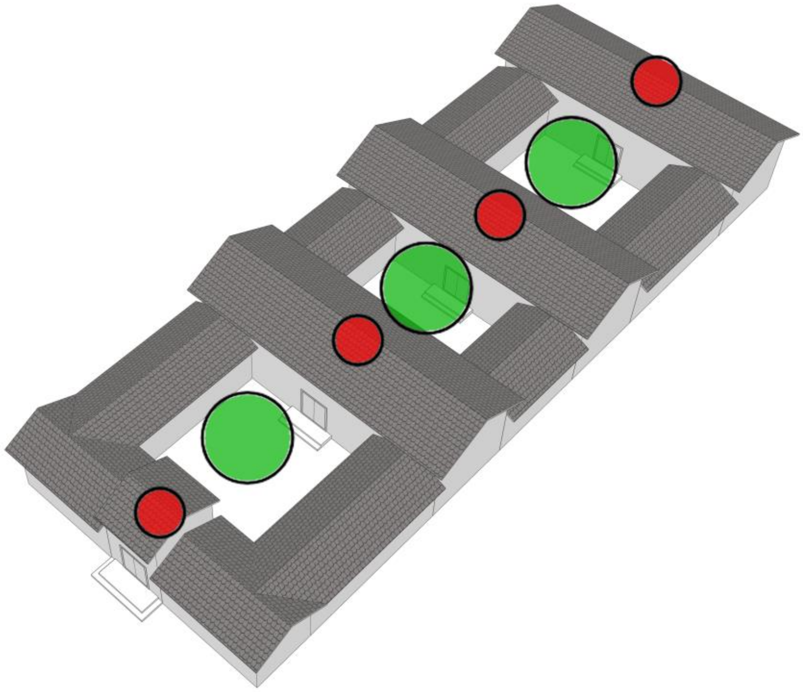


Figure 3-3. Confucian Culture - Ritual Residence

(2) The isolation of transportation gave birth to a culture of seclusion

The integration and complementarity of Confucianism and Taoism laid the foundation for the traditional culture of seclusion. Southern Shaanxi has many mountains and rivers and is close to traffic. In the days when transportation was not well developed, Shaanxi's only access to the outside world was from Jingchu to the east. The valley of Hanzhong, which is located between the Qinba Mountains, was closed due to the Qinling Mountains. During the Three Kingdoms period, Shu's northern expedition, the troops passed through the valley by building trestle roads on the cliffs on both sides of the Baoxiao Valley. The closed transportation led to the softness of the people, the closed mentality of the people, and the growth of magical and bizarre legends, while the area ruled by magical and bizarre legends is a hard-to-find place for the hermits of the great men and the magicians. The various myths in southern Shaanxi have remained unchanged for generations, providing the best place for the development of hermitage culture, such as Zhang Liang Temple in Hanzhong.

(3) Numerous merchants and a prosperous merchant culture

Since the Qing Dynasty, the population in southern Shaanxi has been increasing, agriculture and forestry have been developing rapidly, commerce and trade have been expanding, and many merchants have settled down in southern Shaanxi, telling their hometowns, contacting customers, raising funds for each other, and building commercial halls from various provinces in major commercial towns, such as the Shaanxi Huangzhou Hall, Jiangxi Hall, and the Northwest Hall in Wafangdian, Ziyang County, which are the best proof that the merchant culture has gathered in southern Shaanxi.

(4) Well-developed water system and strong fishing and hunting culture

In the days when transportation and material resources were not developed, people in southern Shaanxi relied on natural gifts from the water, and because of the barren land, people in southern Shaanxi relied more on fishing and hunting than farming, which predestined a deep foundation for fishing and hunting culture in southern Shaanxi. The development of the water system has also led to the development of the economy along the water, and there are many docks along the Han River, such as the Hanzhong Eighteen Mile Shop Dock and the Shu River Ancient Ferry Dock, which have brought prosperity to the coastal towns and cultural accumulation and influenced the local human environment. The landscape of southern Shaanxi is mainly mountainous, forming a landscape pattern of two mountains sandwiched by a river, with a clear hierarchy, spatially divided into five sub-regions. The climate is a north subtropical monsoon climate with vertical zonation. The hilly basin along the Han River has a north subtropical climate, with a large number of settlements and a large scale; the southern slopes of the Qinling Mountains and the low hills of the Daba Mountains have a medium scale of settlements and the population is mainly concentrated near the river valleys; the southern slopes of the Qinling Mountains and the subalpine middle mountains of the Daba Mountains have a small scale of settlements and are scattered.

3.2 Traditional Settlement Form in Southern Shaanxi

In the process of settlement construction, the site selection, spatial distribution, scale level, and spatial morphology are influenced by both the natural and human environments. For the southern Shaanxi region, the landscape pattern in the natural environment is the main factor affecting the traditional settlement form.

3.2.1 Layout Pattern of Traditional Settlements

1. The landscape pattern of "two mountains, three rivers, one river, and three cities

The southern part of Shaanxi Province is located on the southern slope of the Qinling Mountains and the northern foot of the Daba Mountain Range and is the core part of the Qinba Mountain Region in China [18]. The plain basin includes the Hanzhong Plain and the Shiquan-Shaanxi Basin in the Han River Basin, the Shandan Basin in the Dan River Basin, and the Luonan Basin in the Luo River Basin; the low mountainous hills are mainly located in the basin of the Han River and its first-class tributaries, the Dan River and its first-class tributaries, and the Jialing River; the middle and high mountains refer to the high and middle mountainous areas of the Qinling Mountains and the Daba Mountains, mainly located in the upper reaches of the Jialing River, the second-class and higher tributaries of the Han River and the Dan River, and the Luo River. The upper reaches of the Jialing River, the tributaries of the Han and Dan rivers, and the upper reaches of the Luo River and its tributaries.

The administrative division of southern Shaanxi shows a landscape pattern of "two mountains, three rivers, one river, and three cities". The "two mountains" are the Qinling Mountains and the Daba Mountains, the "three rivers" are the Han River, the Dan River, and the Jialing River, the "one river" is the Luo River, and the "three cities The "three cities" are Hanzhong on the Hanzhong Plain, Shaanxi in the eastern part of the Shiquan-Shaanxi Basin, and Shangluo in the western part of the Shangdan Basin.

2. "By the mountains and water, attacking the location of the river-bend" settlement site selection

There are many rivers in southern Shaanxi, and the water system meanders in a dendritic distribution. There are significant differences in hydrological conditions and topography among the three different geographical units, but traditional settlements are mostly built in places surrounded by river inlets, following the principle of traditional Chinese settlement site selection of "by the mountains and water, attacking in the river-bend"[19].

(1) Flat land, living by water" - the location of the plain basin settlements

The topography of the Plain Basin is less restrictive to the site selection and construction of settlements, and most of the larger towns are located here, so the site selection of settlements reflects the characteristics of "living in the middle of the plain, by the water".

The traditional urban areas of Hanzhong City, Chenggu County, Mian County, and Yang County on the Hanzhong Plain are all located on the north bank of the Han River, looking north to the Qinling Mountains and south to the Ba Mountains. The small towns tend to be located along the main transportation routes, such as Shangyuanguan and Xiecun. Rural settlements tend to be built along the river, such as Guangu and Yangzhai. The traditional urban area of Shaanxi City in the eastern part of the Shiquan-Shaanxi Basin is located on the southern bank of the Han River, on slightly undulating slopes, with high mountains to the north and south and gentle rivers to the east and west; the traditional urban area of Shangluo City in the western part of the Shangdan Basin is located on the northern bank of the Dan River, which is low and flat, with majestic mountains in the north and hills surrounding it in the south.

(2) "Leaning on the mountain and choosing water" - siting of low hill settlements

The construction of settlements in low hill areas is restricted by water systems and topography, so the site selection of settlements makes full use of the relatively gentle low hill slopes and the foot of slopes in the river valley, reflecting the characteristics of "leaning on the hill and choosing the water".

Xunyang County is located at the confluence of the Han River and Xun River, is China's famous "Taiji City", the traditional city and the new area are located in the river on the south bank of the Xun River, surrounded by the bay; Shuhe Town is located in the east of Xunyang County, in ancient times, is an important transit and distribution center for the intersection of logistics in E, Shaanxi, and Sichuan, north of the Qinling Mountains, south of the Ba Mountain, holding the Han

River and carrying Shu River, the town The new area and the ancient town are located on the gentle slope of the east and west sides of the confluence of Shu River and Han River.

Ningqiang County is located in the river valley at the confluence of the Yutai River and the Xiao River, and the main urban area is located in the flat dams and less undulating slopes on both sides of the river; Qingmuchuan Town is located in the west of Ningqiang County, at the confluence of the Jinxi River and its eastern tributaries, and the ancient town is located on the south bank of the river, while the new town is built on the north bank of the river, surrounded by mountains.

(3) "To live in the valley by the mountain and follow the trend"--Siting in the middle and high mountains

The number of towns is relatively small compared with that of the plain basin and the low mountain hills. Traditional settlements are mostly located on the terraces on both sides of the river at the bottom of the mountain valley and are built along the contour line.

Zhenba County is located in a deep mountain valley, with the east and west mountains facing each other. The traditional city is located on the east bank of the Jing Yang River, and the new city area is located on the west bank, and the city is built parallel to the mountains on both sides and developed along the river; Phoenix Town is located on the bank of Shechuan River in Zhushui County and is located on the delta where the outlets of Shechuan River, Soap River Ditch, and Shuidigou meet, with abundant water supply, backed by Daliang Mountain and facing Phoenix Mountain. The delta belongs to the compound terrain of flat land, a flat dam, and a gentle slope of the valley bottom.

"The location of towns and villages in the three different geographical units in southern Shaanxi is a common feature of the towns and villages, each with its characteristics due to factors such as transportation and farming radius, reflecting the wisdom of the people of southern Shaanxi in respecting the laws of nature and making good use of the landscape environment. The topography and hydrological conditions are the main natural factors that influence not only the location of the settlement but also the spatial form of the settlement, which is constantly changing.

3. The spatial form of the colony of "following the rituals and adapting to local conditions

According to the geographical unit in which the settlement is located and the relationship between it and the landscape, the traditional settlements in southern Shaanxi can be divided into five types: flat land type, river valley type, slope foot type, slope land type, and valley type.

(1) Flatland Cluster

Flatland settlements are mainly located in the Hanzhong Plain and the Shiquan-Shaanxi Basin in the Han River Basin, where the terrain is flat and the ground is less undulating. The settlements are built near the river, and between them and the mountains are vast farmlands. Due to the excellent farming conditions, the construction is less restricted by the topography, and the settlement is larger in scale, generally in a circle development, showing the spatial morphological characteristics of group clustering.

The traditional urban area of Hanzhong has a regular plan, with square walls on the east, north, and west sides, and the southern wall has the same plan as the flow of the Han River. The city wall has four gates, and the main streets from north to south and east to west opposite the gates form two vertically intersecting central axes, and the city's square road network is orderly and centrally defined. The traditional urban area of Shaanxi is a trapezoidal city in the north and south, with the old city near the Han River in the north, where commercial facilities and Traditional houses are concentrated, and the new city in the south, which is on higher ground, mainly for defense purposes. The two cities are connected by the "Wanliu Causeway", which is connected to the regular grid of roads within the city to form the north-south axis of the traditional city.

(2) River Valley Settlement

River valley settlements are mainly located in the Luonan Basin in the Luohe River Basin, the Shandan Basin in the Danjiang River Basin, and the low mountainous hilly areas. The settlements are built on flat land near the river, and the sloping land or terrace farmland is between them. These settlements have ample land for construction, are of a certain scale and have a regular shape, and show the spatial morphological characteristics of group clustering, with representative settlements such as Shangluo City, Hanyin County, and Xixiang County. The traditional urban area of Shangluo is nearly square in plan, with no gate in the northern city wall and two gates in the southern city wall. The east and west gates are connected by the east-west street, and the north-south street connects the south gate with the Shang Shan Shrine in the north of the city, with a clear axis and a simple structure.

(3) Slope-footed settlement

The slope-footed settlement is mostly located in the low hill area, on the flat land between the mountain and the river, with steep mountains on the opposite bank of the river. These settlements are generally small towns, and their spatial patterns are characterized by band-like clustering. Typical settlements include Qingmuche Town, Ningqiang County, Hanzhong City, and Deihua Town, Danfeng County, Shangluo City. The traditional township of Qingmucheon has a compact layout along the Jinxi River and follows the mountainous terrain to the south. The spatial characteristics of the entrance to the town are obvious, with the main street running parallel to the river and interspersed with Traditional houses, stores, restaurants, shopping malls, and hotels on both sides, forming an activity and landscape center at the head of the wind and rain bridge in the middle of the town.

(4) Slope Type Settlement

Slope-type settlements are mostly distributed in the low mountainous areas, the relatively gentle slopes between the mountains and the river, and the steep mountains on the other side of the river. These settlements are generally small-scale counties and small towns, which are limited by the distance between the mountains and rivers and the ability to use the terrain, so the spatial pattern of the counties shows the characteristics of cluster clusters, such as Ziyang County, Shaanxi City; small towns are mostly strip clusters, such as Shuhe Town, Xunyang County, Shaanxi City, and Manchuanguan Town, Shanyang County, Shangluo City. The traditional urban area of Ziyang is built on the slope of the north bank of the Hanjiang River, with an approximately oval shape, high internal concentration, and clear axes. The city has a close relationship with the ferry port and the road into the city. The city wall has three gates, but there is no south gate because the height difference between the south side and the river bank is too great. The main facilities of the city are concentrated on the high ground to the north of the east and west main streets. Due to land constraints, important buildings such as Wenchang Temple and Guandi Temple are located outside the city. The traditional township of Shuhe extends from south to north along the narrow slope of the west side of Shuhe and is a traditional trade town. The internal functional structure of the settlement is clear and the spatial hierarchy is well-defined. To make full use of water transportation, commercial facilities are mostly arranged along both sides of the main north-south roads in the township and combined with public buildings such as halls and temples to form the spatial nodes of the township. The traditional township of Manchuanguan is developed along the slope of the eastern bank of the Jinjia River, and the land for township construction is closely integrated with the topographic contours, with clear boundaries. The town has a clear north-south axis, flexible streets and alleys, intertwined public service facilities and residential areas, and major commercial facilities along the river, forming the center of public activities in the town at the town hall and temples.

(5) Gully-type settlement

The valley-type settlement is mainly distributed in the middle and high mountains, mostly in the narrow valley between two mountains, with steep mountains on both sides of the valley and a small amount of flat land for building and sloping land for farming at the wider valley bottom. Due to the constraints of the terrain, these settlements are mostly small-scale villages with a low degree of agglomeration and blurred settlement boundaries. The main roads inside the settlements are mostly paved along the rivers, and the houses are scattered along the rivers and roads, forming a relatively independent spatial unit together with the surrounding cultivated land, and the spatial form reflects the characteristics of free dispersion. Typical gully-type settlements include Miaowan Village in Cheyan Town, Shaanxi Xunyang County, and Guojia Laoyuan in Zhaowan Town.

4. Spatial distribution of settlements of "leaning on the water and choosing the land, stopping at the mountains"

(1) Spatial distribution of towns and settlements "by water"

The division of geographic units and the characteristics of water systems in southern Shaanxi play an important role in the spatial distribution of urban settlements, and the alluvial intensity of rivers affects the scale of agricultural production and urban construction. The spatial distribution of urban settlements is mainly concentrated in the plain basins of the Han River, Dan River, and Luo River basin and the low mountainous areas on both sides of the basin, but less in the middle and high mountainous areas, reflecting the spatial distribution characteristics of urban settlements of "choosing the land by water".

The plains basin is easy to cultivate and build, and the convenient land and water transportation strengthen the connection between towns, so the towns are large and densely distributed, such as Hanzhong city, Shaanxi city, Shangluo city, and Mianxian, Chenggu, Shiquan, Danfeng, Luonan, and other counties. The low mountain hilly areas are interwoven with low mountains, river valleys, and wide dams, and the scale of towns is relatively small compared to the plain basin; among them, the wide dams are flat and have relatively good farming conditions, which makes it easy to form towns with large populations, such as Xunyang, Xixiang, Shangnan and other counties and ancient towns like Qingmuche and Shuhe. Middle and high mountains with steep slopes, inconvenient traffic, and lack of arable land, so the settlement size is small and sparsely distributed, such as Foping, Zhenba, Zhenping, and other counties and ancient towns such as Phoenix, and Yungui Temple.

(2) The spatial pattern of rural settlements of "Chuanxing Mountain Stop"

Rural settlements are evenly distributed in three geographic units: plain basins, low mountain hills, and mid-alpine areas. The spatial pattern of rural settlements is characterized by the difference in topography and the choice of the water system from the Shuo River in the plain basin to the low hills to the hinterland of the middle and high mountains.

1) The spatial pattern of rural settlements in the Plain Basin

The plain basin has a flat topography and convenient transportation, and the rural settlements are mostly located in the water network formed by the natural water system and artificial irrigation canals, so there are sufficient water sources. The excellent agricultural production conditions and the close connection between settlements provide favorable conditions for the equal and concentrated distribution of rural settlements, and the rural settlements show a spatial network pattern with the town as the center and the village as the network.

2) Dendritic spatial pattern of rural settlements in the low hills

The rural settlements in the low hill areas are mainly distributed along the river valleys and are mostly concentrated near the river banks formed by the alluvial flow of rivers. Roads extend along the water system, and traffic between settlements is not smooth. As the level of the water system decreases, the scale and density of settlements gradually become smaller, and the distribution of rural settlements shows a dendritic spatial pattern with the township and its main streams as the main axis and the villages and tributaries as branches.

3) Vine leaf spatial pattern of rural settlements in the middle and high mountains

The rural settlements in the middle and high mountains are mostly concentrated on the slopes and terraces on both sides of the source streams of the valleys. Due to the limitation of arable land area, river water volume, and transportation facilities, rural settlements are generally small in scale and scattered in layout, showing a leaf-like spatial pattern with rivers as vine trunks and settlements as leaves.

3.2.2 Spatial Morphological Characteristics of Settlements

(1) Topography and hydrological conditions affect the spatial morphology of settlements

The principles of site selection for settlements in the three geographic units in southern Shaanxi are the same, but the spatial patterns of three types of settlements, namely, agglomeration in clusters, agglomeration in strips, and agglomeration in groups, reflect the different evolutionary processes that settlements undergo in the unique natural environment after formation [20].

The larger clusters and ribbon clusters are concentrated in the plain basin, and the flat land formed by the alluvial rivers is conducive to the compact and intensive development of the clusters, with square external boundaries and neat internal regulations, and the public service facilities are mostly located in the center of the clusters. Smaller clusters and ribbon-like clusters are mainly located in low mountainous areas with limited land for construction between mountains and rivers, and the clusters are highly clustered or extended along rivers; the external boundaries of the clusters are curved and dynamic, the internal spaces are staggered, and public service facilities are arranged along the main roads of the clusters. Most of the clusters are located in the valleys of the middle and high mountains, and the small scale and discontinuous production and construction land cause the scattered layout of the clusters, so the boundary of the clusters is blurred and the internal clusters are relatively independent.

(2) Interdependence and the interrelationship between spatial form and construction of settlements

The construction activities inside the cluster are the combination of different functions, spaces, and the land of the cluster. There are clear axes inside the colony, and large public buildings are arranged along the axes, and the center of the colony is at the intersection of the axes; the square grid road is suitable for the layout of various buildings [21]. Because of the river valley, the traffic organization flow direction is clear, and the area around the hall and temple becomes the main public space inside the settlement. The construction in the group diffusion type settlement shows a high degree of flexibility; the road width is narrower and is mostly built along the contour line; the buildings are mainly residential, and the family ancestral hall is the main public building; the layout and construction of the buildings depend on the mountain and the combination form is variable.

3.2.3 Spatial Distribution Characteristics of Settlements

(1) The scale of settlement is consistent with the change in the water system scale

The three geographical units in southern Shaanxi provide the innate conditions for the emergence and development of settlements, which determine the scale of settlements. The plain basins formed by the alluvial deposits of the Han River, Dan River, and Luo River provide sufficient water supply and land for production and construction for traditional settlements, and the convenient land and water transportation provide favorable conditions for economic exchanges among settlements and with the outside world, leading to the expansion of settlement scale [22]. The low mountainous areas are affected by the first and second tributaries of the Han River and Dan River and the topography, and the water and land resources are limited, and the economic exchanges between settlements and with the outside world are lacking due to the inconvenience of transportation and the lack of land support for spatial expansion, resulting in the small scale of settlements. Middle and high mountain settlements are mostly located in the valleys of single-line source streams on both sides, because of the small amount of land for production and construction and scattered in a dotted distribution, the scale of the settlement is small, and the lack of transportation links between the relatively independent closed.

(2) Unity of settlement function and natural and social environment

The natural environment in southern Shaanxi is complex and diverse, and the social environment is diverse and intermingled, both of which interact with each other to influence the functional composition of the settlement. The plain basin, with its topography, water resources, and transportation advantages, is conducive to the formation and development of traditional settlements, and the functions of settlements are complex and diverse. As the altitude rises, the scale of the water system becomes smaller, and material distribution, agricultural and by-product processing, and agricultural production become the main functions of the low hills and middle and high mountain settlements.

The social environment was influenced by the cultures of the Central Plains, Huguang, Basho, and Jingchu. In addition to bringing a large number of laborers and advanced production technologies from other provinces to the agricultural production of southern Shaanxi, immigrant craftsmen were also employed in many workshops in southern Shaanxi, which contributed to the rapid development of traditional handicraft production. In some areas with frequent migrant activities and active cultural exchanges, several trade settlements have been formed, such as Ziyang County, Shuhe Ancient Town, Manchuan Pass Ancient Town, Phoenix Ancient Town, etc.

3.2.4 Analysis of Traditional Settlements' Morphological Characteristics

(1) Analysis of the natural environment of traditional settlements in southern Shaanxi

The natural environment is the decisive factor affecting the settlement form in southern Shaanxi, and the settlement form is the specific performance of adapting to the natural environment. On the one hand, the natural environment has different degrees of influence on each stage of the settlement form, and the ability to use the natural environment and the demand for land is the precondition for the continuous development of the settlement. In the early stage of the formation of the settlement, the ability to transform the natural environment is limited, the population scale is small, the demand for production and construction land is small, and the settlement construction makes full use of the current topography, showing the characteristics of a small-scale agglomeration. With the improvement of production level, the ability to comprehensively utilization of natural environment is strengthened, and the demand for land is increased due to the expansion of population-scale so that the topography can be reasonably modified when the settlement expands, and the settlement form evolves into a belt-like cluster or group-like layout. On the other hand, the difference in the natural environment makes the settlement show high heterogeneity in spatial distribution, scale level, economic function, settlement spatial form, etc. The natural environmental elements inject distinctive regional characteristics into the artificial environment, and the functional layout, spatial structure, transportation organization, and construction of the settlement show a good human-land relationship with the natural landscape pattern.

(2) Analysis of the cultural environment of traditional settlements in southern Shaanxi

The natural landscape pattern and social development in southern Shaanxi have fostered a diversified and active cultural environment, which has had a profound impact on the development and construction of settlements. The unique geographical location of the region has made it a melting pot where Guanzhong, Basho, Huguang, and Jingchu cultures collide and merge. The larger-scale cluster and band-like settlements are mainly located in the Hanzhong Plain, Shaanxi-Shiquan, and Shangdan Basin, which are influenced by the Guanzhong culture. The small-scale belt-like clusters and group diffusion clusters are located in the low hills and the middle and high mountains, which are deeply influenced by the immigrant culture from the south, and the spatial form of the traditional clusters is adapted to the local conditions, with various forms and free movement, and the traditional architectural style shows the compatible characteristics of Sichuan-Shaanxi, Jing-chu, Ba-shu and Shaanxi-chu cultures by region.

3.3 Types and Characteristics of Traditional Residential Buildings in Southern Shaanxi

Although there are common features in the geographical distribution of the houses in southern Shaanxi, the architectural characteristics of different districts are different. Located in the west at the source of the Han River, it is connected to Shu in the south and Guanzhong in the north, and there are many ancient post roads connecting the north and south of Qinling in the territory, which strengthens the connection between southern Shaanxi and Sichuan, showing the characteristics of Sichuan-Shaanxi with the alternating influence of Qin and Shu culture; the central part is located at the intersection of three cultural circles, and the cultures are compatible, and the counties and districts show differences due to different migration backgrounds. Shu culture influence, from west to east by the Shu culture to Chu culture transition; the southeast of the land is connected to Jingchu, is the historical "Huguang fill Sichuan and Shaanxi" immigration channel, frequent cultural and trade exchanges, climate conditions, terrain and landscape, and Hubei have similarities, the regional culture mainly reflects the characteristics of Jingchu; northeast has a north to Guanzhong, east of the Central Plains, south of Hubei The north-eastern part of the country is connected to Guanzhong in the north, Zhongyuan in the east and Huguang in the south, presenting a more obvious cultural personality of Sanqin and Zhongyuan with Huguang characteristics.

The houses in southern Shaanxi mainly include three types of houses: storehouses (street houses), independent courtyard houses, and rural farmhouses. The first two types of houses have a complete spatial pattern and outstanding stylistic characteristics, representing a high level of residential construction wisdom. While a large number of ordinary farmhouses exist in the countryside and mountainous areas, they are simple in form, but they are good at using local materials to form a unique regional construction style, giving the building a simple and simple temperament, while not losing the richness and variety of expression.

3.3.1 Western Region Houses Compatible with Sichuan and Shaanxi

The western region is connected to Shu in the south and Guanzhong in the north and has been an important place to connect the north and south of the Qinling Mountains since ancient times. In the form of houses, northern Sichuan and southern Shaanxi have influenced each other and have more similarities, while also relating to the influence of medium northern regions, showing a more north-south blend of Sichuan-Shaanxi characteristics. The houses in this region pay attention to site selection and coordination with the natural environment, fully reflecting the natural and environmental view of "the unity of nature and man".

The main characteristics of the houses in the western region and the differences between them and other regions in southern Shaanxi are mainly in the following aspects.

(1). Spatial Form

The topography and height difference is well used to organize the courtyard, forming a combination of various plan layouts and rich spatial levels. This kind of craftsmanship is clearly shown in the street houses and independent courtyard houses. For example, the old street houses in Hulongchang, Qingmuchuan Town, Ningqiang County. The old street is laid out along the river, bending and curving with the river, with an arc-shaped plan. The layout of the street houses on both sides of the 860-meter-long street is complete and well-preserved. The plan form is not like Shaanxi, Shangluo similar street house with a long and narrow patio organization of the courtyard, but with the topography of the terrain, and flexible layout, derived from the width and narrow ratio of the different, horizontal and vertical combination of a variety of patio form, space is more relaxed and open, common main courtyard, partial courtyard, front and back yard, and cross-yard. Entrances are also not central and are often placed on one side in combination with function or topography. At the same time, due to the undulating terrain and tight land use, Traditional houses are often organized with the topography and height difference, and each courtyard or even the front and side rooms of the same courtyard are often not on the same contour, with steps, stairs, corridors, etc. connecting each space, so that the space is richly layered. For example, "Hong Sheng Chang" and "Rong Sheng Kui", are known as "dry boat houses". Both of them are named after the patio courtyard with a four-slope roof and the ridge of the roof is in the form of a rolled-up shed to shelter from the wind and rain, resembling a crow-top boat). Freestanding courtyard houses are generally located in the back of the mountains or back of the mountains and fields on the foot of the flat dam, compared to the street house has a more relaxed land condition, the courtyard space scale and closed closer to the northern residential, less open hall, corridor. Such as Qingmucheon town Wei's manor and the old street of Huilongchang a river, the back of the mountain, facing the water, facing southwest, the site is open, by the "field" layout of the new and old two homes, the courtyard space is wide and open almost square (about 10 meters square), the central axis of symmetrical two courtyards. Affected by the topography, the front yard is about 2 meters lower than the back yard, connected by steps, and the roof height is leveled by the way of the first 2 layers and the second 1 layer, to obtain a strict and uniform appearance (Figure 3-4). The courtyard of the Wang family compound in Yuan Gong Village, Chenggu County, has similar spatial characteristics: the entrance gatehouse is on the southeast side, but the internal axis is symmetrical, and the upper and lower rooms and compartments are enclosed into a wide courtyard of nearly four sides. The roofs are all far-reaching overhanging roofs with pierced wooden frames, which still show a strong Shu style.

Figure 3-4. Traditional Residence-Wei's Manor

(2). Structural Features

The main load-bearing system is the wooden pierced frame, and the rear of the house and the two mountain faces are more often made of rammed earth walls or adobe masonry walls, up to the height of the eaves or the top of the first floor, with the exposed wooden pierced frame, and the front side is generally made of wooden paneled windows and doors.

(3). Exterior shape

The exterior is both elegant and heavy, with a deep overhanging tile roof (e.g., the eaves of Huilongchang Street House are 2 meters deep, forming a continuous gray space under the eaves), contrasting white bamboo rammed earth walls and dark exposed wooden buckets as the main features. The wooden panel walls and the wooden frame through the bucket reflect the genes of Shu culture, while the thick rammed earth walls reflect the influence of Qinlong culture. The building is less decorative and simple in style.

3.3.2 Diversity and Integration of Houses in the Central Region

The central region is bordered by Guanzhong in the north, Chongqing, and Hubei in the south, and is located at the intersection of Sichuan, Shaanxi, Hubei, and Chongqing, and has long been subject to the impact of multiple cultures. At the same time, due to different migration backgrounds, local differences are significant. The traditional houses are often characterized by various forms of hard-hill fireproofing, brick and stone hollow bucket walls, and the Bashu style with overhanging roofs, pierced wooden frames, and thick rammed earth walls combined with wooden panel walls. The main architectural features of the traditional houses in the central region are.

(1) Integration of Jing-chu and Ba-shu characteristics

The old street houses of Houliu ancient town in Shiquan County are typical examples of this feature. Shiquan County is the intersection of the ancient Ziwu Road, the ancient trade routes of Sichuan and Chu, Qin and Sichuan, and the Han River culture, and the houses bring together the genes of Chu and Shu culture, concentrating on the diversity of houses in the central region. The ancient town is located on the Han River, surrounded by water on three sides. The town has an old street of about 300m, paved with blue stone slabs, which are winding, undulating, and narrow. The style of the two sides of the street is very different, with one side of the street showing the Basho style with overhanging roofs, pierced wooden frames, and wooden panel walls, while the other side has a hard hill and horse head walls, brick, and stone hollow buckets or rammed earth walls, reflecting the influence of Jingchu culture. The "Shu Feng" residential complex on the river side of Old Street inherits the pure and simple characteristics of the Traditional houses in northern Sichuan. The overhanging green tile roofs have far-reaching eaves, asymmetrical long and short eaves according to local conditions, exposed wooden diagonal walls with eaves, small square wooden windows, and no carving or painting. For example, the "house wrapped in trees" houses. It is noteworthy that there are many houses with the characteristics of Bashu in Old Street, but they no longer use the custom of building rammed earth walls, but use the masonry of brick and stone with empty buckets, which reflects the cultural integration and also shows the high economic level obtained by the prosperity of the local merchant culture (Figure 3-5).

Figure 3-5. The fusion of diverse central residential houses

(2) Diverse construction materials, rich morphological types, and unconventional changes

The topography of the central region is more complex and diverse than that of the western region, and the mountainous terrain is characterized by a rich variety of natural building materials, resulting in a variety of architectural expressions of local houses, including rammed earth and adobe houses mixed with earth and wood, stone and slate houses mixed with stone and wood, and hanging foot buildings of various shapes and sizes.

The "open house" in Hanyin County is a typical representative of rammed earth houses in the central region, with a hall in the middle, living rooms on the left and right, and a farming room attached. The roofs are green tiles, and the walls are asymmetrical, shorter on one side and longer on the other side facing the courtyard. The walls are mostly thick adobe walls, often painted with lime, showing the ruggedness of the Qin region, while the slender wooden elements such as squares and corridors reveal the beauty of lightness and elegance, containing the flavor of Sichuan.

Slate house is a unique type of dwelling in central and eastern Shaanxi, and is distributed in Xixiang, Shiquan, Hanyin, Ziyang, Xunyang, Baihe, Luonan, and other places, and Ziyang slate house is the most famous. Ziyang not only has good tea, but also produces natural tile slate, which can be laid directly on the roof without any secondary processing, forming a natural texture of different sizes and shapes, like fish scales, and has the characteristic of "light in sunny days and no leakage in rainy days". In addition to the roof, the stone was also used for masonry walls, foundations, and floors, forming a veritable "stone house", the exterior of the stone walls are often painted with grass mud, through the ages, shedding more ancient and vicissitudes.

The central region of southern Shaanxi, where Ziyang County is located, was once the habitat of the ancient Ba people, and the complex topography of the mountainous area gave rise to the Ba and Yu characteristic partial elevated architecture - the hanging foot tower. Most of them are located in remote mountainous areas or waterfront places, with a simple plan form, mostly "a lock" or "key head" (a word type, a square, and a compartment type). After generations of evolution, many of the empty parts on the ground floor of the hammock have been transformed into closed storage spaces with wooden boards and bricks or replaced with brick, stone, and concrete pillars to save wood, and in the riverside areas it has developed into a "long hammock, the high platform" living form, but few of the original traditional wooden hammocks remain.

3.3.3 Houses in the Southeastern Region of Jingchu

The southeastern region is located in the eastern part of the Qinba Mountains and the middle reaches of the Han River, at the junction of Shaanxi, Chu, and Chongqing provinces. The area is known as "eight mountains, one water, one field", with peaks and ravines. While the traditional houses are influenced by the culture of the Central Plains, they also have a lot of natural adaptation, layout, and image to the houses of the two lakes, and have formed their characteristics after centuries of immigrant settlement. The main architectural features of this area are (Figure 3-6).

Figure 3-6. Southeastern houses in Jing-Chu Style

(1) Strong characteristics of mountain houses

In the southeastern region, there are few flat places, so houses are often built on slopes. To adapt to the changing terrain, the plan is not bound to a certain pattern, and the vertical height change of spatial form is freer than in other areas, forming a variety of construction methods by the shape, showing the mountain settlement tradition and the unique double three-dimensional spatial characteristics of houses, such as the ancient town of Shuhe in Xunyang County and the old street houses of Qiaogou in Chengguan Town, Baihe County.

The town of Chengguan in Baihe County is built around a mountain, and the terrain is cramped, so the land is very tight. Qiaogou Old Street is located at the bottom of the Changchunjian ditch on the north slope of the mountain, south of the city's North Lower River Street, winding, waterway intersection, with an average width of 2.8 meters, 458 steps of green stone paving, and the river street constitute a "T" shaped pattern. Old Street is dotted with many Ming and Qing houses and has many narrow alleys leading to the surrounding hills. The houses are built according to the topography of the hill, and the spatial layout is flexible. The entrance of the Yi family compound in Shangjie is built on a bridge across the stream. The entrance, front courtyard, and main axis courtyard are arranged in an L-shape due to land constraints. The Luo family compound was built near the stream, using hanging wooden pillars to elevate some of the compartments to gain more space for use within the limited site. The neighboring Geng's compound is built on a platform according to the mountain, forming a stepped pathway and horizontal courtyards on different elevations on the main axis, with a compact spatial layout, which is a typical example of a compound-style residence. The Haegai Baoshantang, on the other hand, is located on a small flat area on a hillside, and is a horizontal courtyard with a width of seven rooms due to the restricted depth, with a winding pathway to the top.

(2) Horizontal multiple roads, symmetrical central axis, unrestricted orientation

Due to the very tight land resources, in order not to occupy the arable land, the independent courtyard houses are mostly built by the mountain, and the depth is limited, even the large houses are mostly 1-2 courtyards, forming the regional characteristics of horizontal development, multiple roads, and less entry. Due to the mountains and rivers, it is impossible to fully follow the layout custom of "sitting in the north and facing south", with various orientations, but it still follows the "central symmetry", "center is the honor" and "left up, right down". The basic law of traditional building layout is "left up, right down". For example, the Zhu family compound in Shuanghe Town, Xunyang County, has a horizontal space, with only one courtyard in the longitudinal direction and a symmetrical central axis. The spatial combination of the Zhang family compound in Kazi Town, Baihe County also reflects this feature: it is located on a small flat dam at the foot of the slope of the river. The upper and lower courtyards are about 300 meters apart. The lower courtyard faces southwest from the northeast and consists of two two-way courtyards (the south courtyard and the north courtyard) adjacent to the north and south.

(3) Strong defensive focus and closed enclosure appearance

The courtyard-style houses are mostly enclosed by the building entities, and a few of them are enclosed by tall walls combined with buildings. The windows on the facade are few and small, and each room often has a small stone window, and the second-floor attic has an air hole. Behind the main house, there are usually no windows or small stone windows, and the side rooms are windowless. The defensive nature of the houses in the area is related to the many years of warfare during the Ming and Qing dynasties. For example, the lower courtyard of the Zhang family compound does not open a window hole to the outside, and only in the second-floor attic compartment opens a small stone ventilation hole, with a strong sense of closure.

(4) The hard mountain and fire sealing forms are varied, showing the characteristics of Jingchu

The architectural form of Traditional houses in the southeastern region is close to that of Hubei, with the common use of hard hill and gray tile roofs, beams or beams, brick hollow walls, and slot doors. Firewalls in various forms, commonly three flowers, five flowers horse head walls, cloud-shaped walls, human-shaped walls, and other styles. Hill wall under the eaves and Edward decorated by the cultural influence of the North and South, the form and theme are rich. From the external view, the wall of the fire seal undulating, crisscrossing, and very spectacular. For example, the front façade of the Zhang family compound consists of five-flowered and three-flowered walls forming a beautiful outline of interlocking undulations.

3.3.4 Houses in the Northeastern Part of Shaanxi and Chu

The northeastern region is located in the Qinling Mountains, with interlocking valleys and rivers. It is bordered by Henan Province to the east, Hubei Province to the southeast, and Guanzhong Province to the north. The special geographic location of the region is influenced by Guanzhong, Hubei, and the Central Plains at the same time, and the culture of the region has inherited the virility of Qin and the softness of Chu. Due to the difference in geographical location between the north and the south, the northern counties such as Shangzhou, Luonan, and Danfeng have a strong Qin style, while the southern and western counties such as Zhen'an, Zhashui, and Shangnan have a stronger Chu style. The main architectural features of the traditional houses in the area (Figure 3-7).

Figure 3-7. Shaanxi-Chu-style northeastern residential houses

(1) Near Qin is Qin, according to Chu is Chu

The northeastern part of Shaanxi Province, which is the junction of Qin and Chu, is a place where Qin and Chu's cultures intermingle, and the houses as a whole show the characteristics of both the south and the north of Shaanxi and Chu, but with the local difference of "near Qin is Qin and near Chu is Chu". Such as Danfeng County Deihua Town, close to Shaanxi Guanzhong, residential space, construction techniques, and appearance very close to the Guanzhong houses: hard roofs, brick stacked Edward shape, not set up the high firewall, the appearance of thick and solid. In addition to the end of the wall or Edward using brick masonry, Le foot above all adobe masonry, the wall inside and outside painted grass mud, the upper part of the wall with a symmetrical "Ji" shaped stone window, the style is simple and clumsy.

The appearance of the houses in the counties adjacent to Hubei Province is mostly characterized by herringbone fire walls slightly above the roof, beam-bearing structures, and masonry hollow bucket walls. Compared with the various forms of firewalls in the southeastern region, the residential walls in this region are simple, with cloud-shaped and fallen walls being very rare, forming their regional characteristics. In addition, the spatial layout, roof form, and detailed decoration of the houses in the area also show the Qin style. For example, the Meng Family Courtyard in Fenghuang Ancient Town, Zhushui County, is similar in height and width to the narrow courtyard in Guanzhong, and the compartments are covered with a single sloping roof instead of the "two sloping water" roofs common in southern Shaanxi, and the eaves and cheeks are also influenced by Guanzhong houses.

(2) Narrow and long patio, three openings, and three entrances rising one by one

The Old Street houses in Fenghuang Town of Zhushui County are typical representatives of the storehouse style in the southeastern region. The Old Street is more than 1,000 meters long and has preserved many Ming and Qing houses. The architectural style inherits the characteristics of ancient houses in Jianghan and shows the influence of Guanzhong and Zhongyuan cultures. The width of the street house is less than 10 feet, but the depth of the house is 30 to 40 meters, forming a long and narrow courtyard with many courtyards, with "three in and three out" as the basic type and rising one by one. The spatial form of the courtyard is very close to that of the narrow courtyard in Guanzhong (three rooms wide, 20 meters deep, or even 30 meters deep, divided into several courtyards). The patio is equipped with a masonry rainwater collection pond, which is also used for water storage and courtyard greening, and the surrounding roofs are sloped toward the patio, forming a "four water to pool" pattern. This feature is also clearly visible in the old street houses in Yungaisi Town, Zhen'an County.

(3) Chain of houses, winding paths

The Southeast region is an important area of China's northwest to southeast, the history of several large migrants to promote economic and cultural development, such as Zhen'an County, Yungaisi Town, Liu's manor, Tiechang Town, Ni's manor and Danfeng County, "double well" Huang's manor and several large homes. The unique feature of this type of courtyard house is that: large scale, including multiple independent patio courtyards, courtyards connected by lanes, courtyards, together constitute a "chain" courtyard-style large residential complex. The most typical example belongs to the town of Yungaisi Liu's manor.

Liu's manor was built in the late Qing dynasty, the site of the foot of the gentle slope, backed by the West Mountain, facing east toward the Heiyao Gou River, magnificent scale, by seven independent patio courtyard synthesis of four water to the hall, a total of 105 houses of various sizes, the whole into a square. Each patio courtyard is a self-contained system with an independent central axis and spatial order, and the courtyards are connected by winding lanes, which is very spectacular. Passing years, the prosperity the end of today's Liu's manor only two complete patio courtyards: the east courtyard is roughly square, the door and hall are five-room "three bright two dark" pattern, three-column floor-beam wooden frame, herringbone seal fire mountain wall. The north and south wings are two rooms each with double-sloped roofs. The present house is in serious disrepair, and only the foundation of the two open rooms and the compartment on the north side of the gatehouse remains. The west courtyard is located under the root of the mountain and is a long and narrow patio courtyard, and the central axis does not coincide with the east courtyard but is offset by one room to the north. The two courtyards are connected by a narrow and winding passage.2.4 Investigation of the Current Buildings in Southern Shaanxi

3.3.5 Characteristics of Traditional Residence

1. Traditional settlements with coupled geographic differentiation

The special features of topography and geomorphology in southern Shaanxi form the geographical differences between horizontal and vertical differentiation, which can be divided into three types: river valley plain basin, low mountain hills, and middle and high mountains. The climatic conditions and resource conditions of the areas where the natural landform types are located determine the spatial combination and association of the habitat environment, and the traditional habitat activities form the differences of settlement distribution under the cultural consciousness of conforming to nature, reflecting the habitat construction culture of conforming to its nature and responding to the situation. The resource constraints, farming conditions, and environmental capacity of the natural environment make the traditional settlements have the basic characteristics of "by the mountains and water, attacking the river-bend" in terms of site selection; according to the geographical elevation and the scale of construction, land can be divided into five types of settlement forms, such as flat land type, river valley type, slope foot type, slope type, valley type, etc., in different geographical units for spatial The spatial distribution of the settlements shows the characteristics of small gathering and big dispersion in the mountainous area; the habitat environment is integrated with the landscape pattern of "two mountains, three rivers, and one river", by the nature and overall coordination. Coordinated.

2. Suitable for the creation of functional and practical architectural space

The construction land conditions in southern Shaanxi are tight, the scale of building units is small, the basic form is simple, the combination of building space is unconventional, the layout is flexible, and the creation of building space reflects the functional and practical characteristics appropriate to the natural, economic and social conditions of the region. Southern Shaanxi residential architecture is represented by the space creation of "one-character type" and hanging foot tower, "one-character type" is the basic unit of composition, through horizontal and vertical expansion, constituting a space combination mainly for use function; hanging foot tower through the vertical combination of topographic elements, in line with the By combining the topographic elements and contour lines, the hanging towers constitute the spatial combination of use function, architectural shape, and natural environment. The public building space is represented by the hall building, where the use function is combined with the economic and social environment factors and formed by the demand for trade activities. Natural materials are widely used in traditional houses, forming a regional construction method. The construction techniques reflect the comprehensive consideration of local climate, topography, and resource use, and are simple, easy to use, economical, and durable.

3. Contains a free and simple architectural art style

The landscape pattern plays a decisive role in the historical evolution of the habitat environment in southern Shaanxi, and the traditional settlement space and architectural style originate from the influence of natural conditions such as life, climate, geography, and topography, combined with ethnicity, culture, customs, characteristics, and aesthetics, etc. The various spatial forms do not adhere to the traditional ritual culture of central symmetry and present free and simple artistic characteristics. Traditional settlements mostly take rivers and contour lines as the base point of spatial structure, and the spatial form is linearly unfolded, and the space of larger settlements is constituted in groups and freely dispersed. The hierarchical order in the combination of architectural space is not prominent, and the typical residential buildings are based on or prototyped by the "one-character three-link room" plan pattern, forming the "one bright and two dark" or "one room and two inside" plan system. The plan form is based on the "one light, two dark" or "one room, two interior" plan, and evolves into a variety of plan space combinations according to the terrain, and the architectural style is simple and plain.

4. Architectural symbols expressing multiple cultures

Southern Shaanxi belongs to the regional sub-cultural circle, and there are different degrees of exchanges with the central cultural circle - the Bashu culture, the Jingchu culture, and the Qinlong culture, and the central cultural circle influences social and economic life. Southern Shaanxi is in one of the three cultural spheres, and most of them choose and seek internal identification with strong cultures based on real needs. At the same time, the migration of immigrants contributed to the great cultural interchange between the north and the south, forming a multifaceted convergence of the cultures of Ba-Shu, Jing-Chu, and Qin-Long in southern Shaanxi. The architectural symbols of southern Shaanxi reflect the influence of cultural fusion, with diverse wall shapes, regionalized ridge decorations, and dexterous and varied carved window bars, reflecting local traditional cultural values, aesthetic orientations, and social psychology, with the regional characteristics of lightness and fluidity, simplicity, unconventionality, openness, and compatibility in the same, and expressing a diverse and integrated architectural culture.

3.4 Chapter Summary

The purpose of this section is to put forward the passive heating technology in line with the traditional dwellings in southern Shaanxi, analyze the local natural environment, and excavate the space, shape, and other features of the traditional dwellings in southern Shaanxi. Through analysis, the paper summarizes the space and shape of traditional folk houses in southern Shaanxi.

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Chapter 4. Energy-saving Design Research and Thermal Engineering Principles

4.1 Building Climate Design Zone

4.1.1 Building Climate Zoning in China

China is a vast country with complex topography. Due to the difference in geographical latitude and topography, the climate varies greatly from place to place [1, 2]. Therefore, there are different approaches to energy-saving design for buildings in different climates. Buildings in hot regions need shading, insulation, and ventilation to prevent overheating, while buildings in cold regions need protection from the cold and insulation to allow more sunlight into the room [3]. To clarify the scientific relationship between architecture and climate, China's "General Rules for Civil Building Design" GB 50352-2005 divides China into 7 main climate zones and 20 sub-climate zones and puts forward different requirements for the architectural design of each sub-climate zone [4] (Figure 4-1).

(1) Building climate zone I: including Harbin, Changchun, Shenyang, Hohhot, etc. The buildings in this zone must fully meet the requirements of being cold-proof, heat insulation, and frost-proof in winter, and may not consider heat-proof in summer.

(2) II building climate zone: including Beijing, Tianjin, Shijiazhuang, Jinan, Taiyuan, Zhengzhou, Xi'an, Lanzhou, etc. The buildings in this zone should meet the requirements of winter cold, insulation, frost protection, etc., and some areas in summer should take into account the heat.

(3) III building climate zone: including Shanghai, Nanjing, Hangzhou, Hefei, Wuhan, Nanchang, Fuzhou, Changsha, Chengdu, Chongqing, etc. The buildings in this zone must meet the summer heat, ventilation, and cooling requirements, winter should be appropriate to take into account the cold. IIIA zone buildings should also pay attention to prevent tropical storms and typhoons, rainstorm attacks, and salt spray erosion; IIIB zone in the northern part of the building roof should also prevent the winter snow hazard.

(4) IV building climate zone: including Guangzhou, Hong Kong, Nanning, Haikou, etc. Buildings in this zone must fully meet the summer heat, ventilation, and rain requirements, winter may not consider cold, insulation. IVA zone buildings should also pay attention to tropical storms and typhoons, rainstorm attacks, and salt spray erosion; IVB zone in Yunnan's river valley area buildings should also pay attention to the roof and wall crack resistance.

(5) V building climate zone: including Guiyang, Kunming. The buildings in this zone should meet the wet season rain and ventilation requirements, regardless of the heat. VA zone buildings should also pay attention to cold; VB zone buildings should pay special attention to lightning protection.

(6) VI building climate zone: including Lhasa, Xining. The buildings in this zone should fully meet the requirements of cold, heat preservation, and frost protection, and need not consider heat protection in summer. VIC area and VIB area should also pay attention to the impact of permafrost on the building foundations and underground pipelines and should pay special attention to sand and

wind. VIC area eastern buildings should also pay attention to lightning strikes.

(7) VII building climate zone: including Yinchuan, Urumqi. Buildings in this zone must fully meet the requirements of cold, heat preservation, and frost protection, and some areas in summer should take into account heat prevention.

Figure 4-1. Building Climate Zoning Map of China

4.1.2 Shaanxi Climate Characteristics

Shaanxi Province forms three climatic zones from south to north, namely the North Subtropical, Warm Temperate, and Middle Temperate zones, each of which is divided into humid, semi-humid, semi-arid, and arid climates [5, 6, 7]. The climate of southern Shaanxi province belongs to the northern subtropical zone and the southern warm temperate zone, among which, the northern subtropical zone is divided into the Hanzhong-Shaanxi Hanjiang River Valley Basin Humid Climate Zone and the Micang Mountain-Daba Mountain Over-humid Climate Zone; the southern warm temperate zone is divided into the Qinling Mountain Humid Climate Zone and the Shangluo Danjiang River Valley Basin Semi-Humid Climate Zone [8, 9]. As shown in Figure 4-2.

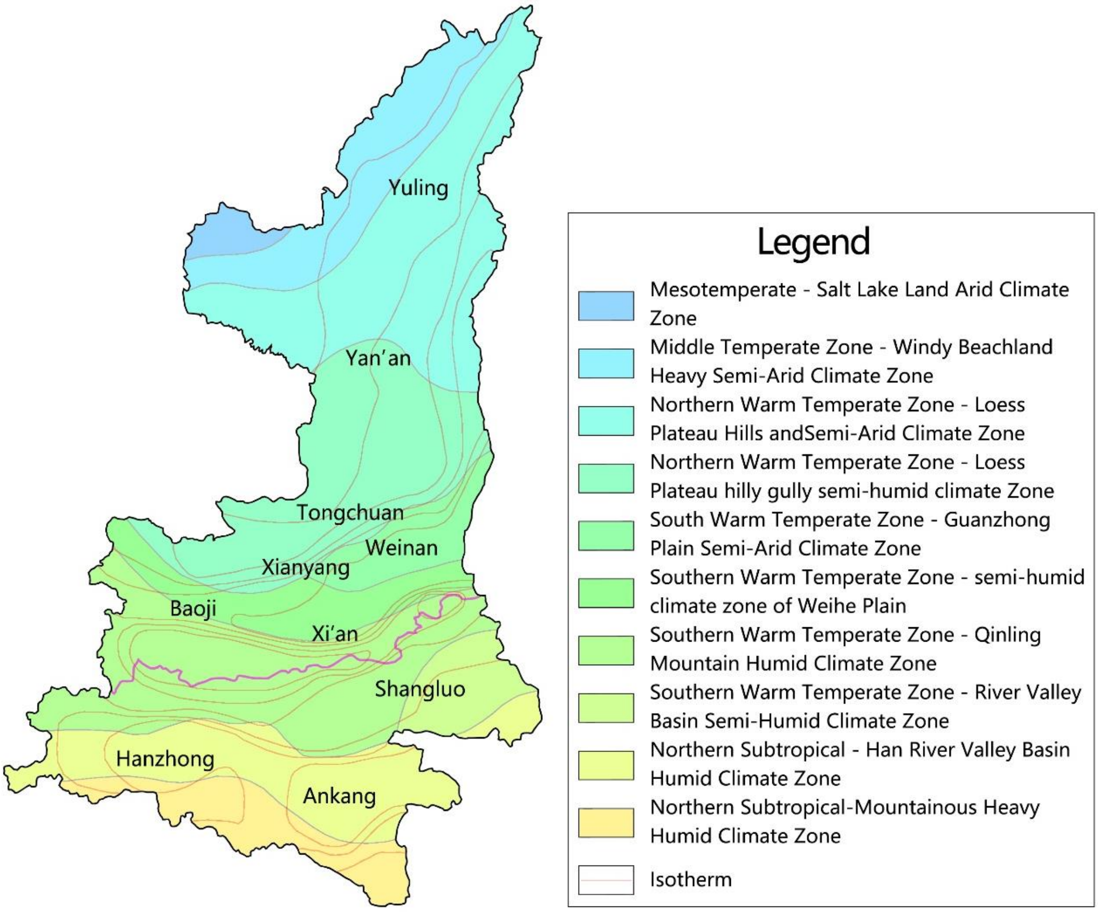

Figure 4-2. Climate map of Shaanxi

4.2 Solar Energy Design Analysis

4.2.1 Analysis of Solar Energy Utilization Potential

1. Solar energy and solar radiation definition

Solar energy in a narrow sense mainly refers to solar radiation, solar radiation reaching the surface of the earth is divided into direct radiation and scattered radiation [10]. Directly projected onto the ground solar radiation for direct radiation, through the atmosphere, clouds, fog, water droplets, dust, and other objects scattered in different directions and reach the ground solar radiation for scattered radiation. Direct radiation is the main source of energy for solar energy utilization. Direct radiation is received and converted for use on the surface of solar power facilities after atmospheric attenuation and urban environmental attenuation. The influencing factors of solar radiation mainly include geographic latitude, atmospheric conditions, topographic relief, etc. Solar radiation can be obtained through field measurements, meteorological observation point data, climatological statistical methods, or computer software simulations. In this paper, the total irradiation of the horizontal plane is used as the evaluation criterion in assessing the solar radiation level of urban buildings. The solar radiation received by the horizontal plane from above within 2π stereo angle (hemisphere) per unit time and the unit area is called the total horizontal irradiance (GHI, Global Horizontal Irradiance) in watts per square meter (W/ m^2) [11].

2. Overview of solar energy utilization

Solar energy utilization methods are photothermal conversion, photoelectric conversion, and photochemical conversion, where photoelectric conversion refers to the use of solar cells to collect solar radiation, the process of converting light energy into electricity [12]. This study refers to the use of solar energy mainly refers to the photoelectric conversion of this use, that is, the use of solar photovoltaic. Solar photovoltaic utilization facilities consist of photovoltaic cells, which are devices that convert solar radiation energy into electrical energy, and photovoltaic modules, which are the smallest indivisible units in a photovoltaic cell assembly device and can be divided into crystalline silicon modules, thin film-type modules, compound modules, and dye-sensitized modules [13]. In this study, photovoltaic cells and photovoltaic modules are also called solar cells and solar modules (Figure 4-3).

The forms of solar PV utilization in China are mainly divided into two categories: centralized and distributed. Concentrated PV utilization relies on abundant and relatively stable solar energy resources to build large power plants to supply long-distance loads, which are generally located in areas far from cities or deserts [14]. Distributed PV utilization refers to grid-connected solar PV facilities built near the customer's side, which can be used to supply the customer's electricity demand, and the excess power can be uploaded to the grid to supply the electricity demand in other areas. The distinctive feature of distributed PV utilization is that it is built near the customer side, effectively reducing the loss of electricity during transmission. It also has the advantages of small investment, flexible construction, effective use of building surfaces, does not occupy ground space and has been developing at a fast pace in recent years. Distributed photovoltaic utilization is a new type of comprehensive energy utilization with broad development prospects, which can effectively solve the problem of power loss in voltage boosting and long-distance transportation. According to the characteristics of urban energy consumption and spatial pattern, distributed photovoltaic utilization is more suitable for urban areas, which can replenish urban energy consumption and improve utilization efficiency. Based on this, the term "urban solar energy utilization" refers to distributed photovoltaic power generation facilities built on the surface of buildings and their attached vacant sites in urban areas [15]. Urban solar energy utilization can be divided into three categories, namely non-integrated solar energy utilization, semi-integrated solar energy utilization, and integrated solar energy utilization. Non-integrated solar utilization refers to how solar power generation facilities exist independently in urban space, such as on vacant sites attached to buildings or abandoned land. Semi-integrated solar energy utilization refers to the installation of solar power generation facilities on buildings or structures, which are independent of each other but are connected through later integration called BAPV (Building Attached Photovoltaic) [16]. Integrated solar energy utilization refers to the inseparability between solar modules and buildings or structures as a composite building material or building component, called BIPV (Building Integrated Photovoltaic).

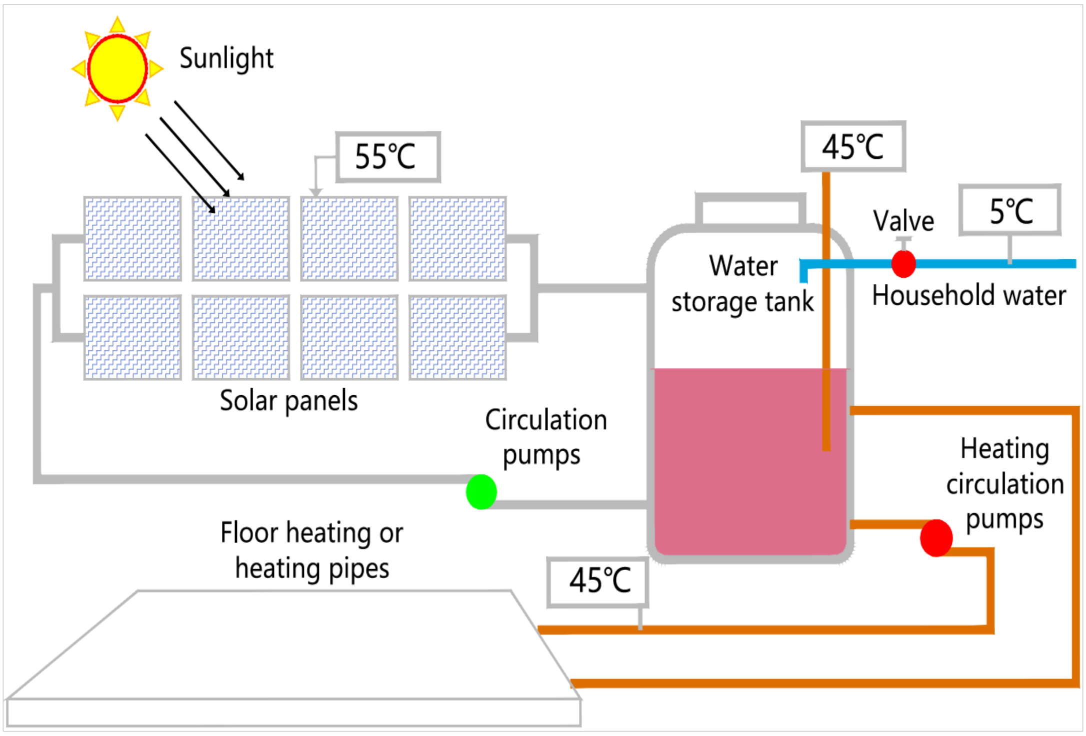

Figure 4-3. Solar Energy utilization principle

3. Useable space for urban solar energy

To cope with traditional energy shortages and environmental pollution and other problems, China began to pay attention to the development and construction of new energy sources as well as the development of the solar energy industry, the use of solar energy on an urban scale is on the agenda, which is of great significance to the sustainable development of cities [17]. The integration of solar energy utilization with the discipline of urban planning begins with the consideration of building layout. Building layout, orientation, spacing, and group combination as important factors that influence the redistribution of solar radiation on the building surface, which is a prerequisite for solar power facilities to obtain the amount of solar radiation to meet the power generation conditions [18]. Broadly speaking, solar available space refers to the buildable space that satisfies the conditions for solar power generation facilities to obtain power generation. Due to the special nature of urban space, urban solar energy available space is the buildable urban space that meets the conditions for power generation while protecting the natural environment and its architecture, culture, and heritage. It includes both spaces that are already utilized (if these utilized spaces are valid, then they are necessarily also available spaces) and spaces that have utilization potential but are not yet utilized. To realize the organic combination of the construction of distributed photovoltaic power generation facilities in buildings and the shaping of the quality of the urban spatial environment, and to guarantee the image of urban space, it is necessary to divide the urban areas that are not suitable as solar energy utilization space, control the construction range of the available space and propose the construction requirements of solar power generation facilities. We call the process of dividing unavailable and available urban solar space and evaluating the degree of availability by weighing solar resources, space, aesthetics, history, and culture as the assessment of available urban solar space. The process of proposing a planning strategy based on the assessment results based on the territorial spatial planning system is called urban solar availability spatial planning [19]. This is a complex decision-making problem, and in general, the steps of urban solar availability spatial planning include the following three steps: assessing urban solar availability space, assessing each space type, and proposing a planning strategy. The assessment of urban solar energy availability space aims to achieve scientific, rational, and effective use of solar energy in urban space, which is a great reference value for the large-scale application of solar energy in cities (Figure 4-4).

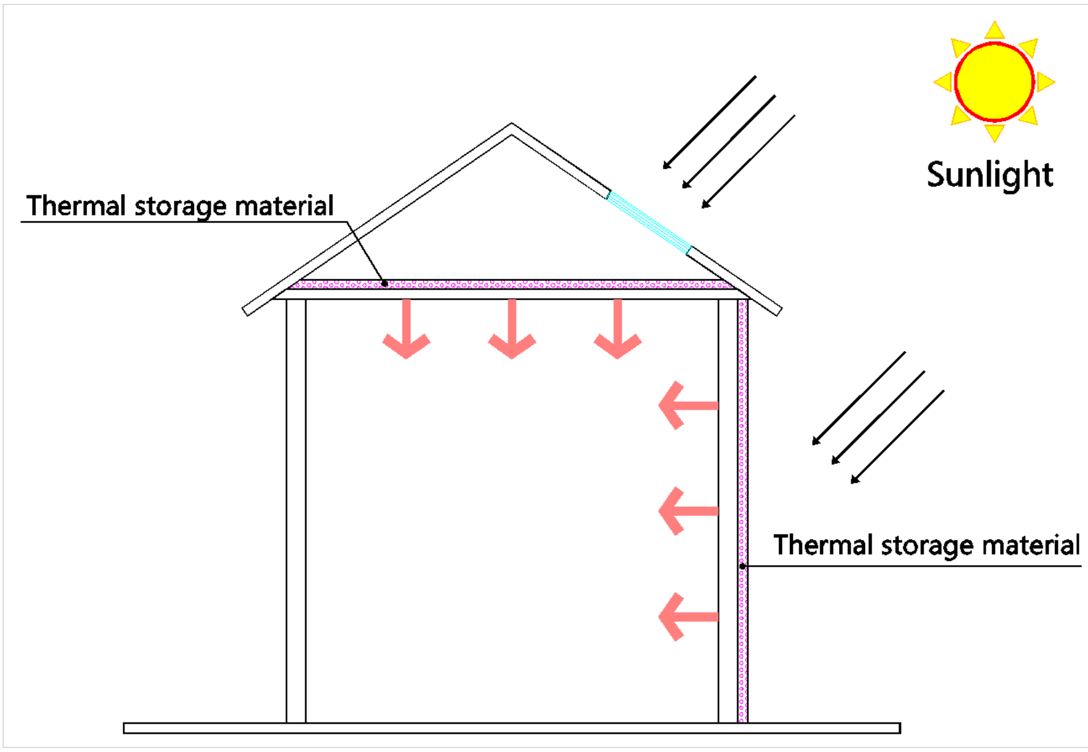

Figure 4-4. Principle of Heat Storage Wall

4. Theory related to solar energy utilization

Solar power facilities in the city scale application need to be supported by solar energy utilization-related theories and technologies, involving solar architecture, photovoltaic buildings, and other aspects of the content of the assessment of urban solar energy available space indicators to determine urban solar energy available space to guide the planning strategy proposed with a certain degree of guidance [20]. The combination of solar energy and buildings is one of the important ways to save energy in buildings. Solar architecture in a general sense mainly refers to the use of solar energy in buildings and is not limited to solar building integration (BIPV). Solar architecture is the intersection of green energy and new architectural concepts, and solar architecture has been widely promoted and used in large numbers in cities around the world, with clear requirements for planners and architects in the European Charter for the Application of Solar Energy in Architecture and Urban Planning proposed by Europe [21]. Solar architecture in China has mostly developed relying on the construction of green buildings and energy-efficient buildings, and with the introduction of projects such as the National Golden Sun Demonstration Project, solar architecture has gained significant development and BIPV has been vigorously promoted [22]. The combination of solar power generation and buildings is dominated by active solar technology, and the installation of solar equipment in renovated old buildings requires a reasonable assessment of whether the building meets the conditions for power generation and installation.

The combination of solar power facilities and buildings can easily affect the effect of architectural design and also affect the urban landscape appearance [23]. Solar building integration integrates solar modules into the building surface so that solar power generation facilities can not only meet the power generation requirements but also take into account the basic functional requirements of the building, eliminating the impact of solar power generation facilities on the appearance of the building. For new buildings, BIPV technology also has the advantage of avoiding duplication of investment and reducing costs. At present, the integrated use of solar energy and buildings still face some unresolved problems, such as technical bottlenecks, interest disputes, and lack of policy. With the continuous development of new energy sources in China and the increasing demand for urban energy conservation and emission reduction, green environmental protection, the feasibility, and economy of promoting solar energy and building integration in architectural practice through technological progress and policy support, making it possible as a construction requirement for new buildings [24]. Solar energy and building integration is a trend in the development of solar energy technology and should be more from the building ontology, the application of architectural aesthetics to adopt new architectural design methods to achieve a multi-dimensional symbiosis with the city. Solar energy and building integration is the future direction of solar energy technology and is the basis for the development of intelligent buildings. Solar building integration has the following advantages: first, it meets the requirements of architectural aesthetics, beautifies the appearance of buildings, and saves space for placing solar power generation facilities; second, it can meet the requirements of building lighting; third, it meets the requirements of building safety performance; fourth, it is easy to install; fifth, it has a long service life, effectively reduces building energy consumption, saves energy and reduces emissions, and is green; sixth, it does not occupy urban land resources [25]. This is especially important for areas with high land prices. The concept of "solar building integration" lays the foundation for promoting the integration of solar power facilities with the urban environment, reducing the visual impact of solar power facilities, maintaining the urban landscape, improving the quality of solar power facilities in combination with buildings, and helping to establish an active solar promotion policy.

4.2.2 Solar Heating Design zone

China's passive building technical specifications put forward that the design of passive solar buildings should follow the principle of adjusting measures to local conditions, and select the appropriate passive building technology in combination with the climatic characteristics, resource conditions, technical level, economic conditions, and building use functions of the area (Figure 4-5) [26]. According to the ratio of the solar irradiance of the southern vertical wall to the indoor and outdoor temperature difference in January and the solar irradiation of the southern vertical surface, it is divided into four passive heating climate areas. Southern Shannxi area belongs to the climate C area, which is more suitable for passive heating technology. According to the solar irradiance, average temperature, and relative humidity in summer, it is divided into four passive cooling climate areas [27]. Shaanxi area belongs to the best climate area, which is very suitable for passive cooling technology. Sherina takes the average temperature of the coldest month, the average temperature of the hottest month, and the percentage of comprehensive radiation as the basis for division. According to the meteorological parameters of typical cities in China and the suitability of passive solar heat collection technology, China is divided into six passive solar building climate design areas I-VI.

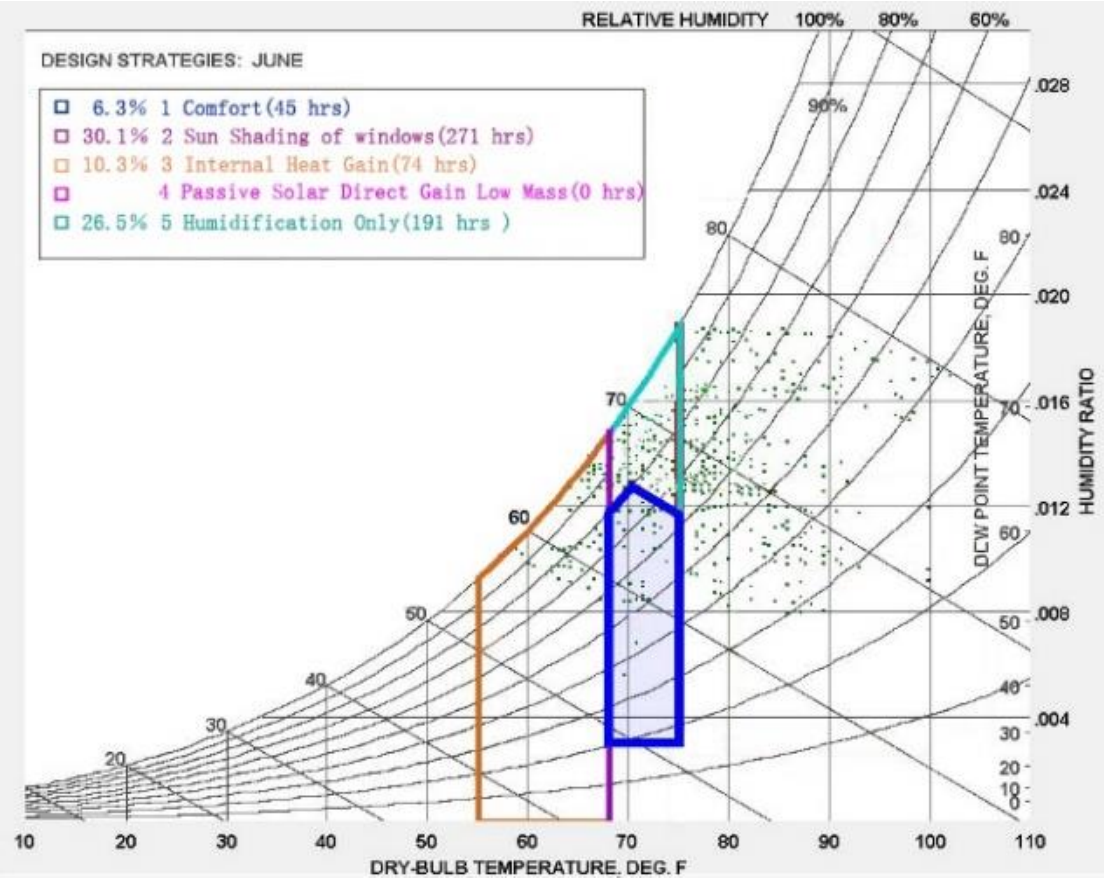

Figure 4-5. Architectural climate design analysis

4.2.3 Residents' Thermal Comfort Needs in Winter

Promoting the use of passive solar heating can not only save energy but also improve living conditions. An important indicator of improving living conditions is improving the thermal comfort of residents [28]. ISO 7730 defines thermal comfort as "a psychological state in which people feel satisfied with the thermal environment". The definition of thermal comfort in ASHRAE standard-

55 of the United States is: "80% of the people feel satisfied with the physical environment". Because the climate characteristics, architectural forms, food culture, clothing culture, and residents' living habits in the Shaanxi area are significantly different from those in other areas of cold climate area. Therefore, the thermal comfort needs of Shaanxi residents are special [29]. The research points out that Shaanxi residents have a certain adaptability to the hot environment, while their adaptability to the cold environment is poor. Compared with the cold environment, residents have a stronger tolerance to the hot environment. For the whole year of Shaanxi, the acceptable temperature range of 80% of residents is 12.28 °C to 31.29 °C.

4.3 Analysis of Energy-saving Design Methods

4.3.1 Architectural Orientation Design

Building orientation refers to the azimuth of the main facade (or facade) of the building. The selection of orientation should provide conditions for the use of solar heating and be conducive to the use of other solar technologies. The principle of orientation selection of Shaanxi residential buildings is to obtain sufficient sunshine in winter and avoid the dominant wind direction and cold wind attack. At the same time, solar radiation should be prevented in summer, the dominant wind at night should be introduced, and the airflow should be used to reduce the temperature of the building surface and indoors (Figure 4-6).

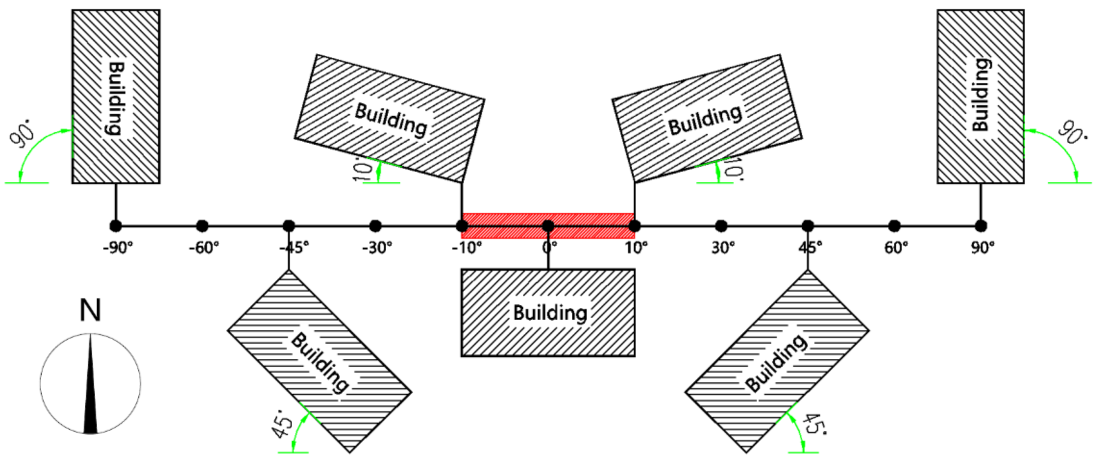

Figure 4-6. Azimuth study

1 Favorable direction of heat collection

The buildings in the Shaanxi area receive different solar radiation in different directions throughout the year: the solar radiation received by the West facade, South facade, and the horizontal plane is the same in January, February, November, and December, while the East facade and North facade receive almost no solar radiation(Figure4). In summer, the monthly average solar radiation on the horizontal plane is very large, followed by the West facade, which is about two-thirds of the horizontal plane, while the south facade is only one-third of the horizontal plane.

2 Design strategy

a. The direction conducive to heat collection is south by East; b. The direction conducive to ventilation is south by West; c. The direction of heat collection and ventilation is 25 ° south by East - 10 ° south by West. Among them, the best orientation is 10 ° south by east. The second orientation is 25 ° south by East - 10 ° south by East, 10 ° south by East - 10 ° south by West.

4.3.2 Window-to-Wall Ratio Design

1 Basic principle

The external window is the main heat gain and loss component of the building [31]. There are two reasons: first, the external window has a high heat transfer coefficient and poor thermal insulation performance. Second, thermal bridges are easy to appear at the junction of the outer window and the enclosure structure, so generally speaking, the larger the area of the outer window, the greater the heat loss. In buildings with good air tightness, if other envelope structures have high thermal insulation performance, windows will become the main part of heat loss and lose about 50% of heat. Even if the R-value of high-quality double-layer glass is 4, it will still lose a lot of heat at night and reduce indoor comfort (Figure 4-7).

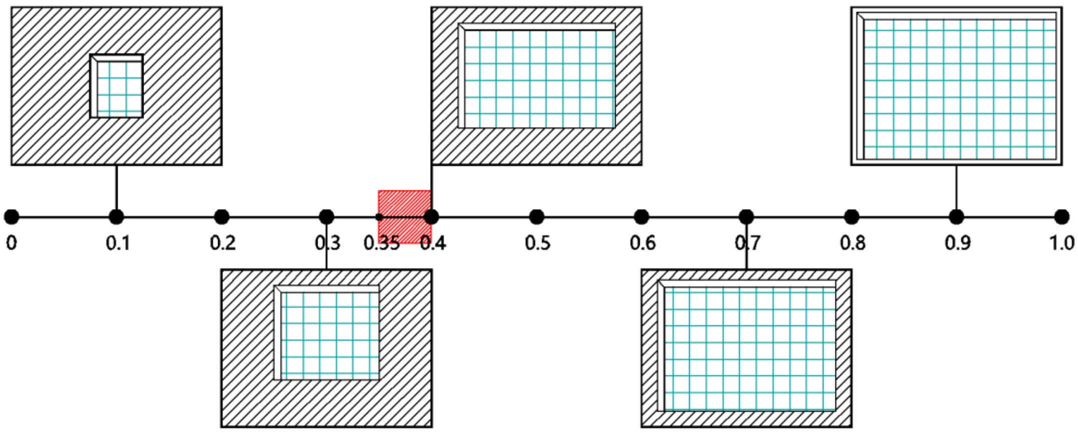

Figure 4-7. Window-to-wall ratio design

2 Influence of window wall area ratio on energy consumption

Window wall area ratio refers to the ratio of the opening area of the outer window in a certain direction to the area of the outer wall in a unified direction [32]. According to the above analysis, this section will study the impact of the change in the multi-directional window wall ratio of the building on various energy consumption. Therefore, a total of 40 models with a window wall ratio of 0.1-1.0 in each direction are established. The change value of the window wall ratio of each model is 0.1, and other design parameters are the same as those of the basic model. When the windows are not insulated [33]. The total building energy consumption and heating energy consumption increase with the increase of window wall ratio, among which the area change of the North window has the greatest impact.① The influence of daylighting and ventilation shall be comprehensively considered in the design of window wall ratio; ② The ratio of East and West windows and walls is within the effective range, and the smaller the better. ③ The south window wall ratio can be appropriately increased according to the design requirements. ④ The smaller the North window wall ratio is, the smaller the heat loss in winter is. When the indoor temperature in summer is higher than that outside, it is better to open windows for ventilation heat dissipation is the main factor. Therefore, the smaller the North window wall ratio, the better. ⑤ Adjustable thermal insulation measures shall be taken, especially for East, West, and south windows.

4.3.3 Solar Heating Retrofit Recommendations

1 Basic principle

The passive solar heating form recommended in the Shaanxi area is a heat collection and heat storage wall type. The room with heat collecting and heat storage wall has small room temperature fluctuation and good thermal comfort [34]. It is suitable for rooms used all day or mainly at night. The heat collection and storage wall with vents can not only use the greenhouse effect for heating in winter but also use the chimney effect to promote natural ventilation and cool down in summer.

Form adaptability and reasonable plane design can optimize the working efficiency of heat collection and storage walls [35, 36]. In Shaanxi folk houses, the rooms with heat collection and storage walls should face south and minimize the depth. If necessary, east-west heat collection and storage walls can be set. Shaanxi residential buildings are suitable for centralized shape to reduce heat loss in winter, but this will limit the available space for heat collection and storage walls. Even if the south wall is a heat collection and storage wall, it may not be enough to ensure the demand for housing [37]. At this time, the heat collection and storage walls can be set on the East and west walls. Therefore, the two walls, which are originally the heat dissipation way, have become heat collection and storage components, and the special structure of the heat collection and storage wall also makes the thermal insulation of the two walls more effective [38]. Therefore, the heat collection and storage wall have considerable adaptability in Shaanxi residential buildings. Combined with the architectural form, it can bring an appropriate heating effect to the indoor environment.

2 Appropriate design parameters

The heat collection and storage wall need to determine whether to set vents in combination with meteorological conditions and heat collection measures [39, 40]. The heat collection efficiency of the heat collection and storage wall with vents is relatively high, and the maximum indoor temperature appears earlier. For the walls of the same material, the thermal inertia of the thin wall is small and the heat transfer through the wall is large, but the thermal insulation effect at night is poor, which may produce a heat backflow phenomenon, and the temperature fluctuation of the inner surface of the thin wall is large, resulting in large fluctuation of indoor temperature [41]. The thick wall has great enthusiasm and less heat transfer through the wall, which is conducive to thermal insulation at night. The temperature fluctuation of the inner surface of the thick wall is small, and the indoor temperature is relatively stable [42]. Therefore, the thickness of the heat storage wall should be reasonably selected, which should not only ensure that it can transfer heat indoors in the daytime but also make it have a certain thermal insulation performance to prevent heat backflow at night. In addition to the existence and area of vents, the thickness of the air interlayer, the thickness of the wall, and the type of glass in the study, the material of heat collection and storage wall also has an impact on its energy-saving effect, which is mainly reflected in the thermal inertia, which is related to the thermal conductivity and heat capacity of the heat storage body [43].

4.4 Envelope Insulation Technology

Energy saving of building envelope improves the thermal performance of the envelope so that the thermal energy supplied to the building can be effectively used inside the building, thus achieving the purpose of reducing energy consumption [44]. Achieving energy saving in building envelope requires improving the thermal insulation performance of building walls, roofs, floors, doors and windows, and other components, and improving the sealing performance of walls, doors, and windows to reduce heat transfer loss and air infiltration heat consumption. In the building, the heat loss of the exterior envelope is the largest, and the walls of the exterior envelope have a large share. In heating areas, exterior walls are the main body of heat loss in building energy efficiency, nearly 50% of the proportion, highlighting the important position of exterior wall insulation as a key technology in building energy efficiency [45]. So the development of building wall energy-saving technology is an important part of building energy-saving technology, and the development of building exterior wall insulation technology is the main way to achieve building energy-saving.

4.4.1 Principle of Envelope Insulation Technology

In winter, to maintain the indoor temperature, the building must obtain heat. The total heat gain of the building includes the heat supply of heating equipment (about 70% -75%), solar radiation heat gain (through windows and envelope structure into the interior, about 15%-20%), and internal heat gain of the building (including cooking, lighting, home appliances, and human body heat dissipation, about 8%-12%). This heat is then dissipated to the outside through heat transfer and air infiltration through the envelope (including exterior walls, roofs, windows, doors, etc.). The total heat loss of the building includes the heat transfer heat consumption of the envelope (about 70%-80%) and the air infiltration heat consumption through the gaps of windows and doors (about 20%-30%), concerning the table with the solar radiation heat gain and the internal heat gain of the building, which ultimately achieves the purpose of energy saving [46]. From engineering practice and experience, improving the thermal performance of the building envelope is the key to energy-saving renovation, and the effective way to improve the thermal performance of the solid protection structure is the first choice of external wall insulation technology.

4.4.2 Building Exterior Wall Insulation Type

In recent years, in the process of continuous development of building insulation technology

[47], mainly formed external wall insulation and external wall insulation and sandwich insulation, and other three technical forms.

1 External wall insulation technology

External wall insulation is to add an insulation layer in the interior of the external wall structure. External wall insulation in China has been applied for a long time, and construction technology and inspection standards are perfect. The heat storage capacity of the exterior wall insulation material is low, when the indoor intermittent heating or intermittent air conditioning is, the indoor temperature can be adjusted to the required temperature faster, suitable for winter is not too cold areas building insulation. About 90% or more of the projects in the construction of exterior wall insulation before 2001 applied internal insulation technology [48]. The disadvantages of internal insulation external wall, mainly the internal wall and floor and external wall junction can not lay the internal insulation material, easy to form a thermal bridge; insulation material is easy to permeate steam, while the structural layer is the opposite, when the temperature difference between indoor and outdoor in winter, there is a possibility of condensation water inside the wall. Therefore, internal insulation and external walls should not be used in cold regions [49].

2 External wall insulation technology

External wall insulation is on the outside of the main wall structure, a layer of insulation material is fixed under the action of bonding material, and the outside of the insulation material is reinforced with a glass fiber network and coated with bonding slurry, to achieve the effect of heat insulation [50]. At present, China's research and development of external wall insulation technology have been more mature, according to the national industry standard "external wall insulation engineering technical regulations" (JGJ144-2004) released in 2004, external wall insulation technology can be divided into EPS board thin plaster external wall insulation system, rubber powder EPS particle insulation slurry external wall insulation system, EPS board cast-in-place concrete external wall insulation system, EPS wire mesh frame board cast-in-place In 2007, the Technical Specification for Rigid Foam Polyurethane Insulation and Waterproofing Engineering (GB50404-2007) was released to include rigid foam polyurethane exterior insulation project. In recent years, external wall insulation technology has developed rapidly, and rock wool external insulation systems, XPS board external insulation systems, prefabricated insulation board external insulation systems, insulation and decoration integration external insulation systems, sandwich external insulation systems, etc. came into being. External wall insulation technology is not a simple combination of several materials, but an organic combination of the system. Exterior wall insulation technology system integration of insulation materials, bonding materials, alkali-resistant grid glass fiber mesh cloth, anti-cracking materials, putty, paint, brick, and other materials in one, through a certain technical process and practice collection and become. Generally divided into six layers or seven layers, of which insulation materials can be divided into molded polystyrene board, extruded polystyrene board, polyurethane, and other materials; bonding materials generally have a binder, cement, quartz sand composition, according to the mixing method is divided into the two-component, one-component mortar, according to the use of different positions, according to a certain proportion of the combination can become bonding mortar, anti-cracking mortar. surface layer according to the need, can be painted, tiles, etc.. external wall insulation structure, form can be divided into thin plaster external wall insulation system, prefabricated surface layer external wall insulation system, with network cast-in-place external wall insulation system, no network cast-in-place external wall insulation system, and other forms, the combination of various materials to form different external wall insulation structure, the impact of the quality of the external wall insulation material system depends not only on the quality of various materials but also on whether the various materials are integrated.

3 External wall sandwich insulation technology

External wall sandwich insulation technology is set in the middle of the insulation material in the external wall, which is conducive to better playing the role of the wall itself to the protection of the external environment, the practice is to divide the wall into load-bearing and protective parts, leaving a certain gap in the middle, filled with inorganic loose or block insulation materials such as slag, expanded perlite, etc. [51], or unfilled materials made of the air layer. The material requirements for insulation materials are not high, and convenient for construction, but the wall is thicker, reducing the use of the area. When using sandwich insulation, ring beam, and structural column because the general is solid, difficult to deal with, and very easy to produce thermal bridges, the effectiveness of insulation materials does not give full play. Because of the filling insulation material settlement, pulverization, and other reasons, the internal easy-to-form air convection, also reduces the effectiveness of insulation. In non-cold areas, the external wall with sandwich insulation is thick compared with the traditional wall. Because the inner and outer walls need to be connected with connectors, the construction is more complicated than traditional walls, and the construction is relatively difficult. The seismic performance of sandwich insulation walls is relatively poor, and the building height is restricted. Because of the insulation material on both sides of the wall, there is a large temperature difference, which will trigger a relatively large deformation difference between the inner and outer walls, which will cause cracks and rainwater leakage in many parts of the wall and damage the main structure of the building. This kind of wall has certain heat preservation performance, but its disadvantages are also very obvious, and its application scope is greatly restricted.

4.4.3. The External Wall Insulation Technology Advantage Analysis

Through the external wall insulation, external wall insulation, and sandwich insulation three kinds of insulation comparative analysis, it can be seen that, compared with external wall insulation and core insulation [52], external wall insulation technology better solves the two forms of insulation brought about by many comprehensive problems, with, a wide range of application, good insulation effect, low comprehensive investment, can extend the life of the main structure and other advantages, should become China's wall insulation The main form and the development direction of energy-saving building insulation wall. The main technical advantages of external wall insulation are as follows (Figure 4-8).

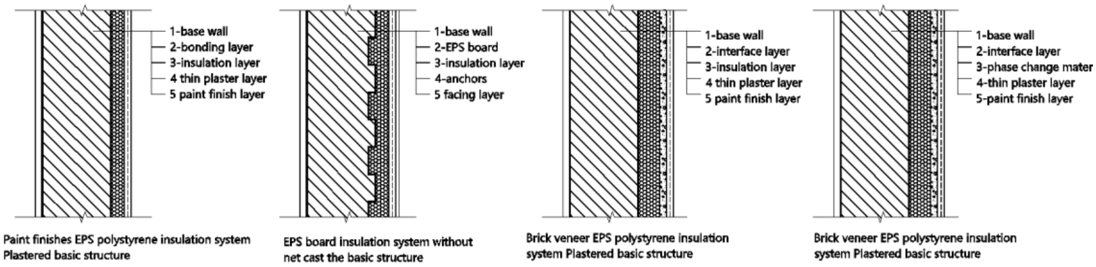

Figure 4-8. Design method of wall insulation

1 Wide range of application

External insulation is not only applicable to heating buildings in cold and severely cold areas in the north but also applicable to air-conditioning buildings in the south that need summer insulation. At the same time, it is not only applicable to new buildings, but also applicable to the energy-saving renovation of existing buildings, so the scope of application is wider. Internal insulation is more suitable for new buildings and is more applied in the southern regions of hot summer and warm winter. In terms of safety, durability and construction, and cost control, external wall insulation has incomparable advantages, which makes it more suitable for residential buildings in South China, especially for high-rise residential buildings [53].

2 Further improve the thermal insulation performance of the wall and facilitate room temperature stability

Sandwich insulation is mainly applied to multi-story buildings, and the application range is smaller in areas where seismic requirements are not high. The quality of the indoor thermal environment is influenced by the indoor air temperature and the surface temperature of the envelope. The external wall insulation is conducive to room temperature stability because the structural layer with larger heat storage capacity is on the inner side of the wall, and when the room is subjected to unstable thermal effects and the indoor air temperature rises or falls, the structural layer of the wall can absorb or release heat, thus contributing to the improvement of the indoor thermal environment [54].

3 Protect the main body of the structure and prolong the service life of the building. The insulation layer structure of external wall insulation makes the inner and outer walls of the building in two different temperature environments respectively. The interior walls and floor slabs are in the indoor temperature environment, and the annual temperature difference is within 10℃, while the exterior walls are in the outdoor temperature environment, and the annual temperature difference is in the range of 60~80℃. And every 10℃ change in ambient temperature will cause the expansion and contraction of the concrete material of the wall by 10,000%. External wall insulation makes the

main structure in two different ambient temperatures and different deformations so that the main structure is not stable all year round. This perpetual instability of the main structure will lead to cracks in multiple walls, and damage the waterproofing of the roof along the exterior walls, causing leakage in the basement waterproofing, etc. These phenomena, which significantly shorten the life of the building structure, are called "internal insulation technology syndrome" [55]. Similarly, this principle of "different temperature environments produce different deformations" also occurs in walls with sandwich insulation. The use of an external insulation technology program, because the insulation layer is placed on the outside of the building envelope, buffering the stress caused by temperature changes in structural deformation, avoiding the structural damage caused by rain, snow, freezing, thawing, dry and wet cycles, reducing the erosion of the envelope by harmful gases and light in the air. Engineering practice proves that the practice of thorough external wall insulation is to put on a cotton jacket on the whole structure of the building so that it is completely under the indoor temperature environment, the annual temperature difference generally fluctuates little, and the impact of its deformation can be ignored. It is only the outer surface of the external insulation that is affected by the outdoor ambient temperature. As long as the wall and roof insulation material selection is appropriate, and thickness is reasonable, external insulation can effectively prevent and reduce the temperature deformation of the wall surface, and eliminate wall cracks. Therefore, external insulation can not only reduce the temperature stress of the enclosure structure but also play a protective role for the main structure, thus effectively improving the durability of the main structure, which is more scientific and reasonable than internal insulation and sandwich insulation.

4 The phenomenon of thermal bridges is eliminated

Indoor heat dissipation is related to the number and size of thermal bridges. The large area of the thermal bridge of internal insulation is a low-efficiency form of energy saving [56]. Due to the heat dissipation, the temperature of the thermal bridge part is very different from the non-thermal bridge part. According to the relevant data, in winter, the inner wall surface will produce a temperature difference of more than 10℃, and the outer wall surface will produce a temperature difference of 5℃, which will easily lead to condensation in the thermal bridge area. Inside the insulation technology dew point position is near the inner surface of the outer wall, the northern region of the winter within the thermal bridge part of the insulation project often occurs condensation phenomenon, is not to do insulation in the southern region of the summer due to the influence of air conditioning temperature is low, the outer surface of the external wall temperature is high, the inner surface of the external wall often occurs mold. And the use of external insulation in solving the "thermal bridge" problem than internal insulation is better than some. Such as in the junction of the inner and outer wall parts, external wall ring beam, construction column, door and window openings, and daughter wall and roof panel junction around the thermal bridge parts, the bottom room "thermal bridge" additional heat load accounted for about 23.7% of the total heat load; middle layer room accounted for 21.7%; top layer room accounted for 24.3%. It can be seen that the influence of thermal bridges is greater.

5 Improvement of wall moisture without a vapor barrier. The above is almost difficult to avoid for internal insulation and sandwich insulation, while external insulation of external walls can prevent condensation from thermal bridge parts and eliminate additional heat loss caused by thermal bridges. After adopting external insulation technology, the whole wall temperature of the structural layer is increased, which reduces its moisture content and further improves the thermal insulation performance of the wall. In general, the internal insulation shall set a gas barrier, and when the external insulation technology is adopted, because the main structural material with high water vapor permeability is in the inner side of the insulation layer, the main insulation material is selected appropriately, condensation does not occur inside the wall in general, and there is no need to set a gas barrier.

6 Improved waterproof function and airtightness

Aerated concrete, concrete hollow block, and other walls, in the case of masonry mortar joints and face brick paste are not dense, its waterproofing and airtightness are poor, the use of external insulation structure, it can greatly improve the waterproof and airtight performance of the wall.

7 Especially beneficial for existing building renovation without the implementation of building energy-saving standards 50% of existing buildings generally do not meet the energy-saving requirements. At present, about 43 billion square meters of existing buildings are not energy-saving, so the renovation of existing buildings is an urgent matter, the more important aspect of the renovation of existing buildings is the exterior wall insulation. The biggest advantage of using external insulation to renovate existing buildings is that it does not require temporary relocation and does not affect the user's indoor activities and normal life. At the same time, not occupy the indoor use of the area, but also can effectively avoid the decoration of the insulation layer damage.

In summary, whether from the mechanism of building energy saving or from the actual energy-saving effect to measure, external insulation technology is the best choice. In foreign countries, the use of external insulation in buildings has a history of more than 40 years, in recent years, China's cold regions, cold regions, hot summer, and cold winter regions, and hot summer and warm winter regions have also built a large number of external insulation of buildings, to achieve good economic, social and environmental benefits.

4.5 Insulation Material Analysis

4.5.1 Analysis of Exterior Wall Insulation Materials

As the main carrier of exterior wall insulation, energy-saving insulation materials are an important part of the building wall. The technical performance and quality of insulation materials are closely related to the insulation effect of the wall [57]. Energy-saving materials belong to thermal insulation materials. Insulation materials are materials or material complexes used for building enclosures or thermal equipment, the impedance of heat flow transfer, including both insulation materials and cold retention materials. The significance of insulation materials, on the one hand, is to meet the thermal environment of the building space or thermal equipment, on the other hand, is to save energy. With the increasing tension of energy worldwide, the significance of insulation materials in energy saving is becoming more and more prominent. Only for general residential heating and air conditioning, by using insulation envelope materials, energy saving can be 50%-80% on the existing basis. According to Japan's energy-saving practice, each use of 1t insulation materials, can save 3t/year of standard coal, its energy-saving benefits are 10 times the cost of material production. Therefore, some countries see thermal insulation materials as the fifth generation of " energy " after coal, oil, natural gas, and nuclear energy [58] exterior wall insulation effect mainly depends on thermal insulation materials, the development, and application of efficient thermal insulation materials are to ensure that the effective measures of building energy efficiency. The main development direction of external wall insulation materials is as follows.

1) thermal insulation materials have a large thermal resistance and a small thermal conductivity

Relevant information shows that the general thermal conductivity of organic polymers is less than inorganic materials; the thermal conductivity of non-metals is less than metal materials; the thermal conductivity of gaseous substances is less than liquid substances, and liquid substances are less than solid. Therefore, organic polymer materials or amorphous inorganic materials should be used when conditions permit. In addition, when the pores inside the material are a large number of closed micro-pores, the thermal conductivity of the material is relatively small. At the same time, the thermal resistance of the material is large and is also conducive to thermal insulation.

2) Insulation material moisture absorption performance is low due to the existence of pores, the material in a humid environment, inevitably absorbs water, and the thermal conductivity of water (0.5815W/m·k) than the thermal conductivity of still air (0.0233W/m-k) is much larger. Therefore, when the environmental humidity increases, the equilibrium water content of the material increases, and the thermal conductivity of the material will decrease. Insulation material itself moisture absorption rate should be as low as possible, such as can not be avoided, the material should be water repellent treatment or waterproof material wrapping.

3) Insulation material impact resistance performance

As thermal insulation materials must be able to resist a certain impact load, with the use of the environment consistent with the mechanical strength. Strong impact resistance of insulation materials can effectively solve wind pressure, material cracking, service life, and other technical problems.

4) Insulation materials to have strong durability

Building exterior insulation materials in the external environment, experiencing the sun, wind, rain, cold, heat, and other natural climate, the durability of the material to put forward higher requirements. Insulation materials should have long-term durability that is compatible with the environment.

5) Insulation materials to have the incombustibility

Whether the external insulation system has fire safety, consider the following two aspects of the problem: in the conditions of ignition or fire, the system can be ignited or cause combustion generation, and insulation materials own combustion performance requirements; when there is combustion or fire, the system can spread the flame, the system to the external fire source attack resistance or fire resistance performance requirements. Can meet the above performance requirements and energy-saving materials used for building exterior insulation are polystyrene foam board (EPS and XPS), rock wool board, glass wool felt, and ultra-light polystyrene particle insulation slurry. The above materials have a common feature that there are a large number of closed pores within the material, and their apparent density is small, which is necessary as thermal insulation materials [59].

4.5.2 Research on PCMs

1 PCMs overview

Phase change materials are substances that can achieve two-way temperature regulation with the change of ambient temperature and are often accompanied by a change in the physical state during the process of heating and cooling, thus achieving the purpose of energy storage/release [60]. PCMs have both energy storage and temperature control capabilities and are a very promising thermal energy storage material, which has gradually become a research hotspot in recent years in the fields of building energy conservation and system temperature control. Specifically, when the ambient temperature is higher than the melting point of the phase change material, the material absorbs heat and undergoes a phase transition to achieve energy storage; when the ambient temperature is lower than the freezing point of the phase change material, the material undergoes a reverse phase transition to achieve energy release. This kind of material can absorb or release heat from the environment according to the change of external environment temperature to realize the temperature regulation function is collectively called phase change material. Phase change energy storage materials have many significant advantages over other types of energy storage materials: low preparation cost, high energy storage density, and small temperature variation range during the phase transition. Therefore, PCMs effectively alleviate the mismatch between the supply and demand of energy in time, space, and speed, which is very important for the improvement of energy utilization efficiency and sustainable development of resources (Table 4-1).

Table 4-1. Thermal properties of some PCMs

Material	Melting Temperature (°C)	The heat of Fusion (kJ/kg)
HDPE	120–135	300

$MgCl2·6H2O$	117	168.6
Paraffin wax	64	173.6
Polyglycerol E6000	66	190
Biphenyl	71	119.2
Naphthalene	80	147.7
Palmitic acid	64	185.4
Stearic acid	69	202.5

2 PCMs classification

There are three main methods of classifying PCMs commonly used in engineering: by phase change temperature, by the chemical composition of the material, and by phase change [61].

(1) According to the phase change temperature: PCMs can be divided into high-temperature, medium-temperature, and low-temperature PCMs. The working temperature range of low-temperature PCMs is mainly distributed in the range of -20~200°C, which is also the This is also temperature range that people are most interested in, mainly including hydrogel, ice, and other materials, which have great application prospects in agriculture, construction, military, clothing, and other industries; medium-temperature PCMs are mainly distributed in the working temperature range of 200~5 The working temperature range of medium-temperature PCMs is mainly distributed in the range of 200~500°C, mainly including some crystalline hydrated salts, organic substances, and polymer materials, etc.; the working temperature range of medium-temperature PCMs is mainly distributed in the range of 50 0~2300°C, mainly including metal alloy materials, molten salts, etc.

(2) According to the chemical composition of materials: PCMs are divided into inorganic, organic, and eutectic materials. Organic PCMs mainly include alkanes, kinds of paraffin, organic acids, polyols, etc.; inorganic PCMs mainly include crystalline hydrated salts, inorganic salts, metals, and alloys; eutectic class includes organic-organic, inorganic-inorganic, and organic-inorganic three.

(3) According to the phase change of phase change process: PCMs can be divided into solid-liquid phase change, solid-gas phase change, liquid-gas phase change, and solid-solid PCMs. Considering that solid-gas phase change and liquid-gas PCMs are too large and easy to leak, solid-liquid phase change and solid-liquid PCMs are more commonly used in practical engineering. Solid-solid PCMs are materials whose crystalline form changes from one crystalline form to another accompanied by heat transfer, but since their latent heat values are lower than those of solid-liquid PCMs, the study of solid-liquid PCMs is currently a popular trend. The advantages and disadvantages of various types of PCMs are shown in Table 4-1. Usually, PCMs have problems such as low thermal conductivity and poor heat transfer performance, which seriously reduce the actual heat storage and discharge efficiency of energy storage systems. Most inorganic hydrated salts have corrosive, supercooling, and phase separation phenomena, which seriously affect the reversibility

of the phase change process and directly cause the energy storage capacity of energy storage materials to drop rapidly. The emergence of phase change composites overcomes the shortcomings of single PCMs, improves the problems of leakage, subcooling, and phase separation, and effectively broadens the practical applications of phase change materials. Therefore, the study of shaped phase change composites has become a hot research topic, and there are many related literature and reports (Table 4-2).

Table 4-2. Advantages and disadvantages of PCMs

Organic matter		Inorganic matter		Complex of compounds
Advantages	Disadvantages	Advantages	Disadvantages	Quality
High latent heat of phase transition	Low latent volumetric heat value	High latent heat of phase transition	Large volume change	High latent heat capacity
Phase free separation	Low thermal conductivity in the solid state	High latent volumetric heat value	A serious degree of supercooling during the solid-liquid transition	The high heat of melting
A self-nucleating property	Flammability	Low cost and practicality	Re-use requires nucleating agents	No subcooling during solidification
Good compatibility	High cost	Noncombustible	phase separation	-
Recyclable	-	-	Corrosivity	-

3. PCMs applications

Based on the unique properties of phase change materials, they are widely used in solar thermal utilization [62], building energy-saving cooling systems, heating systems, food cold chains, medicine, aerospace, and other fields have been widely used.

(1) Air conditioning system

The burning of fossil fuels has led to a series of environmental problems, and the use of new and renewable energy (such as solar energy) and energy saving has become the focus of national attention. Solar air conditioning is one of the most promising areas of the use of solar thermal energy. Energy storage technology plays a very important role in the field of solar air conditioning. Building load accounts for 30 to 50% of the total electricity load, and air conditioning and refrigeration are a large part of the building energy consumption, accounting for 85% of the total electricity load during the peak summer season. Refrigeration storage technology has become an important measure to improve the power shortage in China due to its unique load-shifting effect. Cold storage is an effective way to alleviate the conflict between energy supply and demand. Cold storage technology has the following advantages: it plays the role of peaking; it reduces the capacity of refrigeration equipment and power distribution; it reduces operating costs and extends the life of the system; and it serves as an alternative cooling source. Thus, it can be seen that cold storage air conditioners play an important role in energy saving and emission reduction. Usually, solid-liquid PCMs are the main type of energy storage materials. In the energy storage process, phase change energy storage materials have some unique advantages, such as relatively stable operating temperature and high energy storage density. the phase change cold storage materials for low-temperature latent heat storage at 120°C. The classification of cold storage materials into organic and inorganic thermal storage materials of paraffin, fatty acids, inorganic salt hydrates, and eutectic compounds was considered and the importance of thermal cycling tests for the long-term stability of cold storage materials was discussed. Khan et al [63] provided a comprehensive assessment of the selection, integration methods, enhancements, and challenges of PCMs appropriate for the operating temperature of each component in a solar absorption system that affects its performance. In summary, research in storage and cooling air conditioning will have an important impact on energy conservation and emission reduction.

(2) Solar Thermal Utilization

Solar thermal conversion and storage technologies based on PCMs can overcome the intermittent nature of solar radiation. However, low thermal conversion efficiency and thermal transport efficiency have been bottlenecks for high-power density solar energy collection. wang et al [64] constructed a bifunctional vertically aligned and interconnected graphite nanosheet network for synergistically enhancing the solar thermal conversion and thermal transport of graphite nanosheet-based composite PCMs. The bifunctional vertically aligned and interconnected graphite nanosheet network acts as both a light absorber (the exposed part of the graphite nanosheet network) and a thermal conductor (the embedded part of the graphite nanosheet network). Compared with a polyol, the thermal conductivity of the obtained graphite nanosheet matrix composites was improved by 40.0 %. The graphite nanosheet network increased the surface full-spectrum solar energy absorption to 95%, which is superior to conventional coating-enhanced solar thermal conversion materials. In addition, considering the intermittent nature of solar energy, emerging indirect electro-thermal conversion and storage technologies based on PCMs are also important to ensure the reliability of renewable thermal energy utilization. Preparation of leak-proof, low-cost, and highly conductive vertically aligned reticulated graphite nanosheets with high conductivity for high-temperature solar thermal and electrothermal conversion by a pressure-induced self-assembly method [65]. The results showed that the corresponding energy conversion was achieved thanks to the synergistic effect of vertically aligned RGNs within pentaerythritol. The corresponding energy conversion device achieves direct solar thermal conversion and storage at high temperatures (>186°C), as well as direct solar thermal conversion and storage at 0.5°C. The corresponding energy conversion device achieves direct solar thermal conversion and storage at high temperatures (>186°C) and high efficiency of 92.73% electrothermal conversion and storage at an ultra-low drive voltage of 0.34V. This synergistic strategy provides a cost-effective way to efficiently utilize solar and electrical energy to design a high-performance energy management system based on PCM.

(3) Building Energy Efficiency Applications

With rapid urbanization and rising living standards worldwide, the demand for efficient and smart buildings is increasing. The building industry has become the world's largest consumer of materials and energy, accounting for nearly 40 percent of its use. To reduce energy consumption and have a smart life, new efficient and environmentally friendly materials, and building envelope technologies should be developed to achieve energy saving in heating and cooling is important to achieve. Most of PCMs panel walls are made by direct mixing, microencapsulation, and vacuum immersion collapse of PCMs Eddhahak -Ouni et al [66] used the microencapsulation method to incorporate Mi cronalDS5 001XPCMs (from BASF) incorporated into silicate cement. The results showed that the incorporation of PCMs effectively improved the PCM thermal storage capacity of the concrete mixes, but did not have much effect on their thermal conductivity. The small change in thermal conductivity was mainly attributed to the small amount of phase change materials and their lower thermal conductivity. In addition, radiant floor heating systems eliminate dust movement and humidify the air. Therefore, it is a clean alternative to conventional heating systems and can reduce the peak load of air conditioning energy and reduce energy consumption. The underfloor heating system with PCMs in a room in Beijing and analyzed its thermal behavior and practical use. PCMs panels consisted of 75% paraffin wax (phase transition temperature of 52.8°C) and 25% of polyethylene (PE) as a carrier. The shape of the PCMs sheet is stable enough to prevent leakage. above 45°C for more than 10h and its temperature versus time is recorded with a paperless recorder. The system is highly economical because the phase change temperature of the PCMs plate is maintained for a long time, effectively transferring more than half of the total electrical heat energy from peak to off-peak.

(4) Other applications

Introducing phase change materials into the field of smart wearable devices can achieve multiple responses of the devices to external light, electricity, magnetism, and heat. Scholars have prepared flexible electric/optical actuator energy storage polymer fibers with excellent hydrophobicity and self-cleaning properties [67]. The smart fiber is composed of integrated grating conductive nano-silver powder and poly and hydrophobic fluorocarbon resin, and a simple new wet-spun phase change fiber to obtain highly flexible, excellent electrical conductivity, high enthalpy, adjustable phase change temperature, additional shape stability, and excellent The smart fiber material with a maximum elongation of more than 500%.

4.5.3 HDPE Material Analysis

1. HDPE material introduction

HDPE white powder, or granular products. Non-toxic, tasteless, a crystallinity of 80% to 90%, softening point of 125 to 135 °C, use temperature up to 100 °C; hardness, tensile strength, and creep better than low-density polyethylene; wear resistance, electrical insulation, toughness, and cold resistance are good [68]. Chemical stability is good, at room temperature, insoluble in any organic solvents, acid, alkali, and various salt corrosion; film permeability to water vapor and air It is less resistant to aging and less resistant to environmental stress cracking than low-density polyethylene, especially thermal oxidation will make its performance decline, so the resin must add antioxidants and ultraviolet absorbers to improve this aspect of the deficiency. High-density polyethylene film has a lower heat deflection temperature under stress, so care should be taken when applying it.

HDPE is a thermoplastic polyolefin produced by the copolymerization of ethylene. Although HDPE was introduced in 1956, this plastic has not yet reached a level of maturity. This versatile material is still developing its new uses and markets.

The domestic producers of HDPE (HDPE here does not include HDPE produced by full-density polyethylene plants) in China are CNPC, Sinopec, and CNOOC, and as of the end of 2006, there are four sets of HDPE plants belonging to CNPC, namely Lanzhou Petrochemical HDPE plant, Daqing Petrochemical HDPE plant, Liaoyang Petrochemical HDPE plant, and Jilin Petrochemical HDPE plant. Jilin Petrochemical high-density polyethylene plant [69].

HDPE is usually manufactured by the Ziegler-Natta polymerization method, which is characterized by the absence of branched chains in the molecular chain so that the molecular chain is arranged regularly and has a high density. The process is initiated in a tubular or kettle-type low-pressure reactor using ethylene as raw material and oxygen or organic peroxide as the initiator.

High-density ethylene is an environmentally friendly material, heated to the melting point, and can be recycled. Must know that plastic materials can be divided into two categories: "thermoplastic plastic" (Thermoplastic) and "thermosetting plastic" (Thermosetting), "thermosetting plastic "is heated to a certain temperature into a solid state, even if the continued heating can not change its state, therefore, there are environmental problems with the product is "thermosetting plastic" products (such as tires), not "thermoplastic" products (such as plastic pallets) products (such as plastic pallets Note: pallets in Hong Kong and Macao is called "plywood"), so, not all "plastic" is not environmentally friendly [70].

2. Thermal performance

The performance of the material to conduct heat is called thermal conductivity. Generally speaking, good conductivity of materials, thermal conductivity is also good, for such as metal materials. In recent years, with the development of science and technology, we put forward new requirements for thermally conductive materials, thermal conductivity is not only an indicator of the metal but also an important physical indicator of plastic materials. But generally speaking, the thermal conductivity of plastic materials is far less than that of metal materials, but the phase change energy storage materials made of W plastic as the base material also have certain heat transfer performance, while also retaining the advantages of plastic performance, including uniform heat dissipation, lightweight, a variety of base resin options, easy molding, and processing, low coefficient of thermal expansion, low molding shrinkage, etc., widely used in various industries [71]. They are widely used in various industries. The working principle of phase change materials is that the material absorbs (or emits) a large amount of heat when the phase change occurs, and the material itself will use this property to bile heat, this material has the advantages of high thermal efficiency, high density, small equipment volume and the process of heat absorption and discharge is constant temperature, etc. Therefore, it has good prospects for application in the field of building insulation, solar energy storage, and industrial fields. It has good application prospects. In this chapter, paraffin waxes and blends of cacodylic acid and lauric acid are used as organic phase change media, which are widely used because they have the advantages of good molding effect in the solid state, less susceptible to subcooling or phase separation, and less toxic. However, the matrix of this type of phase change energy storage material is W plastic, and the thermal conductivity of the organic phase change medium itself is not high, so the heat transfer performance is poor and the utilization rate of heat storage is low in the application, which reduces the effectiveness of the system. To improve the efficiency of organic-type phase change media for heat storage and exergy, it is necessary to strengthen the phase change heat transfer process of organic phase change energy storage materials, i.e., to investigate the thermal conductivity. In this chapter, the analysis of the trend of thermal conductivity, i.e., thermal conductivity, is studied for different organic phase change material types by adding inorganic fillers to the woad density polygon cochineal-based phase change materials, and then the change law of thermal conductivity of organic phase change materials under the influence of inorganic fillers is derived. In recent years, domestic and foreign researchers have done a lot of work to improve the thermal conductivity of organic phase change energy storage materials and achieved certain results, and this research direction will be an important research goal to improve thermal conductivity in the future.

The results showed that the upgraded HDPE material has 2.94 times higher thermal conductivity than before, with an enthalpy of melting of 153.95 J/g and an enthalpy of crystallization of 152.82 J/g, which is valuable for electrical and thermal energy storage. The density of HDPE is 964 kg/m^3, the thermal conductivity is 0.36 W/m·K, and the specific thermal capacity is 2301 J/Kg·K, compared with bricks and other materials, its thermal conductivity is low, and it has high thermal storage performance [72].

4.6 Fundamentals of Heat Transfer and Thermal comfort evaluation

4.6.1 Fundamentals of Heat Transfer

1. Introduction to heat transfer

Various processes are occurring in the world, one of the physical processes most closely related to human survival is the transfer of heat energy: from the HVAC of modern buildings to the formation of natural wind, frost, rain, and snow, from the thermal protection of the shell of the space shuttle when re-entering the atmosphere to the effective cooling of electronic devices, from the change of people's clothing throughout the year to the frozen storage of human organs, all are closely related to the process of heat energy transfer [73]. The process of heat transfer is closely related. Heat transfer is the study of the law of heat transfer caused by temperature differences. The second law of thermodynamics points out that: where there is a temperature difference, there is a spontaneous transfer of heat energy from high-temperature objects to low-temperature objects (the heat energy in the transfer process is often called heat). There are temperature differences everywhere in nature and various fields of production technology, so the transfer of heat energy becomes an extremely common physical phenomenon in nature and production technology. The so-called heat transfer law here mainly refers to the relationship between the heat transferred per unit of time (the amount of heat energy) and the corresponding temperature difference in the object, and the first level of the relationship reflecting this law is called the rate equation of heat transfer (rate equation).

Both heat transfer and engineering thermodynamics are sciences related to thermal phenomena, and in China's engineering education sector, these two courses are jointly called thermal engineering courses. The difference between the research contents of these two scientific fields can be explained in the following aspects. First of all, the most fundamental difference is that engineering thermodynamics is the study of a system in equilibrium, in which there is no temperature or pressure difference, while heat transfer is the study of the law of heat energy transfer when there is a temperature difference [74]. Taking the process of cooling an ingot from 1000C to 100C in an oil bath as an example, thermodynamics can tell us the amount of heat lost per kilogram of ingot during this cooling process. Assuming that the specific heat capacity of the ingot is 450 J/(kg-K), the thermodynamic energy lost per kg of steel is 1 kg x 50 J/(kg-K) x (1 000-100)K = 405 kJ. But thermodynamics cannot tell us how long it takes to reach this temperature. This time depends on the temperature of the oil bath, the movement of the oil, the physical properties of the oil, etc., which is what heat transfer studies are all about. Secondly, for the fundamental reason above, the difference in the units of physical parameters widely used in thermodynamics and heat transfer is that the physical quantities of thermodynamics (e.g., thermodynamic energy, entropy, specific heat capacity, etc.) do not include time, while the main physical quantities of heat transfer are all based on time as the denominator, i.e., they are concerned with how much heat energy can be transferred per unit time.

On the other hand, heat transfer has a close relationship with engineering thermodynamics: the analysis of any heat transfer process involves the use of the first law of thermodynamics, i.e. the law of conservation of energy [75]. One knows from courses in engineering thermodynamics that the expression of the first law of thermodynamics can be written for a closed system (closed system) or an open system (open system). For each system, there are two cases: steady state and unsteady state. The so-called steady state process from the point of view of heat transfer is a process in which the temperature of each point in the system does not change with time, while the temperature of each point in the unsteady state process varies with time. After the analysis of heat conduction processes in solids, the expression of the first law of thermodynamics for closed systems is used, while the expression of open systems is used for convective heat transfer processes. In addition, in the study of heat transfer from one medium to another, the principle of conservation of energy is also used on the dividing surface of the two media. For example, in the case of heat transfer between a solid medium I and a fluid medium shown in Figure 1-1, the energy transferred from the solid interior to the left side of the interface shown in the figure should be equal to the energy transferred from the right side of the interface to the fluid, regardless of whether the process is steady or unsteady. In the heat transfer literature, the term "energy or heat balance" is often used, which is a simple term for the first law of thermodynamics.

The driving force of the heat transfer process is the temperature difference, and heat energy is always transferred from a high temperature to a low temperature. If there is no temperature difference between two media or two parts of the same object, there can be no heat transfer, and this is the basic content of the second law of thermodynamics. Therefore, the first and second laws of engineering thermodynamics are the basis for the study of heat transfer.

2 Applications of thermodynamics

Heat transfer has a wide range of applications in various fields of science and technology [76]. Although the heat transfer problems encountered in various fields of science and technology take various forms, they can be broadly categorized into three types of problems.

(1) Enhanced heat transfer. That is to increase the heat transferred under certain conditions (such as a certain temperature difference, volume, weight, or pump work).

(2) Weaken heat transfer or thermal insulation. That is under a certain temperature difference to minimize the transfer of heat.

(3) Temperature control. To enable some equipment to operate safely and economically, or to get quality products to control the temperature of the critical parts of the object in the heat transfer process.

Reinforcement of the type of heat transfer can be home air conditioners for example. With the improvement of people's living standards, air conditioners have been widely introduced into people's homes. In the last 20 years, the size of home air conditioners has been decreasing and the required energy consumption has also been reduced, mainly due to the results of research on enhanced heat transfer. As we know, a vapor compression type air conditioner consists of a compressor, an expansion valve, a condenser, and an evaporator (referred to as the two devices), of which the volume of the two devices accounts for most of the volume of the air conditioner. In the two devices, the refrigerant condenses or evaporates in the tube, and the air cools or heats the refrigerant outside the tube. In the last 20 years, there have been significant advances in research on both enhanced heat transfer on the air side and enhanced heat transfer on the refrigerant side, leading to a reduction in the size of air conditioners and a reduction in energy consumption.

For high-temperature equipment, the goal is to reduce heat loss. For low-temperature equipment, the goal is to reduce the loss of cold, or heat leaks. To save the liquid nitrogen liquid oxygen cryogenic container (called Duby bottle), for example, by taking a variety of measures to reduce heat transfer, can make the heat transfer in the direction perpendicular to the wall of the Dewar bottle reduced to one-thousandth of the measures taken before, or even less, from the surface to effectively prevent the evaporation of the cryogenic liquid located in the bottle, reducing the energy loss. These two types of problems are related to the issue of energy conservation. The energy problem is the first topic mentioned in China's medium and long-term science and technology development plan, and energy conservation is an important national policy to achieve sustainable energy development in China [77], this book will pay attention to the principle and technology of strengthening weaken able heat transfer.

The type of temperature control can be cited as an example of the cooling of electric devices and the thermal protection of spacecraft during re-entry into the atmosphere. With the rapid development of large-scale integrated circuit technology, the power per unit area of the electronic chip is increasing, and the heat generated by the power consumption of the device is discharged promptly to maintain a certain operating temperature of the device has become a key issue in the further development of current electronic technology [78]. According to statistics, the main cause of damage to the current electronic devices is thermal damage, that is, the operating temperature exceeds the allowable value. To further improve the performance of personal computers (PC) and notebook computers, the effective cooling of their chips has become a bottleneck problem. Currently, in general, the cooling of chips is undergoing a technological development from air cooling (air-cooling) to direct liquid cooling. When the space shuttle re-enters the Earth, it enters the atmosphere at a very high speed of 15-20 times the local speed of sound. The large amount of heat generated by the viscous blocking effect of the gas will cause the surface of the vehicle (especially the leading edge) to be subjected to intense heating [called aerodynamic heating (aero heating)]. For example, when flying at 20 times the local speed of sound, the temperature at the leading edge of the vehicle can reach 10 000 K. How to protect the vehicle from thermal protection under such harsh operating conditions is a key issue in space shuttle design. The crash of the U.S. space shuttle Columbia was caused by the detachment of a thermal protection tile.

3 Heat transfer method

1) Heat Transfer

When no relative displacement occurs between the parts of an object, the heat energy transfer generated by the thermal movement of molecules, atoms, free electrons, and other microscopic particles is called heat conduction. For example, the transfer of heat from a higher temperature part of a solid to a lower temperature part, and the transfer of heat from a higher temperature solid to another lower temperature solid in contact with it are both heat conduction phenomena.

Through the experience of a large number of practical thermal conductivity problems, the law of thermal conductivity has been summarized as Fourier's law, the thermal conductivity of a flat plate where both surfaces maintain a uniform temperature. This is a one-dimensional thermal conductivity problem, i.e., the temperature changes only in the x-direction. For any micro-element layer of thickness dx in the x-direction, the heat conduction through the layer per unit time is proportional to the local rate of temperature change and the area A of the flat plate according to Fourier's law, and the equation is shown below.

$$q=\frac{\Phi}{A}=-\lambda\frac{dt}{dx} \tag{1}$$

In the equation, q is the heat flow density in w/m^2. Φ is the heat flow rate in W. A is the area in m^2 and x is the axis perpendicular to the area A. λ is the proportionality coefficient, called the thermal conductivity, and "-" means that heat transfer is in the direction opposite to the temperature rising direction. dt/dx is the rate of change of the object's temperature along the x-direction.

Fourier's law is also known as the fundamental law of thermal conductivity. It is the mathematical expression of Fourier's law for a one-dimensional steady-state heat time. When the temperature t increases along the x direction, $dt/dx > 0$, and $q<0$, it means that the heat is transferred along the x decreasing direction; on the contrary, when $dt/dx < 0$, $q>0$, it means that the heat is transferred along the increasing direction. Thermal conductivity is a parameter that characterizes the thermal conductivity of a material, i.e., it is a thermo-physical property with the unit of W/(m·K). Different materials have different values of thermal conductivity even if they are the same - a material, the value of thermal conductivity is also related to temperature and other factors, which will be further discussed in Chapter 2. Here only point out: in general, the highest thermal conductivity of metallic materials, good conductors (such as silver and copper), is also good thermal conductors; liquids are the next; gas is the smallest.

2) Heat Convection

Heat convection is the process of heat transfer due to the relative displacement of fluid parts caused by the macroscopic motion of the fluid, and the mixing of cold and hot fluids. Heat convection can only occur in fluids, and because the molecules in the fluid are simultaneously carrying out irregular thermal motion, heat convection must be accompanied by heat conduction phenomena. The process of heat transfer between a fluid and the surface of an object when the fluid flows over the surface of the object is of particular interest to the engineering community and is referred to as convective heat transfer to distinguish it from thermal convection in the general sense.

In terms of the cause of flow, convective heat transfer can be distinguished into two categories of natural convection and forced convection natural convection (natural convection) is caused by the difference in density of the cold and hot parts of the fluid near the surface of the heater heated air upward flow is an example. If the flow of fluid is due to the pump fan or other differential pressure caused by the action, it is called forced convection (forced convection). The oil cooler condenser and other cooling water flow in the tube are driven by the pump, they are forced convection. In addition, engineering also often encounters the convective heat transfer problem of liquid boiling on the hot surface and vapor condensation on the cold surface, respectively, referred to as boiling heat transfer and condensation heat transfer, which are accompanied by a phase change of convective heat transfer. The basic formula for convective heat transfer is Newton's cooling equation.

$$q=h(t_w-t_f) \quad 2)$$

This equation is used when the fluid is heated. q is the heat flow density in w/m^2.t_w is the wall temperature, and t_f is the fluid temperature in °C. h is the surface heat transfer coefficient in $w/(m^2{\cdot}K)$.

The magnitude of the surface heat transfer coefficient is related to many factors in the convective heat transfer process. It depends not only on the physical properties of the fluid and the shape size, and arrangement of the heat transfer surface but also has a close relationship with the flow rate. Eq or Eq is not a specific relationship that reveals the complex factors affecting the surface heat transfer coefficient, but only defines the surface heat transfer coefficient. The basic task of the study of convective heat transfer is to give theoretical analysis or experimental methods to calculate the equation for h in various situations.

3) Thermal Radiation

The way an object transmits energy through electromagnetic waves is called radiation. Objects can emit radiant energy for various reasons, among which the phenomenon of emitting radiant energy due to heat is called thermal radiation. All radiation mentioned in this book refers to thermal radiation.

Each object in nature constantly emits thermal radiation into space, and at the same time constantly absorbs thermal radiation emitted by other objects. The combined result of the radiation and absorption process causes the heat transfer between objects in the form of radiation a radiation heat transfer (radiative heat transfer) is also often called radiation heat exchange. When the object and the surrounding environment are in thermal equilibrium, the radiative heat transfer is equal to zero, but this is a dynamic equilibrium, radiation, and absorption processes are still in continuous progress.

Conduction, convection, these two types of heat transfer only in the presence of material conditions can be achieved, and thermal radiation can be transferred in a vacuum, and in fact, the most effective transfer of radiation energy in a vacuum. There is the basic characteristics of heat radiation are different from heat conduction, and convection heat transfer. When two objects are separated by a vacuum, for example, between the earth and the sun, heat conduction and convection do not occur, only heat transfer by radiation. Radiation heat transfer is different from heat conduction, convection heat transfer is another characteristic that is that it not only produces energy transfer, but is also accompanied by the conversion of energy form that is emitted from heat to radiation energy, and absorbed from radiation energy to heat energy. Experiments have shown that the radiation capacity of an object is related to the temperature, and the radiation and absorption of different objects at the same temperature. Planck's law explains the distribution of blackbody radiant energy by wavelength. For a quantitative description, the concept of spectral radiant power needs to be introduced.

$$E_{b\lambda} = \frac{c_1\lambda^{-5}}{e^{c_2/(\lambda T)} - 1} \tag{3}$$

In the equation, $E_{b\lambda}$ is the blackbody spectral radiation intensity in W/m^3. λ is the wavelength in m. T is the blackbody thermodynamic temperature in K. e is the base of the natural logarithm.c_1 is the first radiative constant with a value of $3.7419*10^{-16}$ $W{\cdot}m^2$. c_2 is the second radiative constant with a value of $1.4388*10^{-2}$ m·K.

The spectral radiation force of a blackbody increases and then decreases as the wavelength increases. The wavelength of the maximum spectral radiation force ^ also varies with the temperature. From the spectral radiation force distribution, it can be found that, as the temperature increases, the peak of the curve shifts to the left, that is, to the shorter wavelength.

4.6.2 PMV-PPD

According to the Chinese building industry's energy conservation design standard, the indoor heat ambient design index for heating in winter is that the interior design temperature of the bedroom and living room should be taken as 18°C [51], so this study uses 18°C to evaluate the improvement effect of internal thermal comfort of the TSWHS as the threshold value of indoor thermal comfort temperature (Figure 4-9). Also, the PMV-PPD thermal comfort evaluation indices were used to assess the residents' perception of indoor thermal comfort. The principle was proposed by the Danish scholar Fanger in the 1970s. The indices are based on his famous thermal comfort balance equation, which considers six parameters: two human factors, namely activity level, and clothing, and four thermal environmental factors [52].

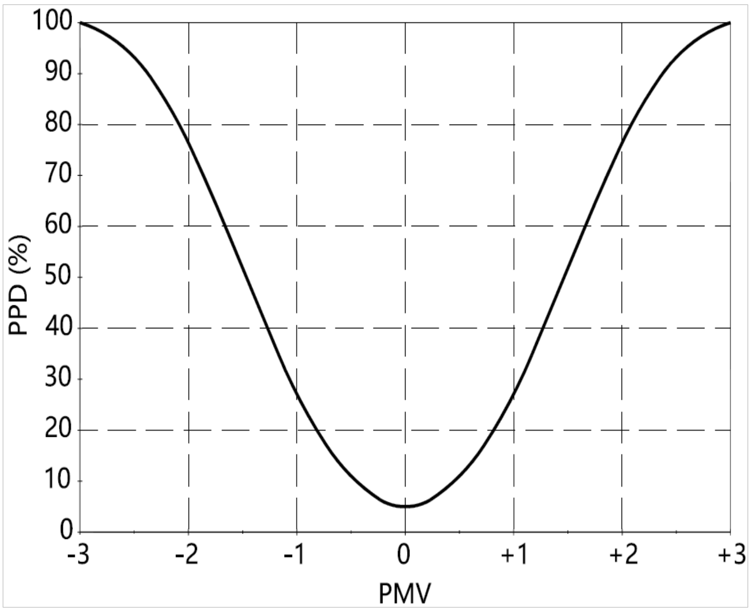

Figure 4-9. PMV-PPD function relationship

By thermal comfort equilibrium equation is meant that in the basic thermal equilibrium equation, Qe is replaced by the body regulation function in the peaceful state, Qe* in the comfortable state, according to the skin surface temperature Ts in the peaceful state. Calculating Qr and Qe in the basic heat balance equation, the radiation heat transfer and convection heat transfer obtained are denoted as Qr* and Qe*, respectively:

$$Q_m - Qe^{*} \pm Qr^{*} \pm Qc^{*} = \Delta Q^{*} \quad (1)$$

If $\Delta Q^*=0$, the thermal environment is considered to be comfortable.

If $\Delta Q^*=L\neq0$, that is, the thermal comfort balance is destroyed. To maintain normal body temperature, the working intensity of regulating function is bound to change. The higher the value of L in absolute terms, the larger the degree of discomfort. According to the experiment, Fanger obtained the functional relationship between the PMV index representing thermal sensation and thermal load L and other factors. PMV is the thermal sensation value of a combination of environmental factors during the experiment.

4.7 Chapter Summary

This chapter discusses several aspects of Chinese building climate zoning, solar energy design principles and methods, envelope insulation technology and insulation materials, heat transfer principles, etc. The utilization technology of solar energy, insulation practices of interior and exterior walls, thermal storage properties of PCMs materials, and thermal properties of HDPE materials, as well as thermal engineering principles and three heat transfer methods, are studied in detail to propose energy-saving and thermal insulation strategies for buildings.

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Chapter 5. Research on Roof Solar Heating Storage System of Traditional Houses

5.1 Research and Development of Rooftop Solar Thermal Storage Heating System

Regarding the research on building energy saving, Krarti et al. proposed the use of new energy to optimize the indoor temperature to save energy [10], including solar energy [11] and geothermal energy [12]. Applying passive solar energy technology to buildings is of great significance for energy saving [13]. Chi et al. developed many energy-saving technologies in combination with solar energy, and the working principle is mainly to improve indoor temperature by using solar energy [14]. The main research content includes three aspects. The first is the use of PCMs [15,16], the second is the partial renovation of buildings [17,18], and the third is architectural design strategies [19,20].

The first aspect of research is the use of PCMs, such as translucent photovoltaic roofs [21], Tromba walls [22], and thermal storage materials [23,24]. Cossu et al. [25] proposed combining silicon micro-cells with photovoltaic modules and setting them between glass plates and then using them on sloping roofs. The results show that the design will not completely block the sun, and the shading rate is 9.7%. Spherical micro-batteries have been proven to be beneficial to improve the greenhouse system. Martins et al. [26] studied the improvement of a building's energy-saving performance by integrating a Trombe wall system, which is another passive solar device. The ventilation system in a large volume is directly proportional to the thickness of the Trombe wall, and the Trombe wall is added to the building envelope. The addition of Trombe walls to the building envelope can reduce heating energy consumption by 16.36%. The device has a simple structure and zero working energy consumption and has been widely used in buildings. To decrease cooling energy consumption and carbon dioxide emissions, Irshad et al. [27] used double glazing and argon space on the Trombe wall, which proved to be feasible under the Malaysian climate. Shen et al. [28] studied the thermal performance of the traditional Trombe wall and the composite wall, established a mathematical model using the finite difference method, and verified it through experiments. Through the simulation of the software TRNSYS and FDM, the results showed that in cold and cloudy weather, the composite wall has better winter insulation performance than the traditional wall. Duan et al. [29] proposed that the thermal efficiency of the Trombe wall is related to the orientation of the building. Rabani et al. [30] analyzed a new Trombe wall that can absorb solar radiation in three directions and conducted research and analysis on its heating performance. Experiments showed that the model has good stability; the new Trombe wall can cause the indoor temperature to reach 10 °C. Al et al. [31] designed four types of vents for the glass roof through fluid mechanics and used Fluent to analyze the surrounding airflow field. The results showed that, in terms of wind speed and quality, vents perpendicular to the roof tilt angle provide the best performance. Wi et al. [32] objectively estimated the thermal performance of 21 commonly used insulating materials. The thermal conductivity was measured by the calorimeter method, and the water absorption was evaluated by a standard method, taking into account the drying conditions to ensure the sustainability of the material and long-term thermal conductivity. So, to solve the environmental pollution and environmental problems caused by plastics, Chavan et al. [33] added heat storage materials (TSM), such as functionalized graphene to recycled plastics, evaluated the thermal characteristics, and found that the optimal concentration of reinforcing materials was added, meaning that the thermal storage capacity of the plastic increased by 54%. Mohammed et al. [34] studied a variety of PCMs and concluded that HDPE has a high latent heat of PCMs, high phase change temperature, and is easy to use. Through experiments on the characteristics of various TSM, Song Jing et al. [35] analyzed and concluded that polyethylene has a long service life, stable performance, basically, no supercooling and delamination, good mechanical properties, is easy to process and form, and has good practical application value. Xian et al. [36] studied composite PCMs such as ultra-high-molecular-weight polyethylene and paraffin. Through microwave sintering, they had high energy storage efficiency in photothermal conversion. Kun [37] synthesized polyethylene glycol and rice husk ash into a new environmental protection material, which raised the heat storage potential by 20.9%. Piyachai et al. [38] studied polymer PCMs, designed the copolymerization of polyethylene glycol and ester polymers, developed the transition polymer PCD, and greatly increased the heat storage potential.

The second aspect of research is the partial renovation of buildings, such as solar chimneys, which are indoor heating devices used in buildings in winter [39]. Through the renovation of the roof, the glass chimney extends out of the roof at a certain inclination angle to receive more solar radiation [40]. The working principle of this equipment is to use passive air circulation to increase the heating effect. The heating principle is the same as the Trombe wall [41]. The research results show that solar chimneys in buildings can decrease the mean daily power requirement of air conditioning in winter by 10–20% [42,43]. Jing et al. [44] set the height ratio of different distances between the solar chimney and the roof, and the selected value range was 0.2–0.6. It was calculated by the model that when the height ratio of the optimal spacing is 0.5, the airflow velocity in the solar chimney is the largest. Miyazaki et al. [45] studied the performance of solar chimneys and programmed software to calculate the cooling and heating loads by CFD. As calculated by this program and compared with basic ventilation, the energy demand of the fan shaft was reduced by 50% throughout the year. In addition, the solar chimney reduced the heat load by about 20%, and the annual heat load was reduced by about 12%.

The third aspect of research is the architectural design strategy, which mainly includes research on the building orientation [46,47] and the window-to-ground ratio [48], and the most suitable combination of orientation and the window-to-ground ratio is obtained, so that the building can receive the maximum solar energy. The amount of radiation effectively increases the indoor temperature in winter to achieve the purpose of energy saving and emissions reduction. Attia [49], Marino [50], and others have studied the window-to-wall ratio (WWR) of buildings. So, to control and adjust the effect of solar radiation and airflow entering the room, a comprehensive analysis of airflow density, temperature, and wind speed was carried out, and the impact of building energy costs was considered. The research results show that WWR is less affected by the external environment and more affected by thermal properties [51]. Obrecht et al. [52] used quadratic equations to calculate the optimal WWR under different European climates, and they showed that the optimal WWR range is 38–42%. Ashrafian et al. [53] studied multiple groups of WWRs in a school building in Turkey and showed that, when the daylighting rate of glass is 50%, it can reduce the demand for artificial lighting and meet the indoor daylighting rate of 15%. Goia et al. [54] studied office buildings located in Italy based on energy demand standards. When the WWR is within the range of 35–45%, the energy demand is the smallest. Goia [55] used Energy Plus software to study office buildings in different climate zones in Europe, mainly analyzing indoor lighting and thermal performance to explore the best WWR. Although the optimal WWR differs due to the environment, orientation, and climate, when the WWR is between 30% and 45%, the energy requirement of the building is reduced by 5–25%. Wen et al. [56] used local climate and window orientation as the main indicator parameters to study the facades of office buildings in 10 different regions in Japan to evaluate the best WWR, and they also studied WWR and building carbon dioxide emissions.

The above research mainly analyzes the materials, local transformation, and design strategy and has made good progress and produced promising results. However, the effect of increasing indoor temperature is limited. In the research of PCMs, in addition to a large number of experiments, we also need to consider production efficiency and economy. In terms of local reconstruction research, taking the research on glass roofs and solar chimneys as an example, scholars only consider changing the roof into glass to raise the range of solar radiation received in the building. However, with the gradual reduction in solar altitude angle, the indoor temperature also decreases, and the practice of absorbing and storing solar energy is not considered. Although the Trombe wall can reduce energy consumption, it only transforms the enclosed structure to decrease the heat transfer rate, to achieve the effect of thermal insulation. However, there is no research on the heat source. On this basis, this study proposes a new passive heating design—that is, the traditional residential roof solar heat storage heating system—which combines the building roof with renewable energy. Firstly, the glass skylight is installed on a traditional residential roof to increase the indoor solar radiation range, and the HDPE thermal insulation and heat storage material are added to the attic floorboards. By absorbing and storing solar thermal radiation, it can not only delay the reduction in indoor temperature and increase indoor heating time, but it can also reduce energy consumption, improve energy utilization, and reduce carbon emissions.

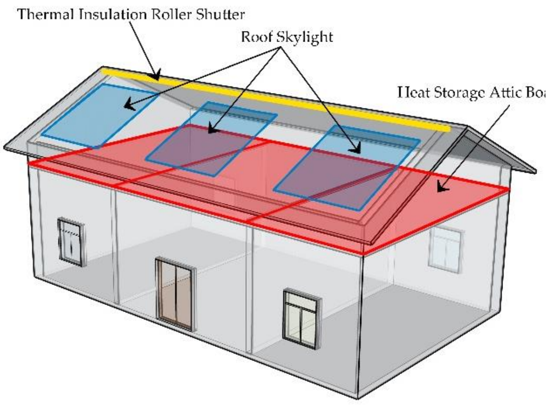
5.2 Research Overview

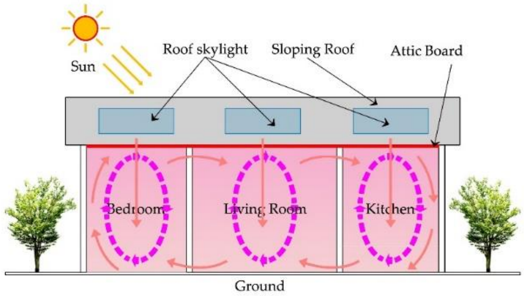
5.2.1 Model Introduction

Most of the Traditional Houses in southern Shaanxi have sloping roofs, one or two floors of a civil or brick concrete structure, and the second floor is low in height. It is mainly used as a storage room. Due to the cold winter in southern Shaanxi, the indoor temperature is low. However, due to the high and uneconomical energy consumption of air conditioning and other power equipment, it is not popularized locally, so passive heating is a good choice. Combined with the characteristics of

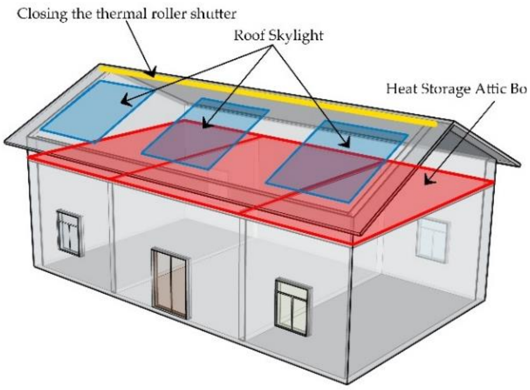
Traditional Houses in southern Shaanxi, local transformation is carried out. A glass skylight is set on the roof, a push-pull thermal insulation roller shutter is added above the skylight, and thermal insulation and heat storage materials are added on the attic floor. In winter, the glass skylight is opened to allow the heat storage materials to fully absorb the solar radiation. The thermal insulation and heat storage performance of TSM was used to improve the indoor temperature. A local traditional residence was selected as the research object. The studied building is one floor as a whole and two floors locally. The sloped roof form is adopted. The story height of the first floor is 3 m and the second is 2.8 m. The wall of the residence is made of red bricks, and the sloped roof is made of green slate or tiles. The model is established in this form (Figure 5-1a). Southern Shaanxi is wet and cold in winter. In addition, the Traditional houses are closely arranged and have long cornices, which reduces the solar radiation obtained by the Traditional houses in winter. Therefore, it is very wet and cold indoors. To solve this problem, residents adopt active and passive heating methods. Active heating includes small suns, electric stoves, and electric blankets. Passive heating includes fire pots, charcoal fire basins, etc. The above two heating methods aim to improve the temperature of a certain part of the room, rather than the overall indoor temperature. Through the research on the roof solar heating storage system, it is concluded that the key to system design lies in the size selection and practice of installing roof transparent glass and the selection of heat storage materials as the attic floor. By comparing the physical properties of HDPE with other thermal insulation and heat storage materials, it is concluded that HDPE has a higher phase transition temperature and latent heat [34]. Therefore, HDPE was selected as heat storage material in this study. The core components of the solar heating system on the roof include heat storage attic floorboards and a roof skylight. The design method of the heat storage attic floorboards was placing a 5 cm-thick HDPE board on the attic floor, to change the ordinary attic floor into a heat storage attic floor and improve the thermal insulation and heat storage performance (the red area in Figure 5-1b). The design method of the roof skylight was to design three groups of 3 m × 3 m ordinary roof opening fans and glass skylights on the south-facing sloped roof, using 6 mm-thick single-layer glass with a shading coefficient of 0.92 and a heat transfer coefficient of 5.818 W/m^{2}k (the blue area in Figure 5-1b). In addition, considering the influence of thermal insulation and heat storage materials on the indoor environment in summer, a thermal insulation roller shutter was set on the roof ridge (the yellow area in Figure 5-1b). In winter, the solar energy heating system is started, the thermal insulation roller shutter on the glass is closed, and the heating system starts to work to make the heat storage attic floor absorb solar radiation (Figure 5-1d). In summer, the thermal insulation roller shutter on the glass (Figure 5-1e) can be opened to effectively reduce the impact of solar radiation on the room. Therefore, the opening and closing of the thermal insulation framework can effectively improve the indoor temperature in different seasons. The working principle is that the roof solar heating storage system uses solar heat radiation to heat the thermal storage attic plate through the roof glass skylight, and it uses thermal convection and radiation to affect the temperature between the walls, to improve the temperature of the whole room (Figure 5-1c).

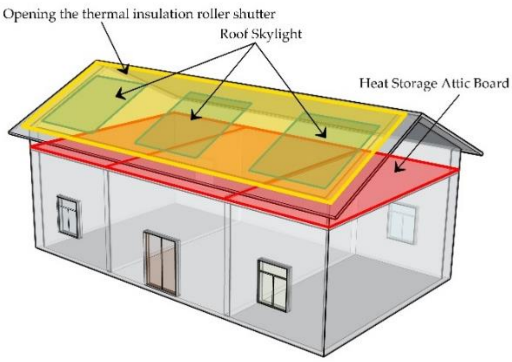
(a) Residential photos





(b) Roof solar heating system **(c) Working principle**



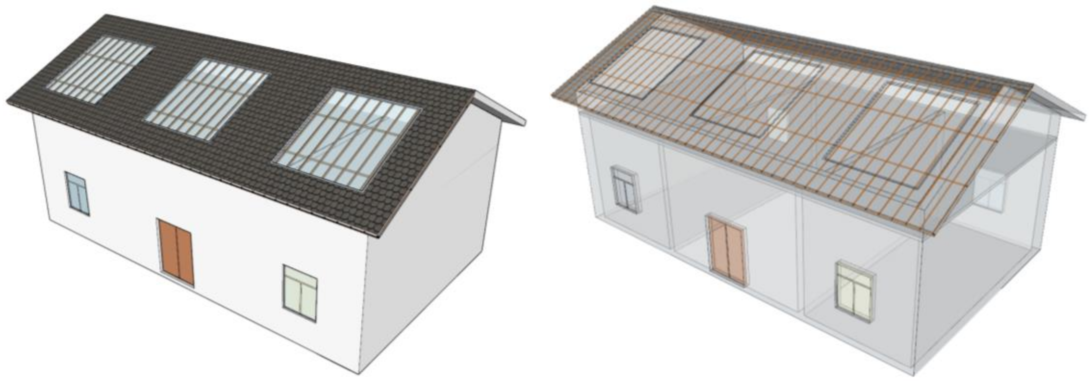


(d) Closing the thermal insulation roller shutter in winter **(e) Opening the thermal insulation roller shutter in summer**

Figure 5-1. (a) Residential photos; (b) roof solar heating system; (c) working principle; (d) closing the thermal insulation roller shutter in winter; (e) opening the thermal insulation roller shutter in winter.

(4) Roof structure study

The roof skylight of this system is added without changing the roof structure by removing part of the original tiles, keeping the horizontal and vertical purlins structure, and installing the skylight on top of the purlins to increase the light area, while replacing the tiles with light quality glass windows, which also reduces the load-bearing burden of the roof. Therefore, this method is beneficial to the lasting protection of the building, as well as to save energy and improve the indoor thermal environment (Figure 5-2).



(a) Roof skylight structure diagram I **(b) Roof skylight structure diagram II**

Figure 5-2. Roof skylight structure schematic

(5) Comparative Analysis of Current Heating Methods

Through the field investigation of heating methods, it can be seen that there are mainly two existing heating methods, namely active heating, and passive heating. In southern Shaanxi, active heating methods mainly include small suns, electric stoves, and electric blankets. These methods' disadvantages include high energy consumption and is uneconomical. According to the investigation, the main parameters and applications of these methods are as follows: when a small sun is used, the power is either between 300 and 500 W, accounting for 36.94% of instances; between 500 and 800 W, accounting for 53.68% of instances; between 800 and 1200 W, accounting for 9.38% of instances. In addition to the power required in use, the time in use should also be considered. In a day, the use of a small sun for 0–3 h accounts for 32.65% of instances; the proportion of using a small sun for 3–6 h is 42.66% of instances; the proportion of using a small sun for 6–9 h is 24.69% of instances. It can be seen that the use frequency of small suns is high, and the time spent using small suns is long.

The frequency of electric furnace use is low because of their high power and large power consumption. Through field measurement, it is found that the power of the electric furnace is generally 2400 W, and it is operated for 5 min, which is equivalent to the consumption of 0.2 kWh. The use frequency of electric blankets is the highest, because the use time of an electric blanket is generally at night, which mainly improves the local indoor temperature. Through the investigation of the power and service time of the electric blanket, it can be concluded that when the electric blanket is used, the power is either between 60 and 80 W, accounting for 31.82% of instances; the power is between 80 and 100 W, accounting for 39.39% of instances; or the power is between 100 and 120 W, accounting for 28.79% of instances. In a day, the proportion of using an electric blanket for 0–1 h is 45.65%; the proportion of using an electric blanket for 2–3 h is 32.36%; the proportion of using an electric blanket for 3–4 h is 21.99% of instances. It can be seen that the three active heating methods mainly rely on electric energy, and the heating effect is poor, as these methods can only heat parts of the indoor space (Figure 5-3).

Passive heating mainly includes charcoal pots and stoves, and burning firewood. The proportion of households using charcoal fire pots was 45.68%, and the proportion of households using stoves was 54.32%. Because passive heating methods have an open heat source, they will emit more carbon dioxide during heating, which is not conducive to environmental protection. Whether it is the small sun, electric stove, and electric blanket for active heating or the carbon fire basin and stove for passive heating, the thermal efficiency is poor, and only part of the indoor space is heated.

5.2.2 Comparison of Simulation Analysis Results and Measured Temperature Results

To verify the accuracy of the software simulation and to derive the indoor temperature improvement of the new system, a three-day hour-by-hour indoor temperature test was conducted on the existing house in sunny weather from December 20 to December 22. The test results were then compared with the simulated results of the basic heating system and the roof storage wall heating system to obtain figure 5-3. The analysis shows that the measured temperature of the current house is almost the same as the simulated temperature of the basic heating system with solar radiation. Therefore, it can be concluded that the results of the software simulation are close to the real values.

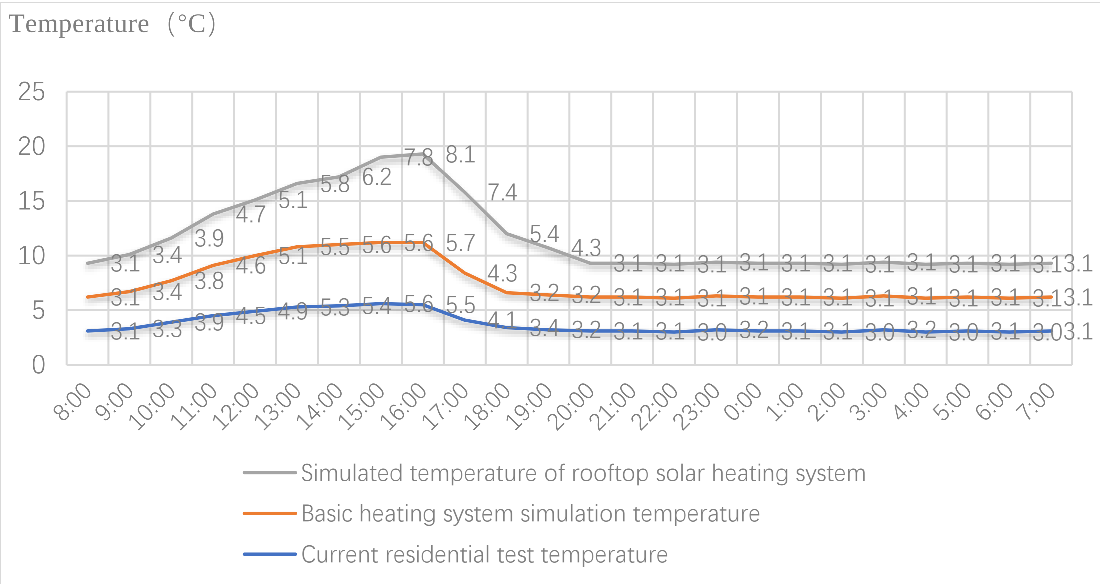


Figure 5-3. Comparison of simulation analysis results and measured temperature results

5.2.3 Roof Solar Heating Storage System

(1) Design of the Roof Solar Heating Storage System

According to the survey, most of the Traditional Houses in southern Shaanxi have one story and are L-shaped, and the space generally has three bays. The roof is mostly made of tiles and slate, and it is a sloped roof; the wall is an adobe wall plus lime paint. Due to the use of sloping roofs, residences have good daylighting performance. In addition, the attic is usually set on top, which provides an important basis for the design of the roof solar heating storage system. To make the simulation true and reliable, a dwelling with three bays and one deep-sloping roof was selected as the model. The design of the roof solar energy storage heating system includes two parts. The first part is the roof daylighting area. A glass skylight is designed on the south side of the sloping roof, which is made of silica—the transmittance is 0.87, the thickness is 6 mm, and the size is 3 m × 3 m. As the residence is divided into three bays, a glass skylight is set in each bay. The second part is the setting of the attic floor. HDPE heat storage material with a thickness of 5 cm is installed in the attic floor, which is also the core of the system. The working principle of this system is that the heat storage material absorbs and stores the heat radiation of the sun during the day, and the exothermic performance of TSM is used to improve the indoor temperature through the heat transfer form of heat radiation and heat convection at night.

(2) Working Principle of the Roof Solar Heating Storage System

The working principle of the solar heat storage system is to heat the attic floor panel through the roof skylight by solar radiation and use the thermal insulation and heat storage performance of HDPE to improve the indoor temperature in the form of thermal radiation and convection. The roof solar heating storage system can be regarded as a solar energy recycling device. The working process of the system is affected by many factors, including the thermal properties of heat storage materials, glass thickness, room size, and indoor and outdoor temperature. The thermal transfer process has three parts: the first part is the heating of HDPE through glass using solar thermal radiation. This heat transfer process is a form of thermal transfer dominated by thermal convection and thermal radiation. The thermal transfer time is mainly based on transient–steady–transient heat transfer, which belongs to the coupled heat transfer of solids and fluids.

The second part is the heat storage of the HDPE material itself. This heat transfer process is a form of heat transfer dominated by heat conduction. The heat transfer time is mainly transient–steady–transient heat transfer. It belongs to the solid-solid coupling heat transfer. According to Borlier’s law.

The third part is when the HDPE material reaches a constant temperature—the temperature between the walls is heated to raise the temperature of the entire room through heat transfer, mainly in the form of heat convection and heat radiation. This process belongs to the coupled heat transfer of solids and fluids, and the heat transfer time is mainly based on transient–steady–transient heat transfer.

(3) Analysis of Basic Heating

1) With solar radiation

The winter in southern Shaanxi is relatively cold, and the commonly used heating methods include active and passive heating methods. Among them, passive heating is mainly basic heating, which mainly includes two aspects: on the one hand, it relies on solar heat radiation, and on the other hand, it relies on indoor heat distribution sources. Basic heating is the combined effect of solar thermal radiation and indoor thermal distribution sources with solar radiation. Solar thermal radiation mainly means that the outer wall of the wall relies on solar thermal radiation to heat the room to raise the temperature of the room. The heat transfer process is as follows: the first step is the absorption of heat by the outer surface of the wall, which mainly absorbs solar energy through a convective heat transfer and radiation. The second step is the heat transfer of the wall itself, and the heat is transferred from the outer wall to the interior wall. The third step is the internal wall radiating heat. After the temperature of the inner wall rises, the indoor temperature rises through the combined effect of heat conduction, convection, and radiation. The heating efficiency of basic heating is low, and the increase in indoor temperature is small. Once the indoor temperature is constant, it is only 2.5 °C higher than the outdoor temperature.

2) Without solar radiation

Basic heating mainly relies on indoor heat sources, mainly including heat generated by electrical appliances, cooking, and the human body. The change in interior temperature will also be affected by building size, material, and structure. In the previous heating research, the two factors of solar thermal radiation and indoor heat distribution sources were considered less often, which made the simulation results poor. In this study, the comparison between the new system and basic heating can fully illustrate the practicability and authenticity of the new system. The interior temperature is only affected by the heat source without solar radiation, and the range of interior temperatures changes to a lesser degree, only rising by 0.1 °C compared with the outdoor temperature.

(4) Analysis of the Situation of the Roof Solar Heating Storage System

1) With solar radiation

The roof solar energy storage system is used to absorb solar energy to improve the indoor temperature of the residences, and the heat absorption and storage capacity of the heat storage plate is used to raise the indoor temperature to achieve the effect of indoor heating in the winter. The heat storage plate adopts HDPE material with good heat absorption and heat storage effects, which can store and release heat while absorbing heat. The working principle of the process of the pool solar heating system absorbing, storing, and releasing heat is shown in Figure 2c. When the heat storage plate absorbs heat, the temperature of the heat storage plate increases significantly. After the temperature of the heat storage plate increased for 1 h, the indoor temperature gradually increased, rising by 0.7 °C. The bedroom temperature reached the highest value of 8.9 °C at 16:00. Compared with basic heating, the bedroom temperature increased more. The heating effect of residential buildings under the new system is better, and the temperature and time spent after heating improved.

2) Without solar radiation

Considering that without solar heat radiation, only the effects of indoor heat distribution sources and electrical appliances are considered, the temperature of the heat storage plate rises slowly and is not much different from the indoor and outdoor temperatures. It can be seen through the simulation of software (American ANSYS Company, Pittsburgh, PA, USA) that the indoor temperature increased by 0.3 °C. In previous studies, less consideration was given to the effects of indoor heat distribution sources and electrical appliances. The addition of these two factors this time can more fully illustrate the effectiveness of the new system.

5.2.4 Simulation Analysis

The simulation software includes ANSYS, Rhino (Robert McNeel & Assoc, Seattle, WA, USA), EnergyPlus (National renewable energy laboratory, Golden, CO, USA), and Matlab (MathWorks, Natick, MA, USA), and the boundary conditions are the presence and absence of solar heat radiation on the wall. ANSYS mainly computes the time required for room heating under basic heating, the new system, and the final temperature. Rhino software is mainly used to build models, and the reduction in heat load is calculated by Ladybug and EnergyPlus. Matlab is used to program the analysis results to output the calculation results. The software ANSYS is mainly used to simulate and calculate steady-state, transient thermal power, and thermal radiation. The steady-state and the transient thermal power are used to compute the heat transfer between the heat storage plates. Thermal radiation simulation mainly computes solar thermal radiation and the change in interior temperature after the heat storage plate released heat. EnergyPlus computes the heat load after adopting the new system. This process includes four steps: building a model in the rhino, importing the model into the ladybug to set relevant parameters, using Energyplus to calculate the heat load circumstances, and finally, using Matlab software to program and output the calculation results.

The simulation in this study included three steps. The first step was to simulate basic heating by building a model based on the measured data and using local winter weather conditions data. The main content was the temperature change after heating. The second step was to simulate the absorption and heat release of the heat storage board after establishing the roof solar heating system, which mainly included a sloping roof skylight and a heat storage board. The content of this simulation was the temperature change of the heat storage plate, the heating time of the outer wall of the heat storage plate, the heating time of the inner wall of the heat storage plate, and the time required for the indoor temperature after equilibrium. The third step was to simulate the suitable time and the reduction in heat load.

5.3 Comparison of Indoor Temperature Simulation of Four Types of Residential Houses

There are four types of traditional dwellings in southern Shaanxi, namely, linear, L-shaped, U-shaped, and patio-shaped. To simulate and analyze the indoor thermal environment of residential houses in winter more comprehensively and accurately, to get accurate results, these four types of residential houses are modeled and simulated separately with the boundary conditions of solar radiation. The simulation results of the indoor temperature of one of the bedrooms were selected for comparison, and the results are shown in figure 5-4. The results show that the changes in the bedroom temperature of the four types of residential houses are the same, and they all have a certain enhancement for the indoor temperature. Therefore, the system is suitable for these types of traditional dwellings, because the building materials and structures of these types of dwellings are similar, and the heating design method is also effective. Therefore, it can be seen that the system can be applied to dwellings in hot summer and cold winter areas.

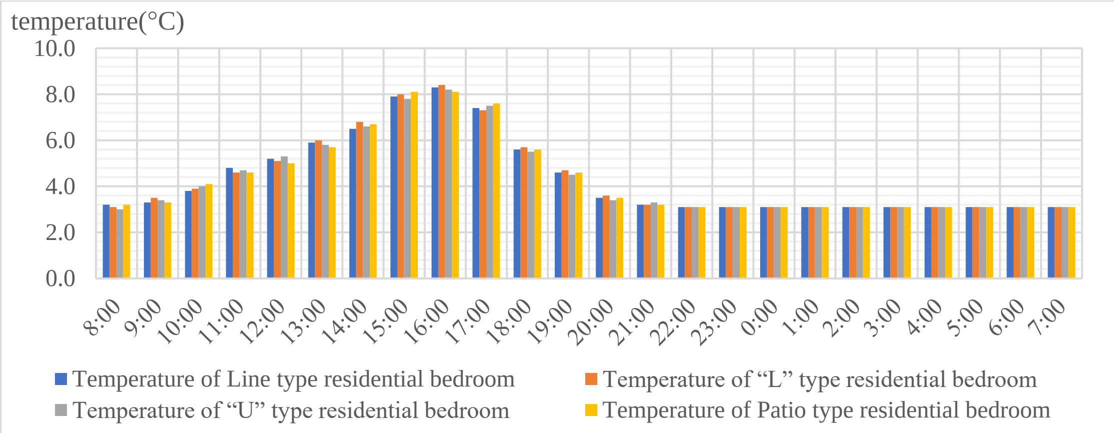


Figure 5-4. Comparison of bedroom temperatures in four types of residential houses with rooftop thermal storage wall heating systems

5.4 Results and Discussion

5.4.1 Comparison between the Two Systems without Solar Heat Radiation

(1) Basic Heating without Solar Heat Radiation

To verify that the new system is still effective without solar heat radiation, the comparative analysis was based on basic heating without solar heat radiation. Basic heating without solar radiation mainly relies on interior thermal distribution to change the indoor temperature. Using software simulations, indoor temperatures under basic heating are similar to outdoor temperatures without solar radiation (Figure 5-5).

The building materials of traditional houses in southern Shaanxi include red brick, gravel, concrete, and wood. The simulation steps are as follows: first, using Rhino software to build a residential model, then importing the model into software, setting the grid, activating the energy equation, selecting the turbulence model, setting the radiation model, adding the thermal properties of the above materials, and assigning materials to the model properties. Then, the boundary conditions and solution method are set. Finally, the flow field to initialize the solution simulation process and perform simulation calculations is set. So, to compare the temperature change with solar thermal radiation, the simulation calculation time was 24 h, divided into day and night. The indoor temperature during the day was greatly affected by solar radiation, and the time was from 8:00 to 18:00. The indoor temperature at night was not affected by solar radiation, and the time was from 18:00 to 8:00. The following three heating conditions used this calculation time. The indoor temperature changed as follows: 18:00 to 8:00 was the night, and the indoor temperature was 2.6–3.8 °C. From 8:00 to 12:00 (Figure 5-6 a, b), the mean temperature of the indoor room was 3.2 °C. The outdoor temperature was low at this time, which had little effect on the indoor temperature. From 12:00 to 14:00 (Figure 5-6 c, d), the indoor temperature remained unchanged, and the mean temperature was also 3.3 °C. From 14:00 to 17:00 (Figure 5-6 e), the outdoor and indoor temperatures also began to rise slowly. After equilibrium, the temperature was 4.2 °C. From 17:00 to 18:00 (Figure 5-6 f), the outdoor temperature dropped, and the indoor temperature was 3.6 °C. The mean indoor temperature was 3.7 °C without solar radiation, which was 0.5 °C higher than the mean temperature outdoors.

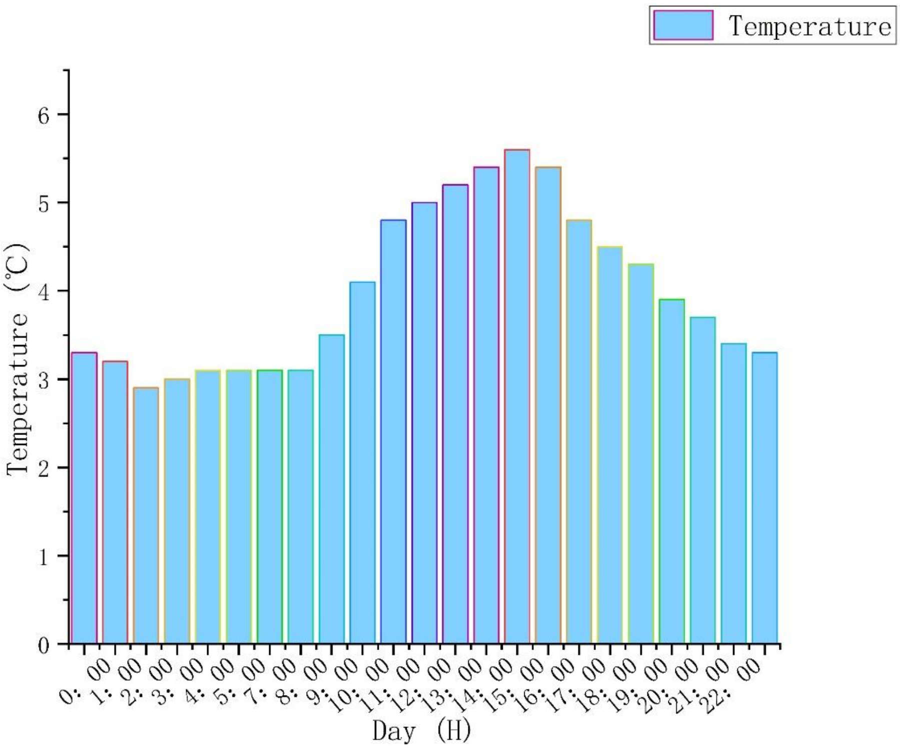
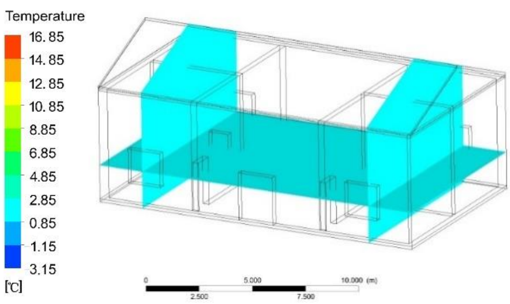
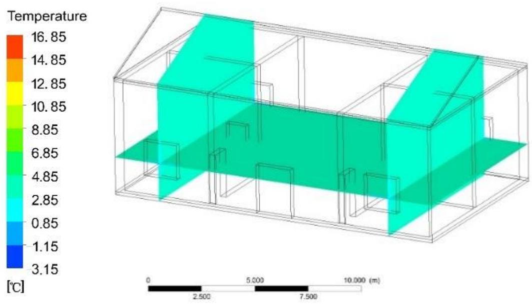


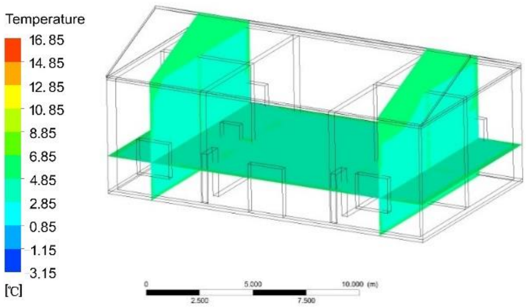
Figure 5-5. Change in outdoor temperature.



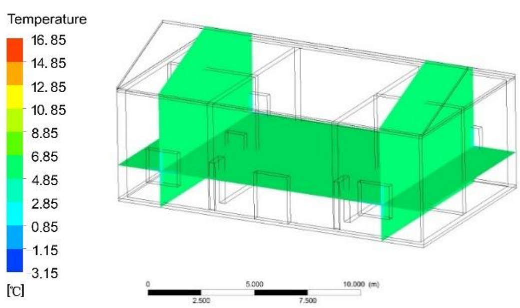
(a) 8:00



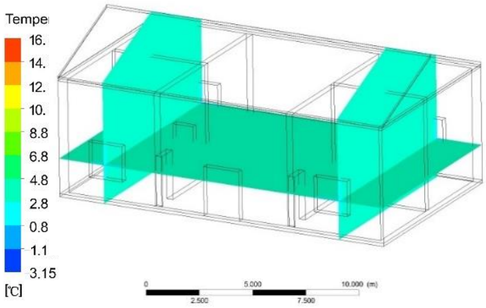
(b) 11:00



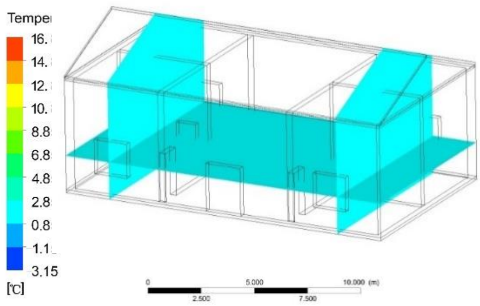
(c) 12:00



(d) 15:00



(e) 17:00



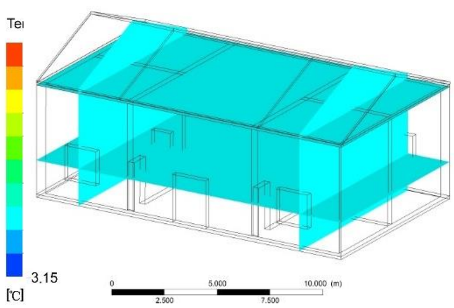
(f) 18:00

Figure 5-6. (a, b) Change in indoor temperature from 8:00 to 12:00; (c, d) change in indoor temperature from 12:00 to 14:00; (e) change in indoor temperature from 14:00 to 17:00; (f) change in indoor temperature from 17:00 to 18:00.

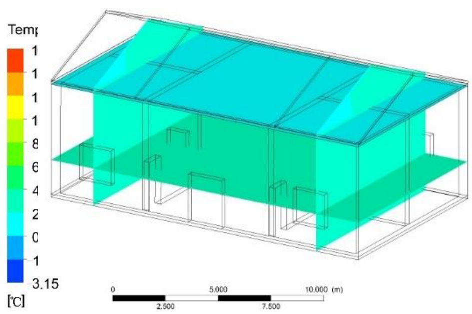
(2) The Roof Solar Heating Storage System without Solar Thermal Radiation

The new system without solar thermal radiation also depends on indoor thermal distribution to change indoor temperature. The indoor and outdoor temperature is balanced, which is the same as basic heating without solar radiation.

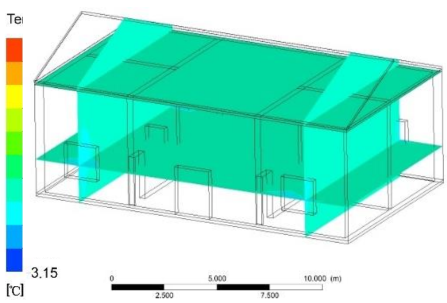
The new system is improved based on the basic heating system, adding roof glass skylights and heat storage material attic slabs. The other building materials are the same as those used in the building with a basic heating system. The same method as in the basic heating experiment was used to build models, set material parameters, and simulate conditions. The indoor temperature changed as follows: from 18:00 to 8:00, the mean temperature of the attic floor was 2.7–3.9 °C. The indoor and outdoor temperatures were the same, at 2.7–4.0 °C. From 8:00 to 12:00, the mean temperature of the attic floor was 3.7 °C, and the mean temperature of the indoor room was 3.6 °C (Figure 5-7 a, b). This had little effect on the indoor temperature. From 12:00 to 14:00, the mean temperature of the attic floor was 3.7 °C, and the indoor temperature remained unchanged, with a mean temperature of 3.6 °C (Figure 5-7 c, d). From 14:00 to 17:00, the outdoor temperature rose slowly. Due to the use of electrical appliances and heating equipment during this period, the indoor temperature began to rise slowly. After equilibrium, the mean temperature of the attic slab was 4.4 °C, and the mean indoor temperature was 4.5 °C (Figure 5-7 e). From 17:00 to 18:00, the outdoor and indoor temperatures decreased. The mean temperature of the attic slab was 3.5 °C, and the mean indoor temperature was 3.6 °C (Figure 5-7 f). The mean indoor temperature did not change much, and it was greatly influenced by the outdoor temperature without solar radiation. The mean temperature of the attic floor was 3.9 °C, and the mean indoor temperature was 3.8 °C. The temperature variation range was small, and the difference in the average temperature between the indoors and outdoors was 0.6 °C.



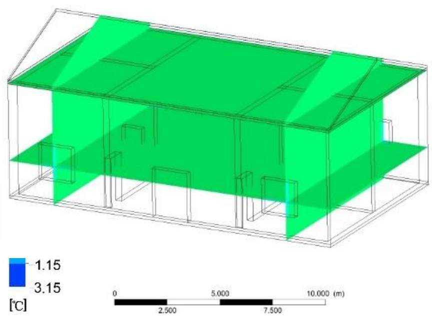
(a) 8:00



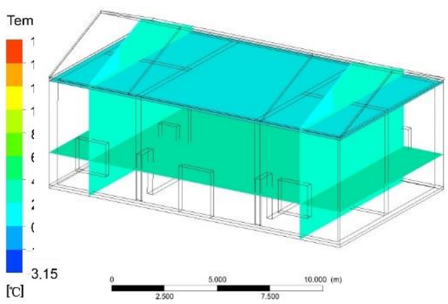
(b) 11:00



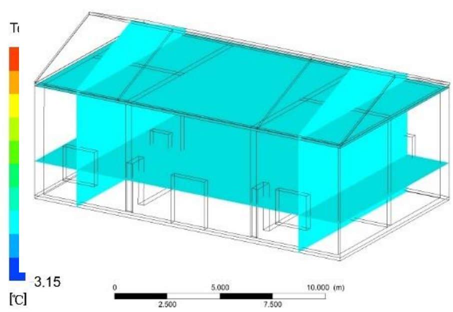
(c) 12:00



(d) 14:00



(e) 17:00



(f) 18:00

Figure 5-7. (a, b) Change in indoor temperature from 8:00 to 12:00; (c, d) change in indoor temperature from 12:00 to 14:00; (e) change in indoor temperature from 14:00 to 17:00; (f) change in indoor temperature from 17:00 to 18:00.

(3) Comparative Analysis

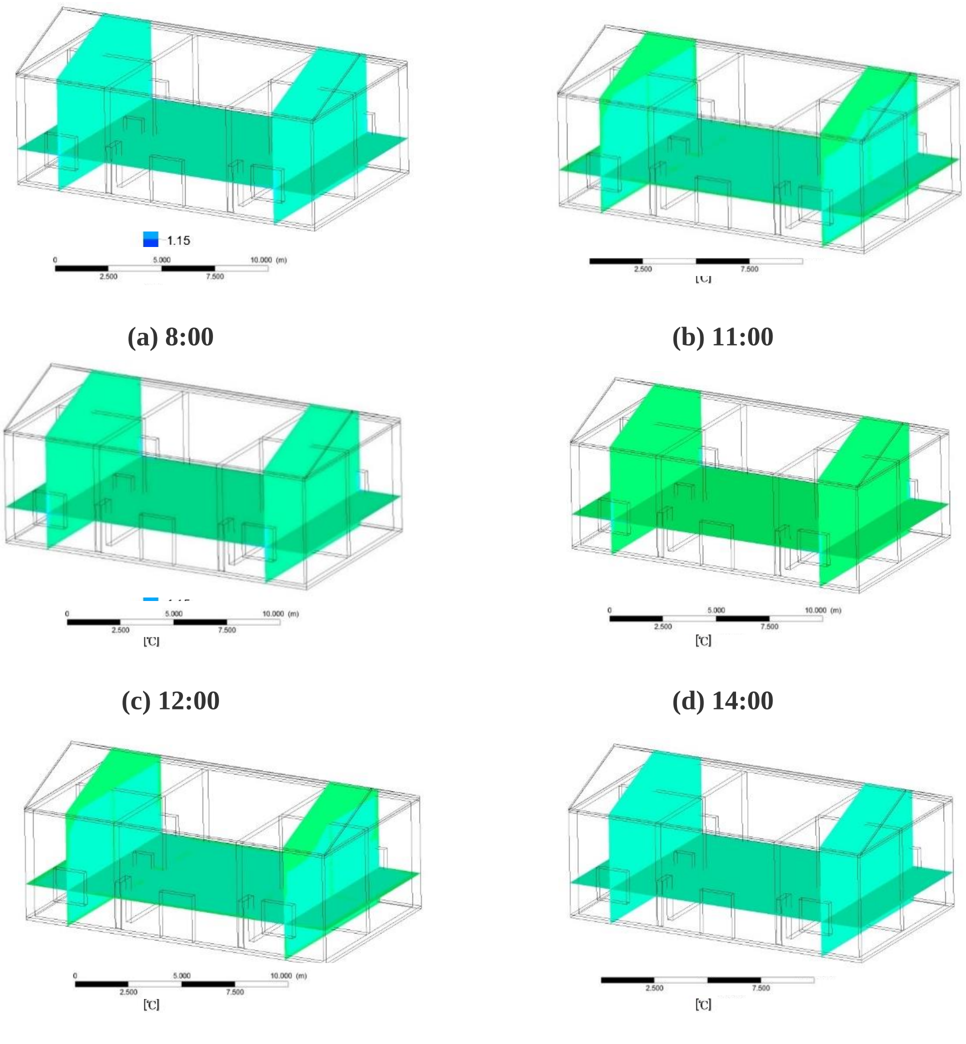
The indoor temperatures of the buildings with basic heating and the roof solar heating storage system were the same without solar radiation. The interior temperature could be increased by 1.1 °C and the heating efficiency was 0.12 °C/h. Using the new system, the temperature could be increased by 1.4 °C, and the heating efficiency was 0.16 °C/h. The reason for this is that without solar radiation, the interior temperature was influenced by the outdoor temperature and indoor thermal distribution. Due to the cold outdoor weather and low temperature in winter, the indoor temperature was low. Therefore, without solar radiation, the heating efficiency of these two heating methods was low, and the improvement effect on indoor temperature was poor.

5.4.2 Comparison between the Two Systems with Solar Radiation

To verify the effectiveness of the roof solar heating storage system, the comparison was made based on the basic heating effect. The specific simulation methods are as follows: first, the residential model was established with Rhino software, then the model was imported into the software, and the grid was set, the energy equation was activated, the turbulence model was selected, the radiation model was set, the thermal properties of the above materials were added and the material properties were assigned to the model, and then the boundary conditions and solution methods were set. Finally, the flow field initialization solution simulation process was set up and the simulation calculation was carried out.

(1) Basic Heating with Solar Heat Radiation

Basic heating depends on solar radiation to increase the indoor temperature by irradiating the wall, glass, and roof with solar heat radiation. The simulation process and simulation time were consistent with those without solar radiation. According to the simulation calculation, from 8:00 to 12:00, the temperature of the east room and the central reception hall began to raise from the initial mean temperature of 3.1 to 5.6 °C. The west room was less affected by solar radiation, the temperature rose relatively slowly, and its temperature variation range was the same as that of the east room (Figure 5-8 a, b). From 12:00 to 14:00, the indoor temperature changed slightly and became nearly stable, and the mean indoor temperature was 5.6 °C (Figure 5-8 c, d). At 16:30, the maximum temperature of the west room reached 5.7 °C, and then it began to decline. The interior temperature in the east room decreased, and the room temperature began to drop from 5.6 to 3.8 °C (Figure 5-8 e). From 17:00 to 18:00, the indoor temperature continued to drop, akin to the outdoor temperature, and the temperature was 3.2 °C (Figure 5-8 f). Under the condition of solar radiation, the mean indoor temperature was 5.6 °C, which was 2.5 °C higher than the mean outdoor temperature.



(a) 8:00 **(b) 11:00**

(c) 12:00 **(d) 14:00**

(e) 17:00 **(f) 18:00**

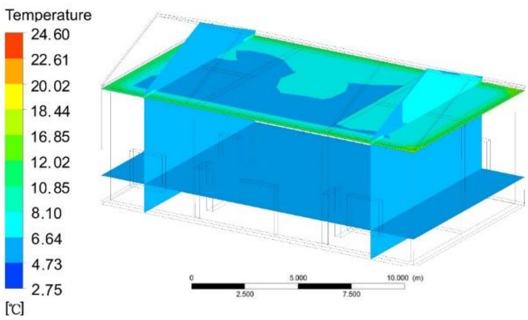
Figure 5-8. (a, b) Change in indoor temperature from 8:00 to 12:00; (c,d) change in indoor temperature from 12:00 to 14:00; (e) change in indoor temperature from 14:00 to 17:00; (f) change in indoor temperature from 17:00 to 18:00.

(2) Roof Solar Heating Storage System with Solar Thermal Radiation

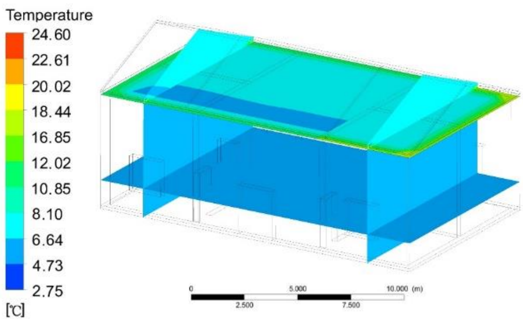
To compare the simulation results with basic heating, the outdoor temperature distribution is similar to that of basic heating. The indoor original temperature was also 3.1 °C. The heating process of the new system includes three stages: solar radiation heating the polyethylene attic floor, the heat transfer of the attic floor itself, and indoor heating by the attic floor.

In the first stage, the polyethylene loft floorboard was heated by solar radiation, and the temperature at the top of the loft floorboard reached a stable state. Due to the change in solar height angle, the temperature changes of the eastern, central, and western loft boards were different, and the indoor temperature change in this stage was small. At 8:00 in the morning, the sun shined on the top of the polyethylene attic floor through the roof glass. The temperature of the east room rose first, followed by the central and western attic floorboards. At 11:40, the temperature of the attic floor was stable. Due to the short heating time of the attic floor in the morning, the indoor temperature changed a little. The temperature changes are as follows:

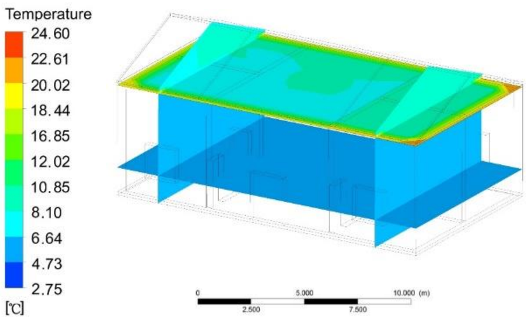
At 8:00, the floor temperature was the same as the indoor temperature, which was 3.1 °C. At 9:00, the temperature of the eastern attic floorboard was 7.1 °C, the temperature of the middle attic floorboard was 6.2 °C, and the temperature of the western attic floorboard was 5.2 °C (Figure 5-9 a). At 9:30, the temperature of the eastern attic floorboard was 7.9 °C, the temperature of the middle attic floorboard was 7.4 °C, and the temperature of the western attic floorboard was 6.9 °C (Figure 5-9 b). At 10:00, the temperature of the eastern attic floorboard was 10.2 °C, the temperature of the middle attic floorboard was 8.6 °C, and the temperature of the western attic floorboard was 7.8 °C (Figure 5-9 c). At 10:30, the temperature of the eastern attic floorboard was 16.5 °C, the temperature of the middle attic floorboard was 10.6 °C, and the temperature of the west attic floorboard was 10.3 °C (Figure 5-9 d). At 11:00, the temperature of the eastern attic floorboard was 20.3 °C, the temperature of the middle attic was 19.4 °C, and the temperature of the western attic floorboard was 18.1 °C (Figure 5-9 e). At 11:40, the temperature of the attic floor was nearly stable. The temperature of the attic floor in the east was 24.5 °C, the temperature of the attic floor in the middle was 24.3 °C, and the temperature of the attic floor in the west was 24.5 °C (Figure 5-9 f).



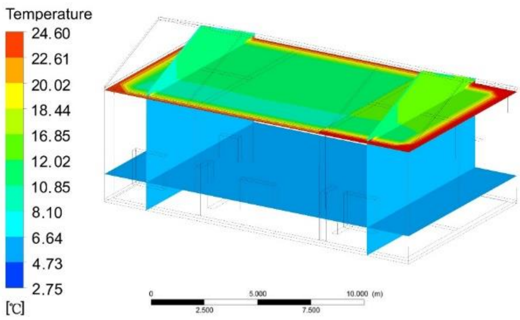
(a) 9:00



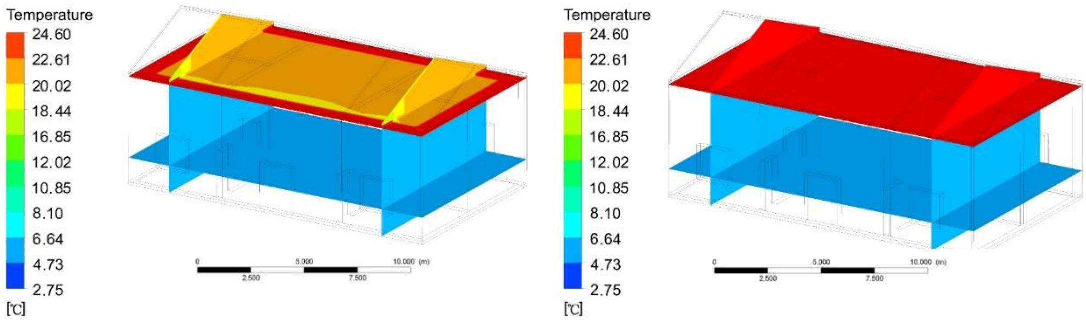
(b) 9:30



(c) 10:00



(d) 10:30



(e) 11:00 **(f) 11:45**

Figure 5-9. (a) Change in indoor temperature at 9:00; (b) change in indoor temperature at 9:30; (c) change in indoor temperature at 10:00; (d) change in indoor temperature at 10:30; (e) change in indoor temperature at 11:00; (f) change in indoor temperature at 11:45.

The second stage was the heat transfer of the attic floor itself. During the heating process, the temperature at the top of the attic floor rose first, and then the bottom was heated. After simulation calculation, after 22 min, the temperature at the bottom of the attic floor was about 23.6 °C. The indoor temperature also began to rise slowly. The temperature change process at the bottom of the attic floor was as follows: at 11:45, the mean temperature of the attic floor was 10.6 °C (Figure 5-10 a). At 11:50, the mean temperature of the attic floor was 15.5 °C (Figure 10 b). At 11:55, the mean temperature of the attic floor was 19.4 °C (Figure 10 c). At 12:07, the mean temperature of the attic floor was 23.7 °C (Figure 5-10 d).

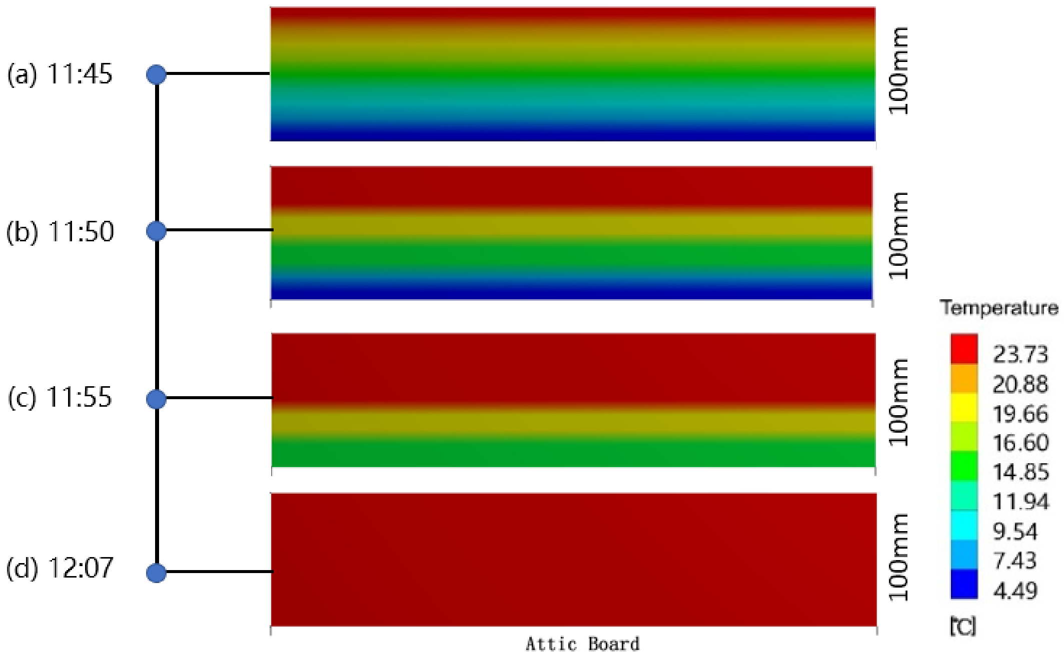
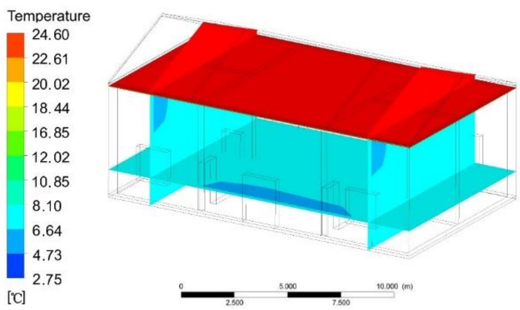


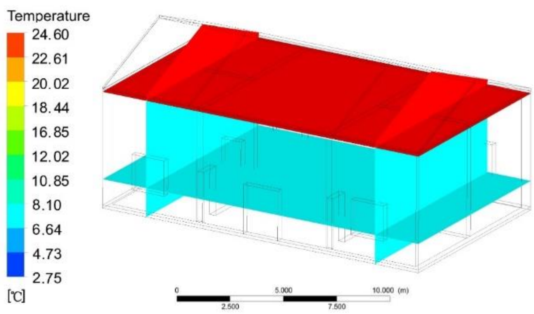
Figure 5-10. (a) The temperature change of the attic floor at 11:45; (b) the temperature change of the attic floor at 11:50; (c) the temperature change of the attic floor at 11:55; (d) the temperature change of the attic floor at 12:00.

The third stage was the attic floor heating the room. The principle of this process was using thermal radiation to heat the indoor air to raise the indoor temperature. From 13:00 to 16:00, the attic floor temperature remained unchanged, and the indoor temperature continued to rise; from 17:00–19:00, the temperature of the attic floor began to decrease, and the indoor temperature also decreased. The changes in the attic floor and indoor temperature are as follows:

From 13:00 to 16:00 (Figure 10a–d), the temperature of the attic floor remained unchanged at 23.5 °C. At 17:00, the temperature of the eastern attic floorboard was 21.4 °C, the temperature of the middle attic floorboard was 22.5 °C, and the temperature of the western attic was 7.6 °C (Figure 5-9 e). At 17:30, the temperature of the eastern attic floorboard was 15.4 °C, the temperature of the middle attic floorboard was 16.7 °C, and the temperature of the western attic floorboard was 17.2 °C (Figure 9 f). At 18:00, the temperature of the eastern attic floorboard was 10.6 °C, the temperature of the middle attic floorboard was 11.2 °C, and the temperature of the western attic floorboard was 12.4 °C (Figure 9 g). At 19:00, the temperature of the eastern attic floorboard was 8.8 °C, the temperature of the middle attic floorboard was 9.1 °C, and the temperature of the western attic floorboard was 9.2 °C (Figure 9 h). From 19:30 to 8:00, the temperature of the attic floor remained stable at 3.1 °C.

At 13:00, the temperature of the east room was 5.5 °C, the temperature of the middle room was 5.8 °C, and the temperature of the west room was 6.2 °C (Figure 5-11 a). At 14:00, the temperature of the east room was 5.8 °C, the temperature of the middle room was 6.2 °C, and the temperature of the west room was 6.7 °C (Figure 5-11 b). At 15:00, the temperature of the east room was 7.7 °C, the temperature of the middle room was 7.8 °C, and the temperature of the west room was 8.1 °C (Figure 5-11 c). At 16:00, the temperature of the east room was 7.9 °C, the temperature of the middle room was 8.0 °C, and the temperature of the west room was 8.9 °C (Figure 5-11 d). At 17:00, the temperature of the east room was 7.3 °C, the temperature of the middle room was 7.4 °C, and the temperature of the west room was 7.6 °C (Figure 5-11 e). At 17:30, the temperature of the east room was 6.5 °C, the temperature of the middle room was 6.7 °C, and the temperature of the west room was 6.7 °C (Figure 5-11 f). At 18:00, the temperature of the east room was 5.1 °C, the temperature of the middle room was 5.4 °C, and the temperature of the west room was 5.3 °C (Figure 5-11 g). At 19:00, the temperature of the east room was 4.2 °C, the temperature of the middle room was 4.3 °C, and the temperature of the west room was 4.5 °C (Figure 5-11 h). The indoor temperature remained stable at 3.1 °C from 19:30 to 8:00 the next morning.

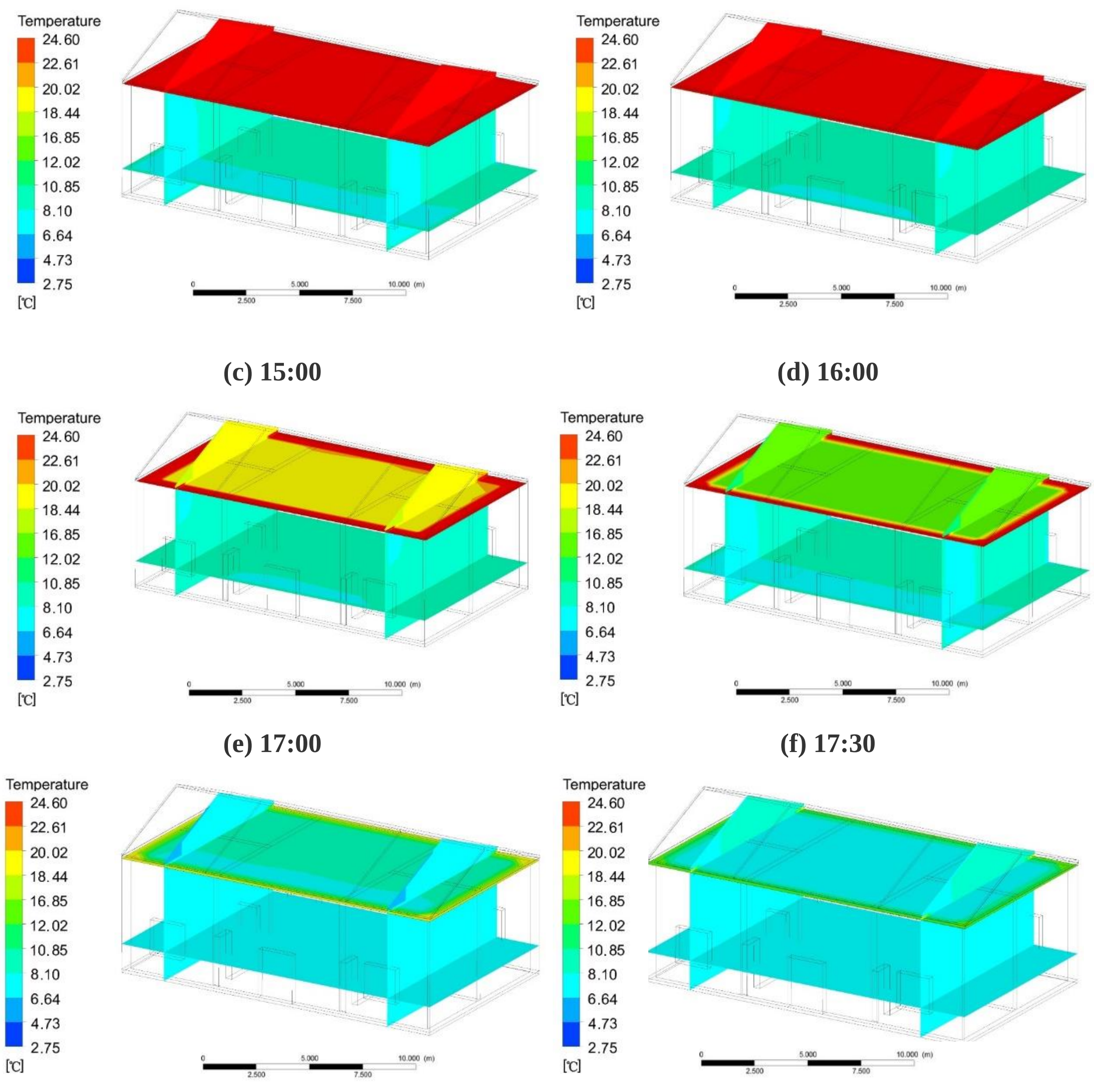




(a) 13:00 **(b) 14:00**

(c) 15:00 **(d) 16:00**

(e) 17:00 **(f) 17:30**



(g) 18:00 **(h) 19:00**

Figure 5-11. (a) The indoor temperature at 13:00; (b) the indoor temperature at 14:00; (c) the indoor temperature at 15:00; (d) the indoor temperature at 16:00; (e) the indoor temperature at 17:00; (f) the indoor temperature at 17:30; (g) indoor temperature at 18:00; (h) indoor temperature at 19:00.

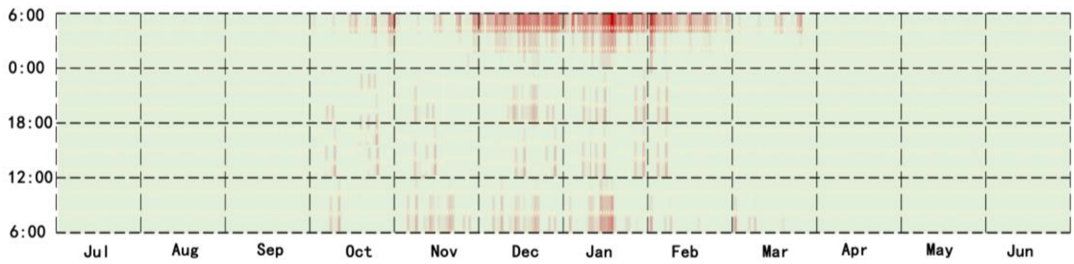
(3). Comparative Analysis

The reasonable use of solar energy can greatly improve the indoor temperature. The roof solar heating storage system was mainly affected by solar radiation with solar radiation. The initial temperature of the attic floor and the indoor space was 3.1 °C, and when the indoor temperature began to rise at 9:00, the mean temperature was 3.8 °C. At 16:00, the indoor temperature was 8.9 °C. The indoor temperature decreased at 17:00, and the mean indoor temperature was 7.9 °C. Therefore, the temperature was increased by 5.8 °C, and the mean heating efficiency was 0.97 °C/h. The basic heating system mainly relies on the heat generated by solar radiation on the wall to influence the indoor temperature. The temperature was increased by 2.5 °C, and the mean heating efficiency was

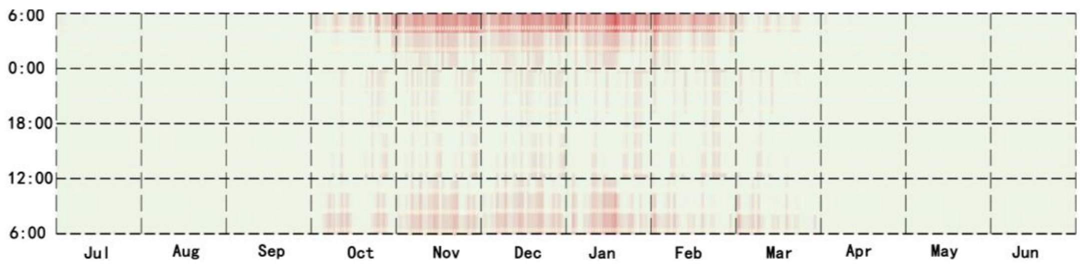
0.42 °C/h. Therefore, the new system mainly depended on the roof glass and the heat storage material attic floor to improve the indoor temperature. Compared with the basic heating system, it greatly increased heating efficiency and heating time.

5.4.3 Heating Time with the New System

The heat load reduced using the use of the roof solar heating storage system was estimated with or without solar radiation for the entire year. The time spent using solar heating was mainly distributed in January, February, March, November, and December. The solar energy system was used for 807 h during the year without solar radiation, accounting for 9.16% of the whole time (Figure 5-12 a). The time spent using the new system in the whole year was 1141 h with solar heat radiation, accounting for 12.95% of the total time over the year (Figure 5-12 b).



(a) Without solar heat radiation

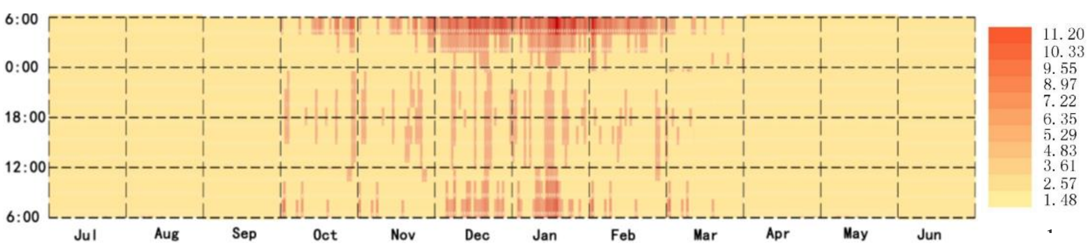


(b) With solar heat radiation

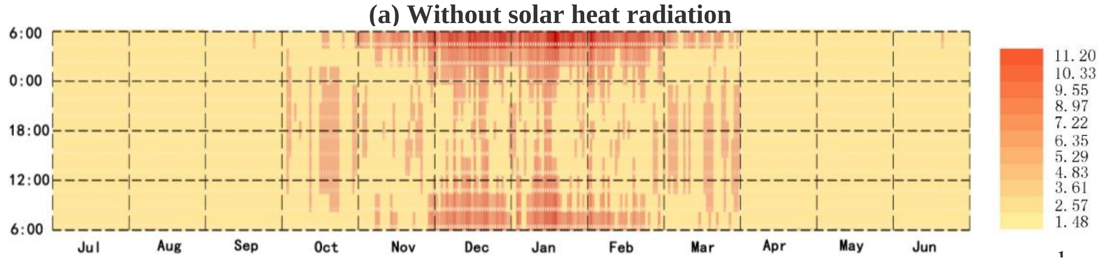
Figure 5-12. (a) The heating time of the new system without solar heat radiation; (b) the heating time of the new system

5.4.4 Energy-Saving Situation of Using the New System

The annual heat load of the new system was simulated by EnergyPlus—it was reduced by 517.84 kW · h without solar radiation, and the reduction ratio was 9.51% (Figure 5-13 a), while it was reduced by 1361.92 kW·h with solar radiation, and the reduction ratio was 25.02% (Figure 5-13 b).



(a) Without solar heat radiation

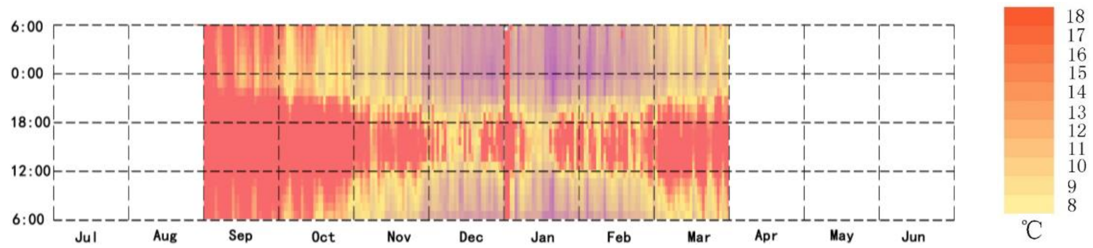


(b) With solar heat radiation

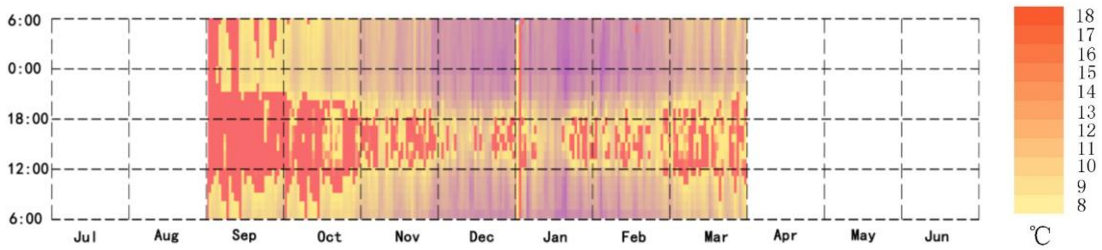
Figure 5-13. (a) The energy-saving situation of using the new system without solar heat radiation; (b) the energy-saving situation of using the new system with solar thermal radiation.

5.4.5 Thermal Comfort with the New System

Taking 18 °C as the limit of indoor thermal comfort, we calculated the time when the new system produced temperatures below 18 °C. Under the condition of basic heating, the time when the solar energy system was adopted, the time when the interior temperature was lower than 18 °C is 4006 h without solar radiation, accounting for 46.36% of the year (Figure 5-14 a). The time when the temperature was lower than 18 °C all year was 3763 h with solar radiation, accounting for 43.55% of the year (Figure 5-14 b).



(a)



(b)

Figure 5-14. (a) thermal comfort of the new system without solar heat radiation; (b) thermal comfort of the new system with solar heat radiation.

5.4.6 Empirical Research

Nowadays, solar heating technology has been tried in rural houses in Shaanxi City, China. The research team conducted a preliminary study and experiment on the solar heating system on 6 January 2019. The experimental site was Lihuaping village, Houliu Town, Ziyang County, Shaanxi City. The experimental object was a one-story sloped-roof residential house. It faces due south, the wall material is 240 mm-thick red brick, and the roof is glazed tile, which is easy to transform. Its functions include a living room, bedroom, kitchen, and storage room (as shown in the figure). According to the demands of the heating system, only the living room and two bedrooms were heated, with a heating area of 66 m^2. According to the requirements of the heat storage roof heating system, the roof was transformed into a glass skylight, and a heat insulation board was placed below the skylight. The specific heat capacity of pebbles was C = 780j/(kg·K), and the thermal diffusivity was a = 11.3×10^{-7} m^2/s, which is more suitable as a heat storage material, and there are many pebbles in the local area. Therefore, 10 cm thick pebbles were placed on the attic floor as heat storage material. Next, the indoor temperature of the reconstructed residential house was measured. The test weather was sunny, the period was 8:00–18:00 in the daytime, and the time interval was one hour. The changes in indoor temperature when the heat insulation board was closed and opened were measured, respectively, for one month. Additionally, effective temperature changes for sorting were selected (Table 5-1). Through analysis and comparison, the average indoor temperature was 6.2 °C in the ten days after closing the heat insulation board, 3.8 °C in the ten days after opening the heat insulation board, and the indoor temperature increased by 2.4 °C. Polyethylene was selected as the heat storage material in this study. Its specific heat capacity and thermal diffusivity are higher than pebbles, so the temperature increase range was greater than before, which also confirms the practicability of the system for improving the room temperature in winter.

Table 5-1. Change in indoor temperature.

DAY	Indoor Temperature with Closed Heat Shield (°C)	Indoor Temperature with Open Heat Shield (°C)
1	5.9	3.7
2	6.3	3.9
2	5.9	3.6
3	6.4	3.6
4	6.3	3.9
5	6.2	3.9
6	6.5	3.8
7	5.9	4
8	6.3	3.7
9	6.3	3.9
10	5.9	3.7
Average temperature	6.2	2.8

5.5 Conclusions

5.5.1 Conclusions

Traditional Houses in southern Shaanxi are the research objects of this study. To raise the indoor temperature, the roof solar heating storage system is proposed. First, we establish the roof solar heating storage system and changed the roof to a partial glass roof, so that the attic slab received the heat radiation from the sun. So, to improve the heat storage effect of the attic floor, HDPE was installed on the attic floor. At the same time, the heat storage material polyethylene was added to the attic floor. Second, the heating time and temperature change of the basic heating system and the new system were calculated and simulated by software. Finally, the results of the influence of the two heating methods on the indoor temperature were compared. The roof solar heating storage system can raise the indoor temperature, and the following conclusions were drawn:

Using the thermal storage roof pool solar heating system, the indoor temperature increased by 4.9 °C with solar radiation, and the mean heating efficiency was 0.82 °C/h. The indoor temperature increased by 1.4 °C without solar radiation, and the mean heating efficiency was 0.16 °C/h.

Using basic heating, the interior temperature increased by 2.5 °C with solar radiation, and the mean heating efficiency was 0.42 °C/h. The indoor temperature increased by 1.1 °C without solar radiation, and the mean heating efficiency was 0.12 °C/h.

The time spent using the solar heating system was mainly distributed in January, February, March, November, and December. The solar energy system was used for 807h all year without solar radiation, accounting for 9.16% of the whole year. The time spent using the new system in the whole year was 1141 h with solar heat radiation, accounting for 12.95% of the whole year.

The annual heat load of the new system was reduced by 517.84 kW·h without solar radiation, and the reduction ratio was 9.51%, while it was reduced by 1361.92 kW·h with solar radiation, and the reduction ratio is 25.02%.

Taking 18 °C as the limit of indoor thermal comfort, we calculated the time when the new system was below 18°C. Under the condition of basic heating, the time when the temperature of the building was lower than 18 °C was 5019 h, accounting for 56.98% of the year. When the solar energy system was adopted, the time when the interior temperature was lower than 18 °C is 4006 h without solar radiation, accounting for 46.36% of the year. The time when the temperature was lower than 18 °C all year was 3763 h with solar radiation, accounting for 43.55% of the year.

5.5.2 Outlook

Future studies mainly include the following:

The appropriate value of the roof transparent area ratio and the roof inclination angle can be further explored to obtain more solar radiation indoors and to achieve the best indoor temperature.

The heat storage plate used HDPE heat storage material. In future research, we should combine the development of science and technology to explore more suitable heat storage materials to further increase indoor temperature in winter.

5.6 Chapter Summary

This chapter proposes a solar roof thermal storage heating system in response to the problems of cold winters and high energy consumption of residential houses in southern Shaanxi, taking into account the local climate, the characteristics of residential houses, and the properties of thermal storage materials. The boundary condition is the presence or absence of solar radiation. The heating time, heating efficiency, and energy-saving rate of the new system are obtained through simulation. Finally, the advantages of the new system are derived by comparing it with the current heating method. It can provide design references for residential buildings in hot summer and cold winter areas.

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Chapter 6. Study on Thermal Storage Wall Heating System of Traditional Houses

6.1 Review of Solar Thermal Storage Wall Research

Scholars around the world have conducted many theoretical studies and practical explorations on winter building energy efficiency, such as the effects of passive heating design [11], building energy efficiency [12] as well as solar buildings [13] and their optimization [14].

Most of the research about passive heating design focuses on the fundamentals of the design of heating and the utilization of other energy sources for heating. Underground water storage tanks [15], fresh air systems with windows [16], and solar thermal air heating systems [17] are used for heating in buildings. For areas with poor solar radiation air source heat pumps can be used for heating [18]. Elmetwalli [19] and Liu [20] modified so-lar water heaters and combined them with other heating methods and both heating efficiencies were improved. Chi et al. proposed a passive dual heat and dual cooling system and applied it to a new building and obtained a 39% energy saving through numerical simulations [21]. Wang [22] and Aksoy [23] and Brown [24] optimized passive heating in terms of building design as well as building parameters, which also led to the improved thermal insulation of the building. Givoni conducted a comprehensive theoretical study of solar heating systems, which provided some guidance for future research [25]. Wang proposed a passive design strategy in China, which plays a part in promoting solar energy in China [26]. These studies have improved indoor thermal comfort to some extent, but only in a theoretical way or only by adding other energy sources for heating, and other factors that affect indoor temperature are not discussed.

Most research on building energy efficiency concentrated on changing energy-intensive traditional energy sources and improving the thermal insulation of the envelope. Kuşkaya [27], Wang [28], Gao [29], and He [30] proposed combining residential buildings with solar energy to greatly decrease building energy depletion. Feng simulated and optimized the program configuration of residential houses in the village to reduce energy consumption significantly [31]. Ménard [32] designed windows retrofitted with adjustable elements and the results confirmed the high energy-saving potential of this method. Liu used solar energy combined with a coal stove for heating, which resulted in a significant reduction in energy consumption [33]. dabaieh [34], Zhang [35], Mi [36], and Kalbas [37] achieved energy savings by improving the envelope Tadeu [38] and Wang [39] proposed energy-saving practices in terms of theoretical analysis. These studies give guidance as well as practices for research on aspects of building energy efficiency, but only in terms of changing energy sources or changing the insulation performance of the envelope, with limited energy savings.

For the study of solar buildings, Wang [40] and Bakos [41] proposed algorithms and control of solar energy as a heating system from the theoretical aspect. Sun proposed the incorporation of PCMs in TSW and concluded that it is effective for increasing the room temperature by studying the heat transfer process [42]. Chandel [43], Athianitis [44], Badescu [45], and Arkar [46] confirmed using solar heating can reduce energy consumption by simulating a solar building. Stevanovic studied optimization strategies for passive solar design and concluded that a combination of various strategies can improve energy efficiency [47]. Li et al. converted a new house in Sichuan into a solar building. The simulated indoor temperature ranged from 8.5 to 21.2°C, which greatly improved the heat and comfort in the region in winter [48]. Zhou proposed a new enclosure with a multi-slab solar energy accumulation wall with a 20% increase in heating effectiveness [49]. Guo studied a solar heating system, developed a mathematical model, and proposed three evaluation indexes. A temperature increase of 55.2% was obtained [50]. These studies have studied solar buildings in terms of theory, simulation, or practice, and have improved the theory in this subject area, but the factor of the presence and absence of solar radiation should be considered in the simulation process, which is also an important factor in comparing and verifying the TSWHS for indoor temperature increase.

To sum up, academics have done much theoretical research and retrofitting practice on winter building heating, and have achieved fruitful results. But overall it includes adding passive heating to existing buildings, using solar energy as an adjunct to other heating methods, and separate studies on the e impact of changing the insulation properties of the enclosure on building heating. Single studies are always limited in their effect on the indoor temperature as well as skills. This study proposes to use solar heating while changing the insulation properties of the envelope (adding HDPE as well as glass inter-layer), and as well as considering the factors of influence of the presence or absence of solar radiation on room temperature, for winter heating of conventional houses to fill the gap in this field.

6.2. Research Overview

6.2.1 Evaluation Indices

According to the Chinese building industry's energy conservation design standard, the indoor heat ambient design index for heating in winter is that the interior design temperature of the bedroom and living room should be taken as 18°C [51], so this study uses 18°C to evaluate the improvement effect of internal thermal comfort of the TSWHS as the threshold value of indoor thermal comfort temperature. Also, the PMV-PPD thermal comfort evaluation indices were used to assess the residents' perception of indoor thermal comfort. The principle was proposed by the Danish scholar Fanger in the 1970s. The indices are based on his famous thermal comfort balance equation, which considers six parameters: two human factors, namely activity level, and clothing, and four thermal environmental factors [52].

By thermal comfort equilibrium equation is meant that in the basic thermal equilibrium equation, Qe is replaced by the body regulation function in the peaceful state, Qe* in the comfortable state, according to the skin surface temperature Ts in the peaceful state. Calculating Qr and Qe in the basic heat balance equation, the radiation heat transfer and convection heat transfer obtained are denoted as Qr* and Qe*, respectively, then.

According to some combinations of these six parameters, the equations are as follows:

$$Q_m - Qe^{*} \pm Qr^{*} \pm Qc^{*} = \Delta Q^{*} \tag{1}$$

If ΔQ*=0, the thermal environment is considered to be comfortable.

If ΔQ*=L≠0, that is, the thermal comfort balance is destroyed. To maintain normal body temperature, the working intensity of regulating function is bound to change. The higher the value of L in absolute terms, the larger the degree of discomfort. According to the experiment, Fanger obtained the functional relationship between the PMV index representing thermal sensation and thermal load L and other factors. PMV is the thermal sensation value of a combination of environmental factors during the experiment.

6.2.2 Research Framework

According to the research, local people mainly use two types of heating. Active heating mainly uses household appliances, while passive heating mainly uses firewood. These two methods can only increase the local temperature indoors, not the overall temperature. Through the study, the key to the design of this system was the addition of HDPE and the optimization of the wall insulation performance. By comparing the thermal properties of several commonly used thermal insulation materials, HDPE's comprehensive performance is better. After multiple considerations, the outer wall was transformed into a TSW. The temperature rises and the house is heated, while at the same time air exchange vents inside the TSW are used to exchange the hot air inside the TSW and the room. Thus, the internal temperature is enhanced by the combined effect of the two systems. Internal temperature variations were analyzed for TSWHS and OHS systems with and without solar radiation, respectively. The optimal heating system is also derived by comparing the heating effect of the four cases. Finally, heating efficiency, heating time, energy saving, and thermal comfort were studied. The research framework was illustrated in Figure 6-1.

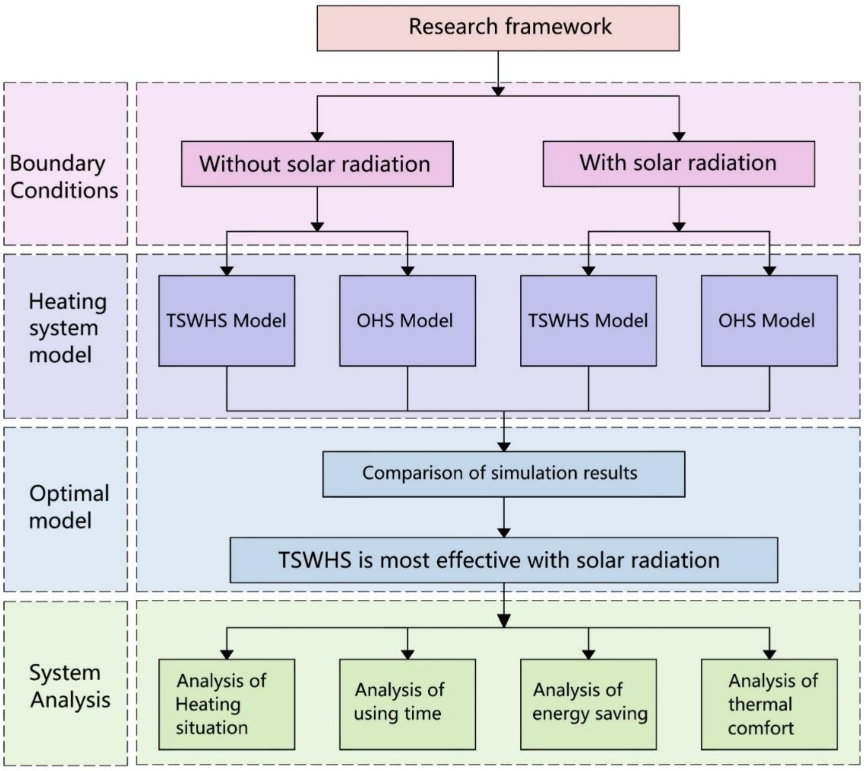


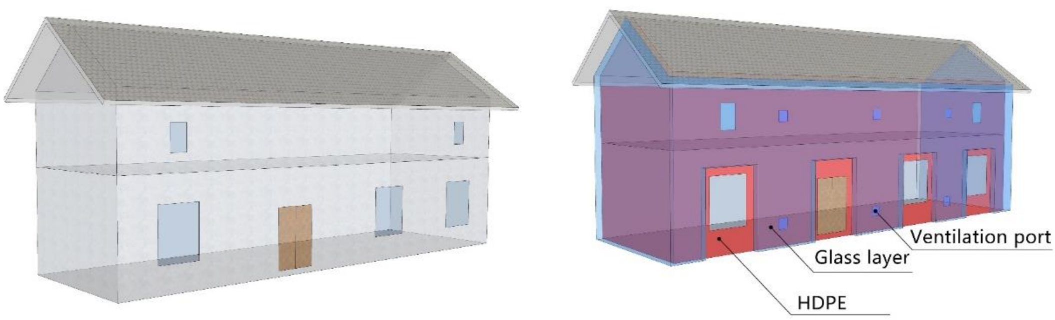
Figure 6-1. Research framework

6.2.3 Induction of TSWHS

(1). System Design

The study reveals that most of the traditional dwellings in southern Shaanxi are "line" or "L" type, and most of the space is three opening rooms. The roof form is a pitched roof and the material is mostly tile or slate. The walls are brick and the outer layer is lime plaster. Based on the architectural information of the current residential house, we used Rhino software to build a residential model with a sloped roof form, with dimensions of 5.1m*17.7m and a total height of 8.2m, of which The 1st-floor height is 3.6 m, and the 2nd-floor height is 2.8 m. The height of the sloped roof is 1.8m (Figure 6-2 a). The southern Shaanxi area has good sunshine conditions and the building structure is simple, so it is more suitable to set up a TSWHS (Figure 6-2 b). Since most of the houses in southern Shaan-xi are oriented north-south, the design of the TSWHS is mainly to transform the walls on the south, east and west sides. A glass layer was added on the outside of the three walls on the west, south, and east sides with a distance of 100 mm between the glass and wall. Inside is the layer of air, PCMs are added on the outside of the walls as a thermal storage layer, and ventilation holes are made in the walls at a certain distance. The heating storage material of the wall is HDPE, the thickness is 10 mm. The glass is a single layer of ordinary glass with a light transmittance of 0.87 and a thickness of 6 mm, The wall material information is shown in Figure 5.

Li et al. investigated PCM by melt mixing and aqueous solvent etching combined with simple vacuum impregnation, which finally solved the shortcomings of leakage and geothermal conduction that have been present in PCM. The results showed that the up-graded HDPE material has 2.94 times higher thermal conductivity than before, with an enthalpy of melting of 153.95 J/g and an enthalpy of crystallization of 152.82 J/g, which is valuable for electrical and thermal energy storage [53]. The density of HDPE is 964 kg/m³ [54], the thermal conductivity is 0.36 W/m·K, and the specific thermal capacity is 2301 J/Kg·K [55], compared with bricks and other materials, its thermal conductivity is low, and it has high thermal storage performance [56]. The heat can be fully absorbed during the day and exothermic at night so that the heat flows to the glass interlayer as well as the interior, which can extend the time of heating the interior. Therefore, HDPE is chosen as the PCMs for TSW. During the day, the air inside the wall was heated, and the HDPE outside is through the glass, which heats the TSW and warms the room. Meanwhile, the heated air inside the glass cavity is exchanged via vents with the cold air in the room. In the case of dual-system heating, the room temperature is increased. The working principle is that HDPE absorbs and stores heat from solar radiation and utilizes the properties of the thermal storage material to raise the room temperature at night.



(a) **(b)**

Figure 6-2 (a) Residence model; (b) Introduction to the main parts of TSWHS.

(2) Operating Principle

The principle of TSWHS is using solar radiation to heat the HDPE and air layer (Figure 6-3). The hot air is exchanged with the cold air in the room through the vents, interior temperature is increased with a dual system heating. Therefore, TSWHS can be considered a solar heating and recovery device. Multiple factors influence the entire heat transfer process in TSWHS, such as solar radiation, thermal properties of the thermal storage material, thickness, glazing size, room dimensions, the Internal and external temperature of the inflatable layer, etc. To clearly illustrate the heat transfer principle of this system, it is presented in three processes (Figure 6-4).

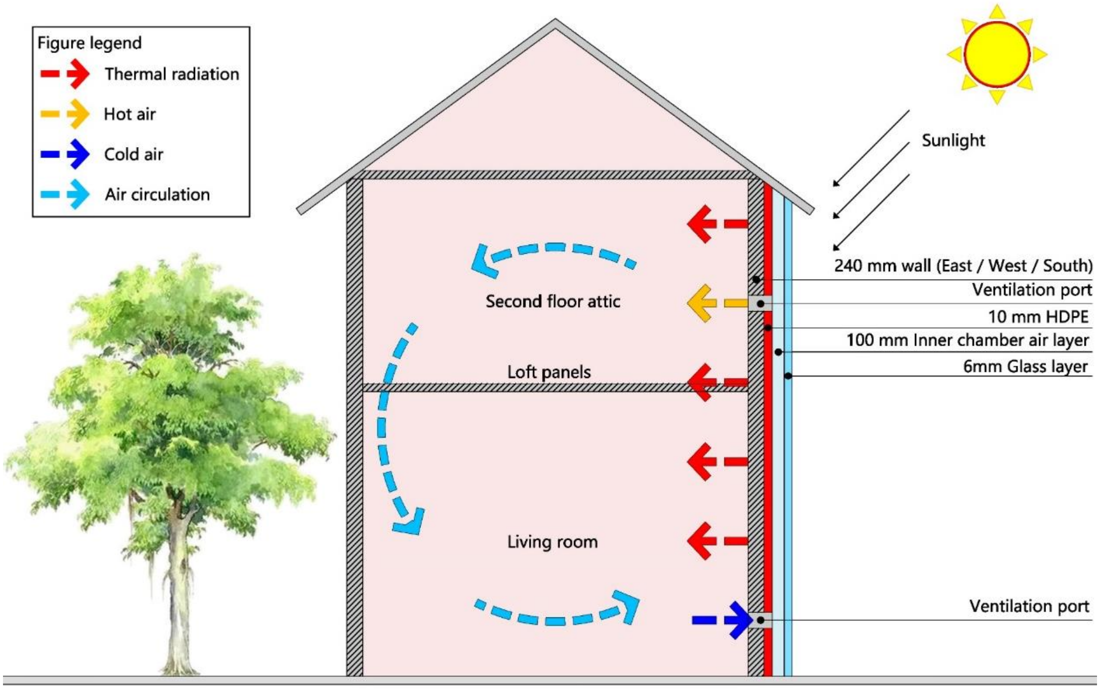


Figure 6-3. Working principle of TSWHS

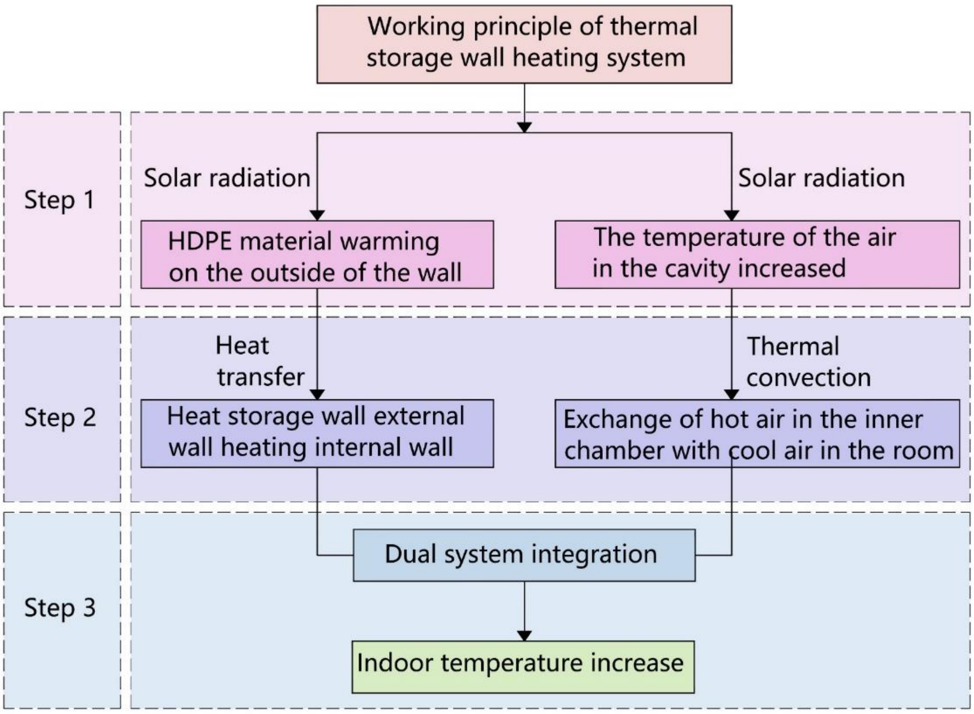


Figure 6-4. Heating transfer process.

The first step is solar radiation heating the internal air layer and the external HDPE. The principle of the thermal process is based on heating convection and radiation. The heat transfer is majorly transient and follows Planck's law.

The second step is that HDPE heated the inner wall, the heat transfer is mainly by heat conduction, which is the same as the heat transfer principle in the first step, and the process is solid-solid coupled heat transfer.

In the third step, when the temperature of the inner surface of the wall (A in Figure 6-5) is the same as the outer surface of the wall (B in Figure 6-5), the TSW raises the entire room temperature mainly by using heat transfer which is mainly the form of thermal radiation. Meantime, warm air in the TSW is exchanged through vents in the wall with interior cold air, thus raising the room temperature.

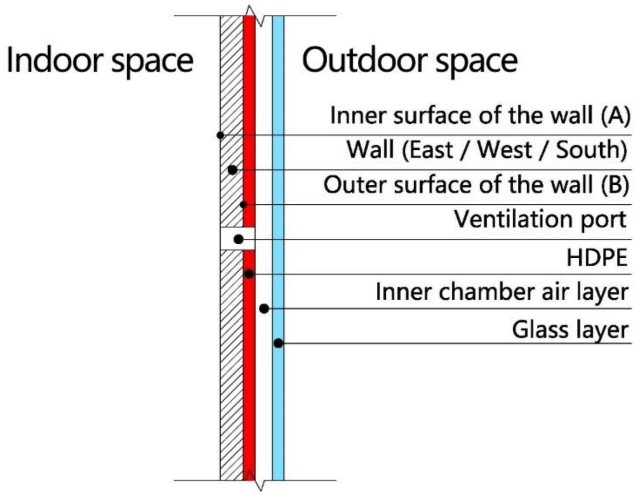


Figure 6-5. Detailed introduction of TSW.

(3) Analysis of OHS

1) With solar radiation

There are two common ways of heating in southern Shaanxi where winters are cold. One of these types is passive heating, called OHS. Where the heat source is mainly solar radiation and internal heat gains. This method of heating via solar radiation mainly heats the walls by heat conduction to raise the room temperature. The first is the outer surface of the wall absorbs heat through solar radiation. The second is the inner surface of the wall was heated by outers via heat conduction. The third is the release of heat from the inner wall, which raises the interior temperature through a combination of three types of heat transfer. It is clear that the efficiency of OHS heating is very low and the internal rise of room temperature is very low. The stabilized temperature is 2.5°C more compared to the outdoor temperature.

2) Without solar radiation

The main source of heating for the OHS is mainly internal heat gain without solar radiation. It consists mainly of heat created by various household electricity and stoves. Indoor temperature is also impacted by building size, insulation, and air tightness of materials. Without radiation, the indoor temperature is only impacted by household appliances and stoves, and the variation of indoor temperature is very small, only 0.1°C above the external temperature.

(4) Analysis of TSWHS

1) With solar radiation

The absorption and storage capacity of HDPE can increase the internal temperature of residential buildings. HDPE with high heat absorption and storage capacity is added to the exterior walls to absorb, store, and release heat to heat the room during the daytime when solar radiation is available. It releases heat at night to warm the room. After the TSW absorbs heat, the temperature rises significantly. 1 hour later, the room temperature rises to 0.7 °C. The maximum temperature of the bedroom reached 8.9 °C at 16:00. Thus, the house was heated better with HDPE, and the increased temperature was improved as well as the heating time after using HDPE.

2) Without solar radiation

The situation is analogous to that of the OHS without solar radiation. The temperature increase in the TSW was slow and very small compared with the external temperature. The interior temperature gained by 0.3°C. In previous studies, the effect of internal heat gains was less considered. In this study, this factor was added to make the simulation results more accurate.

6.2.4 Simulation Analysis

The threshold criterion is turning on or off solar radiation. The steps of the software simulation are as follows. Firstly, the model is created with Rhino. Secondly, import Ansys to set the parameters, perform the simulation, and get the results. Finally, the thermal load is computed by EnergyPlus. The process consists of three parts: firstly, the heating of the OHS is simulated. In the second part, the heat extraction and exotherm of the TSW are simulated. In the last part, the appropriate time and the reduction of the thermal payload of TSWHS are simulated. Table 6-1 shows the building information and Table 6-2 show the properties of the materials.

The simulation process of the paper uses a single control variable method to verify the energy-saving potential of TSWHS by turning on or off solar radiation. To exclude the influence of other factors on the simulation results, the factor of convection in the air is therefore ignored, and the simulated results remain largely consistent with the measured results, so the problem is also solved by applying this idea in the simulation process.

Table 6-1 Architectural details of traditional houses and their material types

Building Detail Name	Material Type
Roof	12 mm thick No. 3 blue tile, 240 mmx200 mm
TSW outer glass	6 mm glass
TSW insulation	10 mm HDPE

Wall	3 mm lime mortar + 240 mm clay brick masonry + 3 mm lime mortar
Door	45 mm wood
Window	6 mm single-layer glass
floor	100mm crushed stone, 10mm cement mortar

Table 6-2. Physical properties of materials of traditional houses.

Type of Material	Density (Kg/m3)	Thermal Conductivity (W/m·K)	Specific thermal capacity (J/Kg·K)
Cement-mortar	1800	0.93	1050
Red Brick	1700	0.76	1050
Lime-mortar	1600	0.81	1050
Gravel Concrete	2300	1.51	920
Wood	500	0.14	2510
Tile	2700	203	920
HDPE	964	0.36	2301

6.3 Result and Analysis

6.3.1 Comparison of OHS and TSWHS without Solar Radiation

(1) OHS without Solar Radiation

To validate the heating effect of TSWHS without solar radiation, OHS was used as a benchmark for comparison. By simulation, the indoor temperature of OHS is not significantly different from the outdoor. The simulated time included daytime and nighttime. In the daytime, the interior temperature was strongly influenced by solar radiation during the period of 8:00 to 20:00. Interior temperature was unaffected by solar radiation during nighttime for the period from 20:00 to 8:00 a.m. This simulated time is used for the following three heating conditions. Depending on the computed values, the variation of interior temperature is as follows. During the night period from 20:00 to 8:00, the temperature gap between inside and outside is small, and the interior temperature is 2.6 °C-3.8 °C. The daytime period was from 8:00 to 20:00, where the mean interior temperature was 3.2 °C from 8:00 to 12:00 (Figure 6-6 a, b). This is mostly because of the low exterior temperature and the lack of other heat sources indoors. From 12:00 to 14:00, the interior temperature was kept constant with an average temperature of 3.3°C (Figure 6-6 c, d). Both interior and exterior temperatures began to increase slightly from 14:00 to 17:00, with the interior temperature stabilizing at 4.2°C. The external temperature started to decrease and the interior temperature was 3.6 °C from 17:00 to 20:00. Without solar radiation, the average interior temperature of OHS was 3.7 °C, which was not much different from the exterior mean temperature of 0.5 °C.

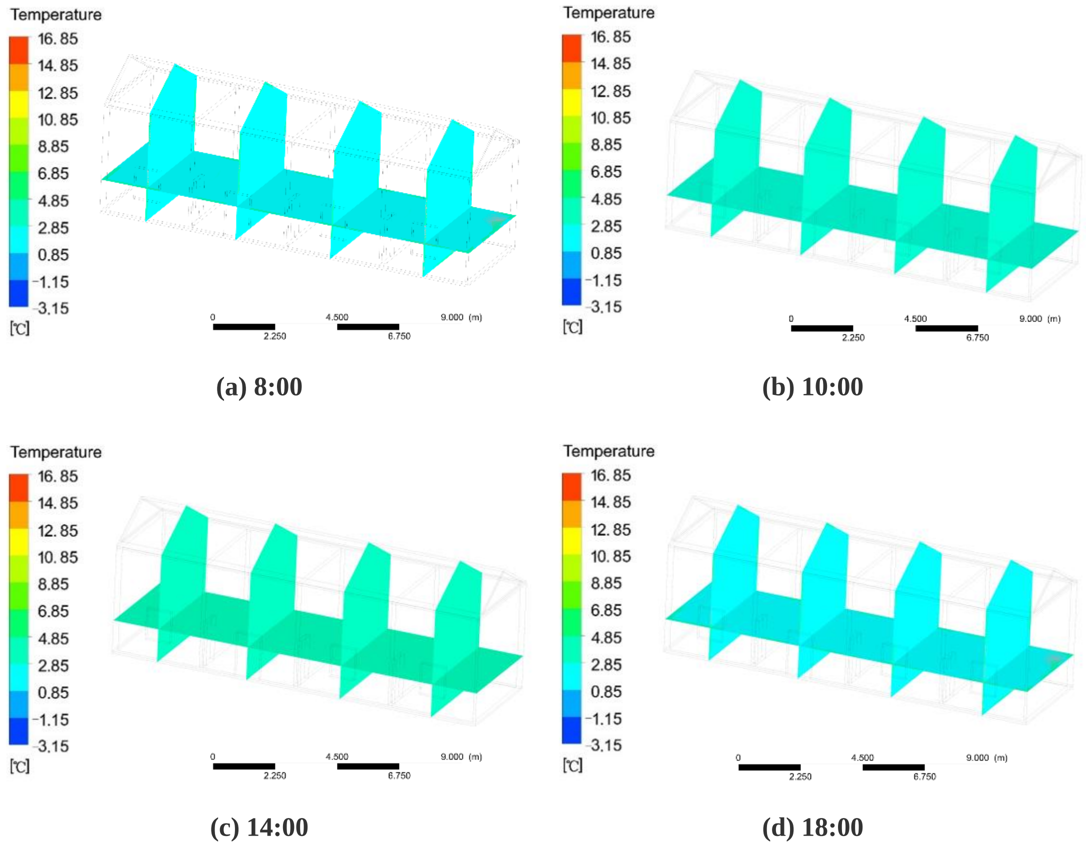
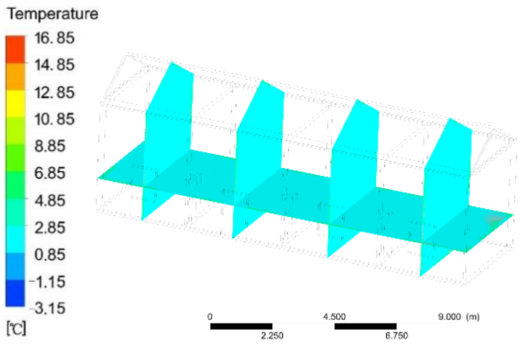


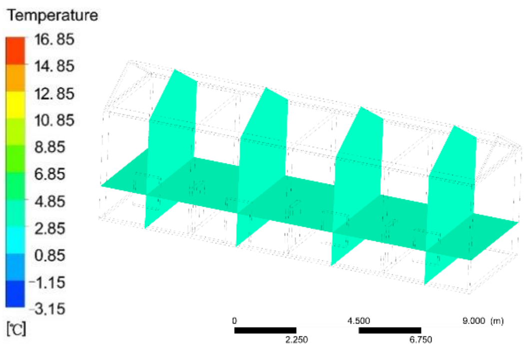
Figure 6-6. (a, b) Indoor temperature conditions from 8:00 to 10:00; (c, d) Indoor temperature conditions from 14:00 to 18:00.

(2) TSWHS without Solar Radiation

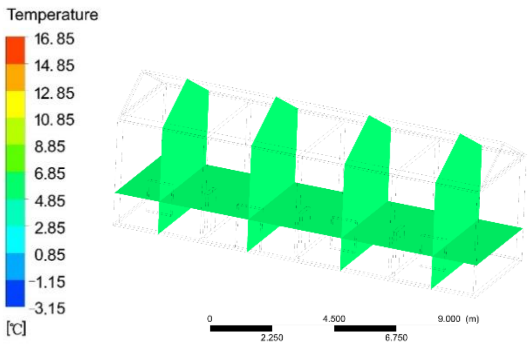
In this case, the temperature gap between the interior and exterior is quite low. TSWHS adds a TSW to the exterior walls of the house. Based on the OHS model, TSW was added to create TSWHS, and then parameters were set and simulated. The simulation resulted in a temperature of 2.7°C-3.8°C at the TSW and a room temperature of 2.9°C-3.9°C between 20:00 and 8:00 at night. The mean temperature at the TSW was 3.9 °C during the period from 8:00 to 20:00 during the day and 3.8 °C during the period from 8:00 to 10:00 in the room (Figure 6-7 a, b). The major cause is due to the very low outside temperature during night time, which greatly affects the interior temperature. The TSW had a mean temperature of 4.3 °C. From 12:00 to 14:00, the average room temperature remained the same with a value of 4.2 °C (Figure 6-7 b, c). From 14:00 to 18:00, indoor household appliances and other heat sources started to be used and the indoor temperature increased slowly. The mean temperature of the TSW was 4.8°C and the mean interior temperature was 4.6°C (Figure 6-7 c, d). The external temperature commenced to drop between 18:00 and 20:00, and the interior temperature dropped accordingly. The mean temperatures of the TSW and the interiors were 4.1 °C and 3.9 °C, correspondingly. If there is no solar radiation, the internal temperature changes little. The mean temperature of the TSW was 3.8 °C and the mean interior temperature was 3.7 °C. The average interior temperature was 0.6 °C above the exterior temperature.



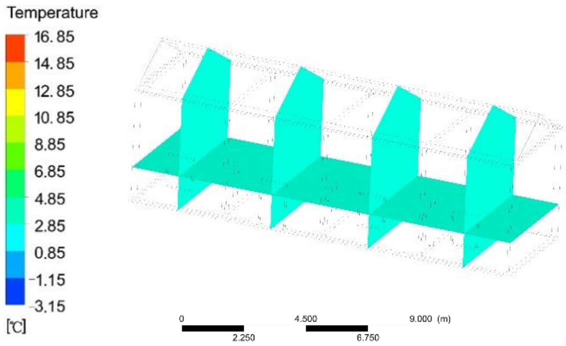
(a) 8:00



(b) 10:00



(c) 14:00



(d) 18:00

Figure 6-7. (a, b) Indoor temperature conditions from 8:00 to 10:00; (c, d) Indoor temperature conditions from 14:00 to 18:00.

(3) Comparison Results

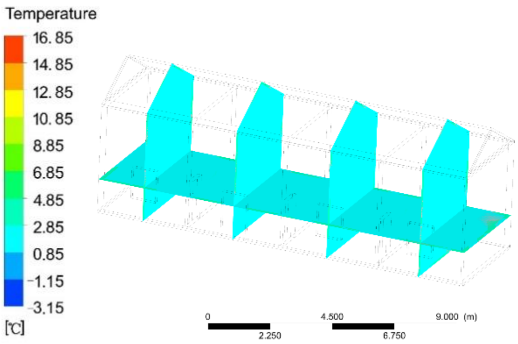
Without sun emission, the interior temperature of OHS and TSWHS has a very little gap with the exterior temperature. When using OHS, the indoor temperature increases by 1.2°C and the heating rate is 0.15°C/h. When the TSWHS was used, the interior could raise 1.3°C and the heating rate is 0.16°C/h. This is because, without sun emission, the interior temperature is mainly affected by the exterior and the heat source is mainly indoor heat disturbance, so the heating rates of both kinds of heating are very low and the enhancement of the interior temperature is limited.

6.3.2 Comparison of OHS and TSWHS with Solar Radiation

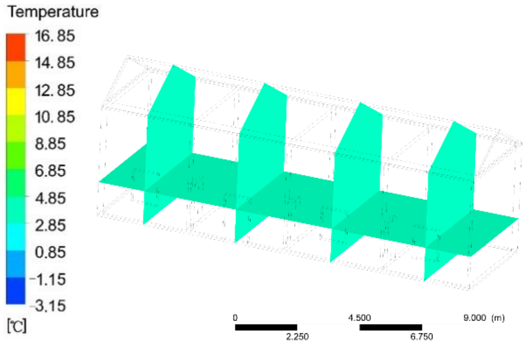
(1) OHS with Solar Radiation

With solar radiation, OHS relies primarily on solar radiation to heat the building envelope to increase the indoor temperature. Simulation conditions and parameter settings are consistent with the case without solar radiation. From 8:00 to 12:00, the temperature of the room increased sequentially from east to west, from the initial 3.5°C to 5.8°C, as the altitude angle of the sun changed. Since the west side of the room received less solar radiation, the temperature increased less (Figure 6-8 a, b). The range of variation in the room temperature is small and the room temperature tends to be stable from 12:00 to 14:00, with an average room temperature of 5.5°C (Figure 6-8 c, d). From 14:00 to 20:00, the west side of the building received more solar radiation.

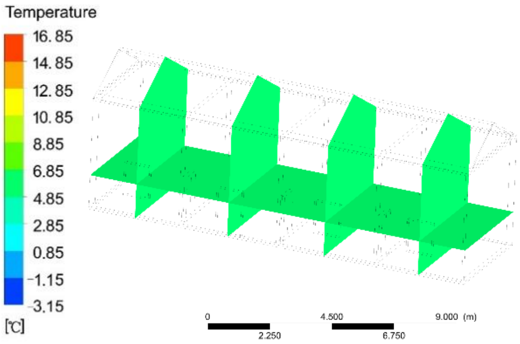
The room on the west side reached the maximum temperature of 5.8°C at 15:00, and then the temperature slowly decreased (Figure 6-8 e, f). At this time, the east side of the building receives less solar radiation, and the room temperature decreases from 5.7°C to 3.8°C. The graph shows that when solar radiation is available, the mean interior temperature at OHS is 5.6°C, which is 2.1°C warmer than the exterior temperature.



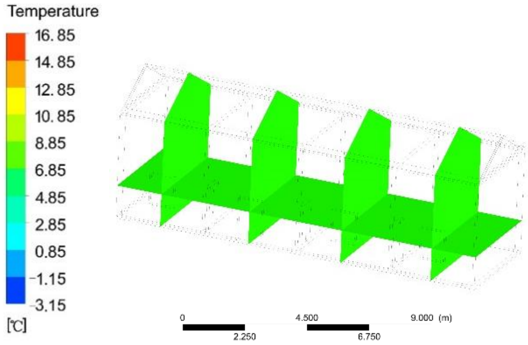
(a) 8:00



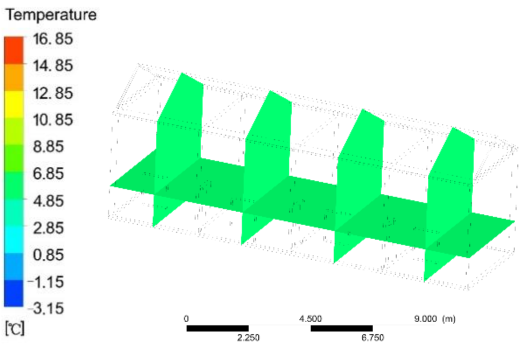
(b) 10:00



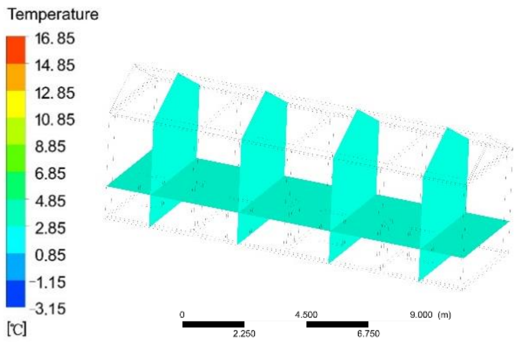
(c) 12:00



(d) 14:00



(e) 16:00



(f) 18:00

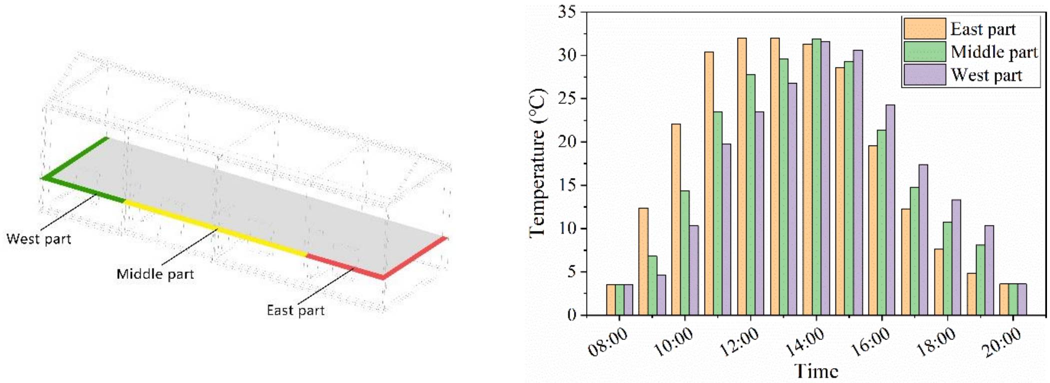
Figure 6-8. (a, b) Indoor temperature conditions from 8:00 to 10:00; (c, d) Indoor temperature conditions from 12:00 to 14:00; (e, f) Indoor temperature conditions from 16:00 to 18:00.

(2) TSWHS with Solar Radiation

To validate the heating efficiency of the TSWHS, the simulation results of the OHS were used as a basis for comparison. The preliminary interior temperature was 3.1°C. The heating process of the TSW is divided into three steps. Firstly, when solar radiation is available, the HDPE temperature and the air temperature inside the glass rise. Secondly, the HDPE heats the inner wall by heat conduction. Finally, the interior wall temperature rises, thus heating the room. Meanwhile, the hot air inside the TSW flows into the room, raising the room temperature by a double action.

Step 1 is solar radiation heating the HDPE and air in the glass layer. The variation of temperature in each direction of the building is slightly different due to the difference in the angle of solar radiation. At 8 a.m., the air inside the HDPE and glass layers is heated. The TSW temperature increases in a stepwise manner from east to west.

To study the temperature evolution of HDPE, the cross-sectional temperature was chosen for the study. The temperature change is such that the temperature of HDPE after receiving solar radiation changes during the day as a result of the change in the azimuth of the sun and the duration of the thermal radiation. The height of the cross-section is 1.5 m above the ground, which is consistent with the height of the human activity space in the room. HDPE was added to the outside of the three side walls of the house at the locations shown in Figure 6-9 a. The temperature variation of HDPE is shown in Figure 6-9 b. The simulation started at 8:00 with an initial temperature of 3.5 °C. At 9:00, the temperatures were 12.4°C, 6.8°C, and 4.6°C on the east, central and west sides, respectively. At 10:00, the temperatures on the east, middle, and west sides were 22.1 °C, 14.4 °C, and 10.3 °C. At 11:00, the temperatures on the east, middle, and west sides were 30.4 °C, 23.5 °C, and 19.8 °C. The temperature achieved the maximum value of 32.0 °C at 12:00. From 12:00 to 14:00, the temperature of the TSW was kept at 32.0°C. From 14:00 to 16:00, the temperature started to drop, and the sun was on the west side of the room, so the temperature of the TSW on the west side was higher than the temperature on the east side. The temperatures of the three parts of the TSW were 25.3 °C, 26.8 °C, and 27.6 °C respectively. At 17:00, the temperatures in the eastern, central, and western rooms were 12.3°C, 14.8°C, and 17.4°C, respectively. At 18:00, the temperatures of the three sections were 7.6 °C, 10.7 °C, and 13.3 °C respectively. At 19:00, the temperatures of the three sections were 4.8 °C, 8.1 °C, and 10.3 °C. The temperature was 3.6 °C at 20:00. From 20:00 to 8:00 the next day, the temperature of the TSW remained the same as the external temperature, which was 3.6°C. The trend of change in the three parts is the same, and the time of the rising phase becomes longer. The eastern wall is the first to receive solar radiation, followed by the central wall, and finally the western wall. The trend of change is the same when the temperature is stable. The decreasing trend of temperature becomes steeper in turn, which is the opposite of the rising phase.

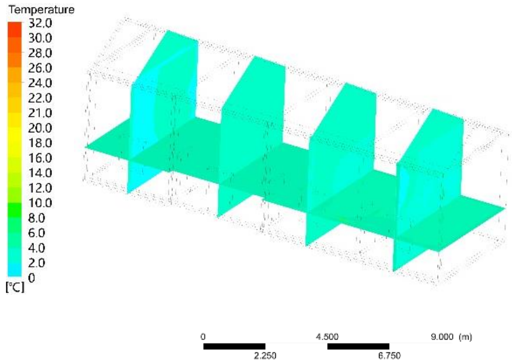


(a) **(b)**

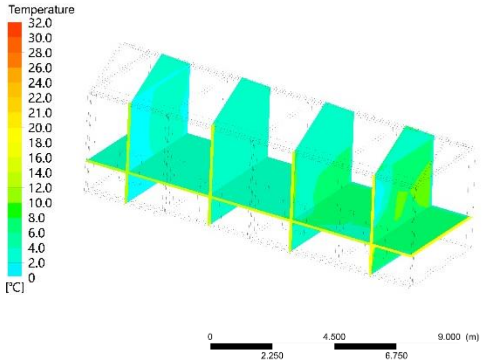
Figure 6-9. (a) Location of HDPE for TSW; (b) Temperature change of the three parts of HDPE for TSW.

Step 2 is the heat transfer from the TSW itself. The principle is that HDPE heats the surface of the exterior wall. After simulation, the temperature of HDPE keeps rising from 8:00 to 12:00. At 13:00, the temperature of the TSW reaches the highest value of 31.6 °C. 12:00-15:00, the temperature of the TSW stays the same at 31.6 °C. 15:00-20:00, the temperature of the TSW starts to drop, and at 20:00 the temperature of the TSW is 3.3 °C. From 20:00 To 8:00 the next day, the temperature of the TSW was 3.3 °C.

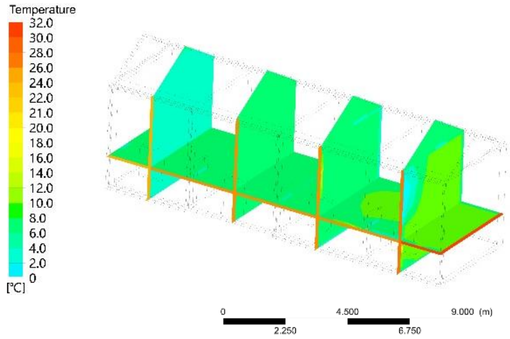
Step 3 is that the interior wall heats the room and the hot air inside the glass flow indoors. The interior temperature changes for 24 hours are as follows: at 08:00, the indoor temperature is 3.5 °C, which is the same as that of the TSW (Figure 6-10 a). At 09:00, the indoor temperatures in the three sections are 5.2 °C, 4.4 °C, and 3.9 °C, respectively. At 10:00, the indoor temperatures in the east, middle, and west sections were 5.9 °C, 4.7 °C, and 4.3 °C respectively (Figure 6-10 b). At 11:00, the indoor temperatures in the three sections were 6.3 °C, 5.2 °C, and 4.6 °C respectively. At 12:00, the indoor temperatures in the three sections were 6.9 °C, 6.1 °C, and 5.5 °C respectively (Figure 6-10 c). At 13:00, the indoor temperatures in the three sections were 7.8 °C, 6.9 °C, and 6.2 °C respectively. At 14:00, the indoor temperatures in the three sections were 8.3 °C, 9.0 °C, and 8.4 °C (Figure 6-10 d). At 15:00, the indoor temperatures in the three sections were 8.3 °C, 9.0 °C, and 8.4 °C. At 16:00, the indoor temperatures in the three sections were 8.2 °C, 8.7 °C, and 9.1°C (Figure 6-10 e). At 17:00, the indoor temperatures in the three sections were 7.5 °C, 7.6 °C, and 8.4 °C. At 18:00, the indoor temperatures in the three sections were 5.2 °C, 5.9 °C, and 6.4 °C (Figure 6-10 f). At 19:00, the indoor temperatures in the three sections were 4.7 °C, 5.2 °C, and 5.6 °C. At 20:00, the indoor temperatures in the three sections were 3.4 °C, 3.5 °C, and 3.6 °C. The indoor temperatures in the three sections were 4.7 °C, 5.2 °C, and 5.6 °C. The interior temperature was maintained at 3.5°C from 20:00 to 8:00 the next day, the same as the exterior temperature.



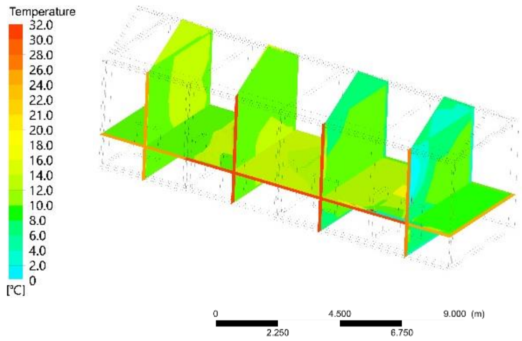
(a) 8:00



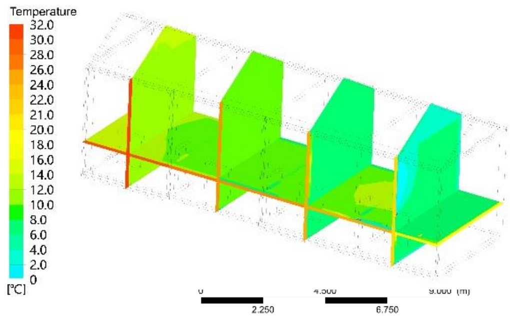
(b) 10:00



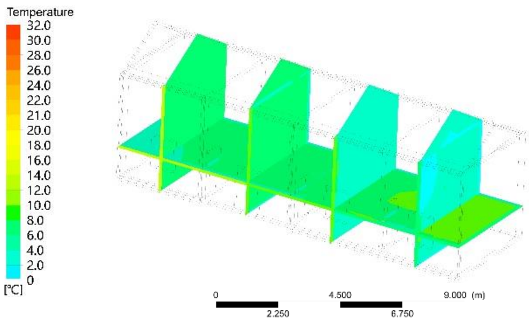
(c) 12:00



(d) 14:00



(e) 16:00



(f) 18:00

Figure 6-10. (a, b) Indoor temperature conditions from 8:00 to 10:00; (c, d) Indoor temperature

(3) Comparison Results

TSWHS is a new green heating system that saves energy and has a good heating effect. TSWHS starts working during the day with solar radiation. The initial indoor temperature is 3.5 °C. After being influenced by solar radiation, the indoor temperature starts to rise at 9:00 with a mean temperature of 4.5 °C. Because of the different amounts of solar radiation received by the three sections of the room, it showed different temperatures. At 15:00, the temperature of the central room reached a maximum value of 9.1 °C, and the average temperature of the three parts of the room was 8.6 °C. The indoor temperature starts to drop at 17:00 with an average indoor temperature of 7.8 °C. The temperature increased by 5.1 °C with an average heating efficiency of 0.64 °C/h. OHS mainly relies on solar radiation heat generation from the walls to influence the indoor temperature, the temperature increased by 2.3 °C with an average heating efficiency of 0.29 °C/h. The TSW heating improved the heating rate and duration effectively compared to the OHS.

6.3.3 Using Time of TSWHS

According to the Chinese building industry design standard [51], the indoor thermal comfort temperature of houses in HSCW zones in winter is defined as higher than 18℃. Accordingly, this study uses 18℃ as the standard value to measure the total time of interior temperature above 18℃ after adopting the TSWHS, to evaluate TSWHS heating and energy efficiency. According to the climatic conditions in southern Shaanxi, the heating time of the TSWHS is concentrated from October to March of the next year. Using EnergyPlus simulation, the use effect of the TSWHS and OHS are evaluated. The results are presented below. The OHS was used in solar radiation for 1023 hours, which is 11.68% of the year. The time of using the TSWHS is 1332 h, accounting for 15.21% of the whole year (Figure 6-11).

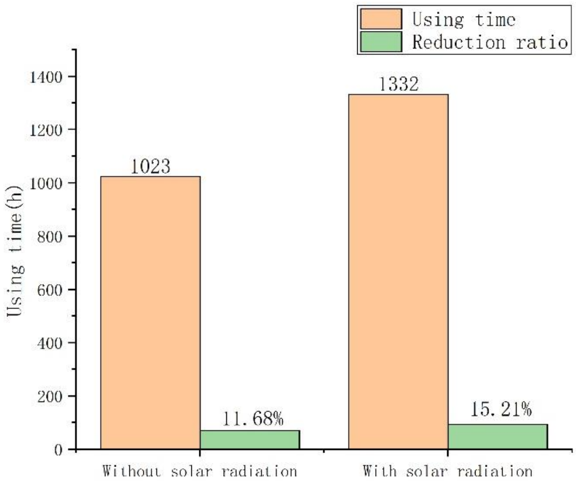
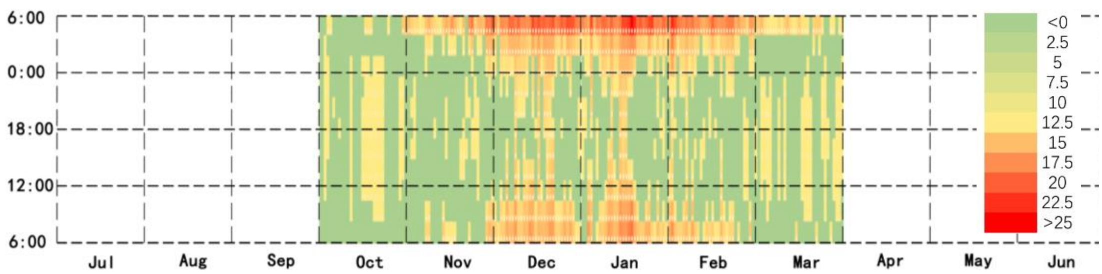


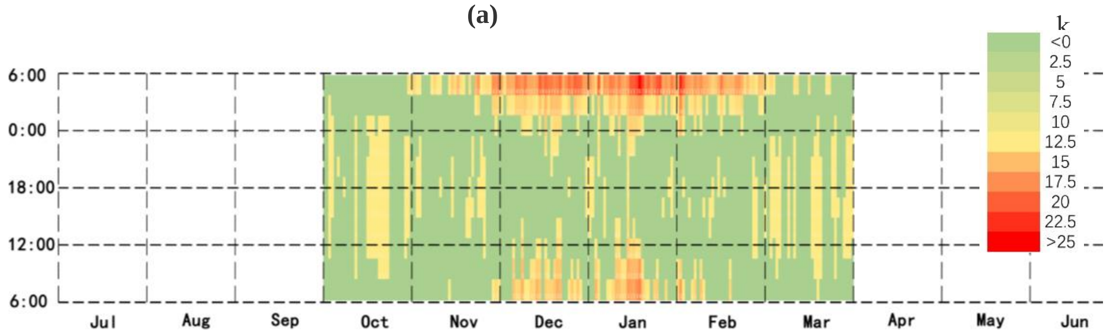
Figure 6-11. Using time of TSWHS.

6.3.4 Analysis of Energy-saving of TSWHS

The annual thermal payload of the house with TSWHS and OHS was calculated using EnergyPlus software simulation, and the result was that the annual thermal payload of the house with OHS with solar radiation was reduced to 625.36 kWh with a reduced rate of 9.87% (Figure 6-12 a). With solar radiation, the annual thermal payload of the house with TSWHS was decreased to 1726.43 kWh with a reduction rate of 27.24% (Figure 6-12 b).



(a)

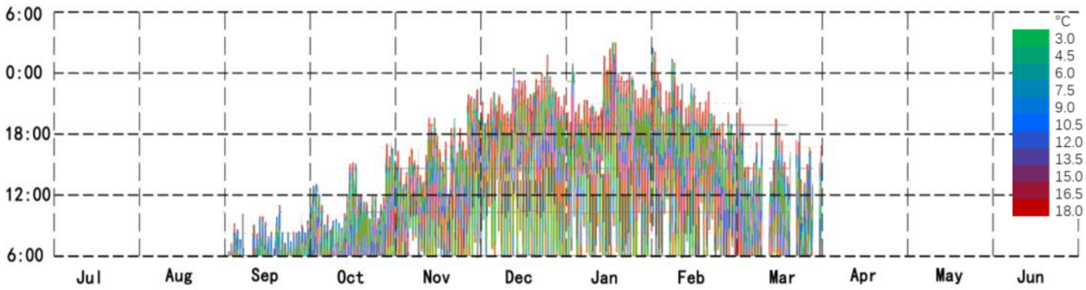


(b)

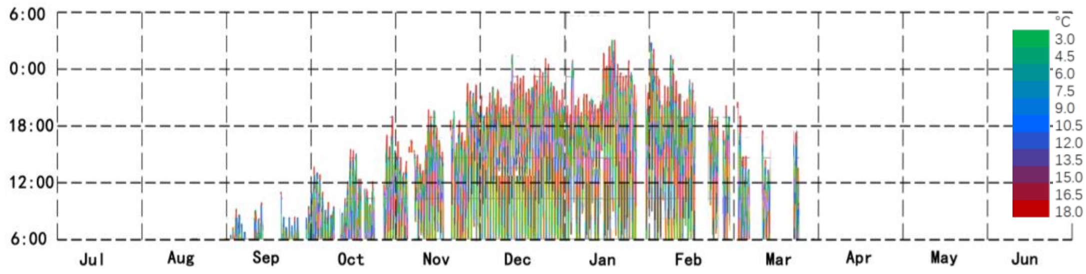
Figure 6-12. (a) Energy consumption of OHS; (b) Energy consumption of TSWHS.

6.3.5 Thermal Comfort Analysis of TSWHS

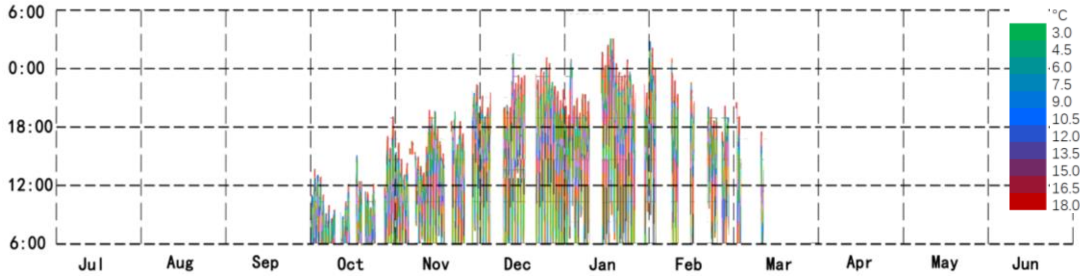
The indoor thermal comfort conditions for OHS and TSWHS with and without solar radiation were obtained by simulations in EnergyPlus. Using 18°C as a standard value for thermal comfort in residential buildings [51], the total number of hours below 18°C throughout the year with TSWHS was calculated, and the advantage of TSWHS was derived by comparing it with the OHS system. Without solar radiation, with the OHS system, the total annual time when the indoor temperature was lower than 18°C is 4806 hours, which is 54.87% of the total annual time (Figure 6-13 a). Without solar radiation, with the OHS, the total annual time when the indoor temperature was lower than 18°C was 4017 hours, which is 45.85% of the total annual time (Figure 6-13 b). With the TSWHS, the total annual time when the indoor temperature was below 18°C was 3645 hours with solar radiation, which is 41.61% of the total annual time (Figure 6-13 c).



(a)



(b)



(c)

Figure 6-13. (a) Analysis of the time below 18 °C with OHS without solar radiation; (b) Analysis of the time below 18 °C with TSWHS without solar radiation; (c) Analysis of the time below 18 °C with TSWHS with solar radiation.

6.4 Application of the system

Traditional houses in hot-summer and cold-winter regions have similar characteristics, including space, structure, function, building materials, building type, and the climatic environment in which they are located. Through simulation analysis, the simulation results of the four types of dwellings are similar, while the climatic environment in hot summer and cold winter regions is consistent, so this study applies to traditional dwellings in hot summer and cold winter regions. It is beneficial for energy saving and indoor winter thermal environment enhancement.

6.5 Discussion

Proper use of solar energy for warming can be effective in reducing building energy depletion. In addition, the thermal retention performance of the enclosure is also an essential factor affecting energy efficiency as well as the effectiveness of indoor heating. This work proposes TSWHS for houses in HSCW, using solar energy for interior heating and installing HDPE insulation, a glazing layer on the outside of the walls, and vents in the exterior walls. The use of insulation and heat storage of PCMs, the greenhouse effect of the glass layers, and the exchange of hot air inside the glass interlayer with cold indoor air through the vents, the room temperature, as well as the effective energy saving, can be enhanced through these three ways together energy saving. To verify the heating effectiveness and energy consumption of TSWHS, TSWHS, and OHS were compared by setting the presence or absence of solar radiation as a boundary condition to prove the effectiveness of TSWHS. Previous studies have focused more on passive designs, such as solar chimneys, Trumbell walls, and air-source heat pumps, or focused on studying the insulation properties of the envelope. To improve both the thermal capacity as well as to solve the limitations of previous studies, passive design has been studied along with the thermal performance of the envelope to further improve heating effectiveness and energy efficiency. As a result of this study could provide a method for winter heating and energy saving in conventional houses in cold winter areas.

There are still some shortcomings in this study, and the cost factors of HDPE and large-area glass are less considered when building retrofitting is carried out. The ease of construction in practice is also not considered, but these factors do not affect the simulation results and can be solved by technical means. In the simulation setup, the starting temperature is assumed to be a fixed value, and the effect of air convection on the room temperature is ignored. However, these factors do exist in reality. In future research, these factors should be further considered, and at the same time, by comparing the thermal insulation performance and cost of different materials, a suitable material should be chosen by the practical situation.

6.6 Conclusions

The challenge and opportunity for passive heating with TSW are to address the problem of cold indoor winter homes and excessive energy consumption in southern Shaanxi, while the region has excellent potential for solar radiation. Of the lack of passive heating design in traditional buildings, the use of solar energy for heating can effectively raise indoor temperatures and save energy. Meanwhile, the thermal insulation of the building envelope and the insulation measures are the most important factors affecting the interior temperature. The innovation of this work is to design a TSWHS that simultaneously achieves daytime heat storage heating, nighttime heat release and extended heating time, and the hot air flow indoors. The heating conditions of OHS and TSWHS were simulated and evaluated using ANSYS and EnergyPlus software, respectively, in terms of usage time, temperature gain, and energy-saving capacity. The study findings are detailed in the following.

1. A new TSWHS is proposed. By installing HDPE material on the outside of the east, west, and south walls of the residential building, the temperature of the HDPE of the TSW increases to heat the room through heat conduction when solar radiation is available. Therefore, heat can be absorbed during the day, and at night by exothermic heat to make the hot air flow indoors, extending the time of TSWHS heating.

2. Proposed a practice of adding glass interlayer outside the wall, so that the glass and the wall between the trip a confined space, using the principle of the sunlight between the greenhouse, so that the air temperature inside the glass interlayer rise, and together with HDPE to heat the room so that the indoor temperature is further increased.

3. Ventilation openings are opened at the top and bottom of the east-west and south exterior walls to make the hot air inside the interlayer exchange with the cold air inside, to enhance the indoor temperature.

4. In the research analysis, with or without solar radiation is proposed as the boundary condition and analyzed by ANSYS and Energyplus software to verify the effectiveness of the TSWHS in terms of heating and energy saving. By comparing TSWHS with OHS, the year-round usage time of the TSWHS as well as the energy savings are discussed in detail. The results were that with solar radiation, the temperature increase with TSWHS was 5.1°C, which is 1.6 times higher than the OHS system. The annual usage time with TSWHS is 1332 hours, which is a 30% improvement compared to OHS. The annual heat load of TSWHS is reduced by 1726.43 kWh, which is a 1.8 times

improvement in energy saving compared to OHS. The annual time below 18°C using TSWHS is 3645 hours, which is 24.16% lower compared to OHS.

6.7 Chapter Summary

This section proposes a thermal storage wall heating system based on the previous section. HDPE thermal storage material and glass layer are installed on the exterior wall, and air exchange ports are opened on the exterior wall. When solar radiation is received, the temperature of the thermal storage material and the air temperature inside the glass layer increase, and the indoor temperature is raised by the dual system of heat transfer and air heat exchange. Through simulation analysis and comparison, it is concluded that it has certain advantages in heating and energy saving.

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Chapter 7. Optimization and Application of Solar Thermal Storage Heating systems

7.1 Optimization of Solar Thermal Storage Heating Systems

Through simulation analysis and comparison with the current indoor temperature, it can be concluded that the solar thermal storage heating system is beneficial for the improvement of the indoor thermal environment and energy saving of traditional residential houses in winter. However, there are still some aspects that can be optimized to make the system perfect and have a better effect on the improvement of indoor temperature and energy saving. The design of the envelope of the residential building has a decisive role in energy-saving of the residential building, and its main components include the exterior walls, roof, ground, doors, and windows. After research, it is found that the entrances and exits, roof structures, and windows of residential buildings have no thermal insulation measures, the thermal insulation effect is poor, and the indoor heat loss in winter is serious. Therefore, the following optimization strategies are proposed for these problems.

7.1.1 Door Insulation Design

Most of the traditional residential houses in southern Shaanxi use thick and heavy walls as the outer envelope structure, which reduces heat loss due to its large thermal resistance making it difficult for indoor heat to be transferred out through the walls. However, thin and light structures such as doors, windows, and roofs become the main factors affecting the indoor thermal environment of residential buildings in winter. Therefore, measures to improve the winter thermal insulation performance of residential buildings should also be set in reasonable entrances and exits and doors and windows with good thermal insulation performance. If the entrance and exit are set in the north direction of the building, a large amount of cold air will enter the room when the door is opened in winter, making the room temperature of the residence drop 1~3℃, and the heat consumed can reach 10% of all heating energy consumption. Therefore, the first step is to take measures to prevent cold air invasion at the entrance and exit. Traditional residential exterior doors are mostly single and double doors, with poor sealing of wooden doors, and cold wind intrusion is more serious. According to the heat transfer coefficient and thermal resistance of different doors and windows, it is recommended to use aluminum alloy doors and plastic steel doors with better sealing effect.

Specific measures to improve the airtightness of the door and window openings can be roughly the following: fill the gap between the door and wall with efficient insulation materials, and then sealed with sealing paste; or around the door with felt plugging or installation of brush sealing. Use foam seal, and rubber strip to seal the gap between the window frame and the window, the return air slot, high and low joints, etc. should also do the same treatment. Through these measures, the penetration rate of cold wind through the gaps between windows and doors can be reduced by 75%, and the indoor temperature can be increased by 2~3℃ accordingly.

7.1.2 Roof Insulation Design

The roofs of traditional houses are mostly tile combinations, and their air tightness is relatively poor, while the attic of the roof is not completely closed, and the indoor heat is easily lost from the place. The insulation effect has a great impact. Of course, demolition will be replaced by tiles, replaced by insulation performance and good airtightness of the roof material are not desirable, one is the high cost, and the second is the construction is difficult, for the traditional residential style has also been changed. The energy-saving renovation of the wooden roofs of residential houses in southern Shaanxi Province can be based on the actual situation by choosing the appropriate renovation methods.

① When there is no indoor ceiling and no insulation on the roof, a keel ceiling is made on the original roof frame, and then loose insulation material or block polystyrene board is added to the ceiling. The additional ceiling layer needs to have good durability and fire resistance and can load the weight of the insulation layer. The air interlayer formed after the renovation can well improve the indoor thermal environment and solve the heat insulation problem in summer at the same time. After setting the ceiling, a vapor barrier should be made with thick plastic or oil paper under the insulation material to prevent vapor penetration, and ventilation windows should be opened on the mountain walls at both ends of the house.

②When there is a suspended ceiling indoors and no insulation on the roof, and the ceiling can load the weight of the insulation layer, open a manhole on the surface of the ceiling and add a block of polystyrene board or loose light insulation material through the manhole on the ceiling.

7.1.3 Window Insulation Design

Wooden windows and doors are still the main forms, but they are gradually eliminated due to the lack of corrosion resistance and short life cycle. In recent years, plastic steel windows and doors and aluminum alloy windows and doors have been used in housing renovation, and although plastic steel windows and doors have relatively good heat insulation performance, they are not commonly used in traditional houses. Wooden windows are generally in the form of casement windows, which will be deformed during long-term use, resulting in poor closure, forming cold air infiltration, and reducing indoor thermal comfort. Some windows in residential buildings will add a layer of plastic film or paste the window seam in winter to reduce cold air infiltration; plastic steel windows and aluminum windows are generally opened in a push-pull manner, and the sealing performance of plastic steel windows is relatively good. The survey found that the exterior windows of residential houses in southern Shaanxi generally use single-layer glass windows, and most of them use an ordinary single-layer glass of 3-5mm thickness, which has a very small thermal resistance and poor heat insulation effect. Because of the current situation, consulting relevant information and specifications, it is more appropriate to choose aluminum single-pane windows with single-frame double glass.

7.2 Application of Solar Thermal Storage Heating Systems

Traditional dwellings in hot-summer and cold-winter regions have similar characteristics, including space, structure, function, building materials, building type, and the climatic environment in which they are located. By simulating and analyzing four different types of residential houses, the simulated indoor temperature results are similar, while replacing other different geographical locations, the results are also consistent. Therefore, this study applies to traditional houses in hot-summer and cold-winter regions. It is beneficial to energy saving and improvement of the indoor thermal environment in winter. For the residential houses in this climate zone, the application strategies of solar thermal storage heating systems are as follows.

1. Adding heat storage walls to the exterior walls

For traditional residential houses, heat storage walls are added outside the east, west, and south exterior walls, and the detailed practice is described in Chapter 6. When receiving solar radiation, the temperature of HDPE material rises, while the air inside the glass layer also rises, heating the room through the air exchange port. The double heating effect, makes the indoor temperature rise.

2. Roof skylights and attic panels to increase heat storage materials

The roofs of traditional houses are opened with skylights to increase the light area, and the heat storage materials on the attic panels receive solar radiation, thus increasing the temperature, which in turn raises the indoor temperature.

3. Connecting with the room on the south side

Since the heat storage wall is located on the south side, the room on the south side rises first. If a traditional house has multiple rooms in the north-south direction, the room on the north side can be connected to the room on the south side, thus increasing the temperature of the room on the north side.

Chapter 8. Conclusions and Prospect

8.1 Conclusions

This study investigates the indoor thermal comfort and energy consumption of residential buildings in hot-summer and cold-winter regions of China, and through theoretical studies and code comparisons, the problems of poor indoor thermal comfort, high energy consumption, and lack of exterior wall insulation design are derived. Two solar heating systems are proposed through theories of thermodynamics, solar technology, and thermal performance of thermal storage materials. HDPE is selected as the thermal storage material to enhance the indoor temperature and extend the heating time. And through simulation as well as energy consumption calculation, the effectiveness of the heating system in terms of heating as well as energy saving is derived. The relevant conclusions are as follows.

Traditional Houses in southern Shaanxi are the research objects of this study. To raise the indoor temperature, the roof solar heating storage system is proposed. First, we establish the roof solar heating storage system and changed the roof to a partial glass roof, so that the attic slab received the heat radiation from the sun. So, to improve the heat storage effect of the attic floor, HDPE was installed on the attic floor. At the same time, the heat storage material polyethylene was added to the attic floor. Second, the heating time and temperature change of the basic heating system and the new system were calculated and simulated by software. Finally, the results of the influence of the two heating methods on the indoor temperature were compared. The roof solar heating storage system can raise the indoor temperature, and the following conclusions were drawn:

1. Using the thermal storage roof pool solar heating system, the indoor temperature increased by 4.9 °C with solar radiation, and the mean heating efficiency was 0.82 °C/h. The indoor temperature increased by 1.4 °C without solar radiation, and the mean heating efficiency was 0.16 °C/h.

2. Using basic heating, the interior temperature increased by 2.5 °C with solar radiation, and the mean heating efficiency was 0.42 °C/h. The indoor temperature increased by 1.1 °C without solar radiation, and the mean heating efficiency was 0.12 °C/h.

3. The time spent using the solar heating system was mainly distributed in January, February, March, November, and December. The solar energy system was used for 807h all year without solar radiation, accounting for 9.16% of the whole year. The time spent using the new system in the whole year was 1141 h with solar heat radiation, accounting for 12.95% of the whole year.

4. The annual heat load of the new system was reduced by 517.84 kW·h without solar radiation, and the reduction ratio was 9.51%, while it was reduced by 1361.92 kW·h with solar radiation, and the reduction ratio is 25.02%.

5. Taking 18 °C as the limit of indoor thermal comfort, we calculated the time when the new system was below 18°C. Under the condition of basic heating, the time when the temperature of the building was lower than 18 °C was 5019 h, accounting for 56.98% of the year. When the solar

energy system was adopted, the time when the interior temperature was lower than 18 °C is 4006 h without solar radiation, accounting for 46.36% of the year. The time when the temperature was lower than 18 °C all year was 3763 h with solar radiation, accounting for 43.55% of the year.

TSWHS is proposed for the problem of cold interiors and excessive energy consumption for Traditional houses in southern Shaanxi in winter. The heating conditions of OHS and TSWHS were simulated and evaluated separately using software, covering the usage time, temperature increase, and energy-saving capability. The reliability and practicality of TSWHS are also discussed in depth, and the following conclusions are drawn.

1. With TSWHS, the room temperature increased by 1.3°C on average over the original temperature without solar radiation, with an average heating efficiency of 0.16°C/h. With solar radiation, the room temperature increased by 5.1°C with an average heating efficiency of 0.64°C/h.

2. In the absence of solar radiation, the room temperature increased by 1.2°C with an average heating efficiency of 0.15°C/h. With OHS, the room temperature increased by 2.0°C with solar radiation with an average heating efficiency of 0.25°C/h.

3. According to the climatic conditions in southern Shaanxi, the heating time of TSWHS is mainly concentrated in winter and spring. The effectiveness of using TSWHS was evaluated by simulation. The results are as follows. In the absence of solar radiation, the heating time using TSWHS is 1023 hours, which is 11.68% of the year. In the presence of solar radiation, 1332 hours were used, accounting for 15.21% of the year.

4. The annual heat load of TSWHS was simulated by software. The result is that in the absence of solar radiation, the annual heat load of the house is reduced to 625.36 kWh with a reduced rate of 9.87%. The annual heat load reduction of the building with TSWHS in the presence of solar radiation was 1726.43 kWh, a reduction rate of 27.24%.

5. The indoor thermal comfort conditions of OHS and TSWHS with and without solar radiation are obtained by simulation as shown in Figure Using 18°C as the standard for the thermal comfort value of the building, the time that the system is below 18°C is calculated. With OHS in the absence of solar radiation, the time when the indoor temperature is below 18°C is 4806h, which is 54.87% of the total time of the year. In the case of solar radiation, the time when the room temperature is below 18°C is 3645h, or 41.61% of the total time of the year, when using the thermal storage wall system. In the absence of solar radiation, the time when the room temperature is below 18°C is 3929h, accounting for 44.85% of the year.

8.2 Prospect

Proper use of solar heating can effectively reduce building energy consumption. In addition, the insulation performance of the envelope is an important factor that affects the energy efficiency as well as the effectiveness of indoor heating. This work proposes a solar heating system for houses in the HSCW, using solar energy for indoor heating, with HDPE insulation installed on the outside of the walls or above the roof attic panels. Using the insulation and heat storage of PCMs can increase the room temperature as well as save energy effectively. To verify the effectiveness and energy consumption of the solar heating system, the effectiveness of the new system was demonstrated by setting the presence or absence of solar radiation as a boundary condition to compare the new system with the status quo heating. Previous studies have focused more on passive designs, such as solar chimneys, Trumbell walls, and air source heat pumps, or have focused on studying the insulation performance of the envelope. To improve the thermal capacity as well as address the limitations of previous studies, the thermal performance of the envelope was studied along with the passive design to further improve heating effectiveness and energy efficiency.

This study still has some shortcomings in that the cost factors of HDPE and large-area glazing are less considered when performing building retrofits. The difficulty in actual construction was also not considered, but these factors do not affect the simulation results and can be solved by technical means. In the simulation setup, the starting temperature was assumed to be a fixed value and the effect of air convection on the room temperature was ignored. However, these factors do exist in reality. In future studies, these factors should be further considered, and at the same time, suitable materials should be selected according to the actual situation by comparing the insulation performance and cost of different materials.

In future research, more attention should be paid to the following points.

1. Based on the climatic conditions of different regions and the actual situation in winter, the appropriate PCMs should be selected by considering the thickness, type, cost, and actual construction difficulty of the thermal storage materials.

2. Other energy-saving design methods can be added to the system, such as internal wall insulation, window-to-wall ratio, and a combination of other green energy sources, to make the system more energy-efficient.

3, the results of this study need to be verified in actual cases and the system should be made better by repeated comparison between theory and practice.