DOCTORAL DISSERTATION

Mechanism of Cold Alley and Passive Energy Saving in Traditional Settlement in Southern Shaanxi

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Abstract

China's building energy conservation study and implementation are mainly concentrated in urban areas, but according to 2016 statistics, the rural population accounts for 42.65% of the total population, and the potential for energy conservation in rural housing is huge. However, the importance of energy consumption in rural residential buildings needs to be increased. Chinese rural houses are mostly courtyard-style independent houses. This type of house has the characteristics of small interaction between houses, strong flexibility in renovation, and easier use of the natural environment to develop passive energy conservation. Therefore, rural houses have great potential for energy saving. In this study, firstly, using wind speed, wind direction and turbulence intensity values as evaluation indicators, the ventilation performance of villages with complex architectural layouts was studied. SKE, RNG and RKE solvers are used in the CFD-3D steady-state Reynolds average navier-stokes (RANS) to simulate the wind environment of the village. For the simulation of the rural wind environment with complex building layout, it is necessary to evaluate the steady-state simulation solver in detail to verify its accuracy. Therefore, taking a village with a complex architectural layout in Shuhe Town, southern Shaanxi as a study case, three steady-state simulation solvers are used to evaluate the ventilation performance of the village. Compared the simulated data with the measured data to find the most suitable solver for this kind of village wind environment simulation. The results show that the SKE solver should be the first choice for simulating wind environment distribution.

Secondly, the cold alley between buildings were used for the first time as an energy source for passive cooling and ventilation. Traditional houses in Shuhe, China were used as a case study. The cold air in the cold alley is ventilated by hot pressure, and is introduced into each room by the accumulation effect of the corresponding patio, which greatly improves the indoor ventilation efficiency.

Finally, on the basis of the original cold alley ventilation and cooling, a further in-depth study was carried out. In order to have better ventilation and cooling effect in the room, connect the two sides of the patio to the room with air pipes to improve the cooling efficiency. Study variables include the presence or absence of wall heat radiation (WHR), and verify the importance and influence of wall heat radiation on indoor conditions. The cold air trapped in the new system forms an air partition wall, which effectively blocks the direct influence of solar radiation on the room, reduces the heat transfer rate of the residential wall, and consumes part of the heat. In winter, based on the use of air ducts as supporting members, a glass roof is added to the patio to improve the heat storage capacity of the patio and turn it into a constant temperature heater to heat the interior of the building.

Keywords: traditional houses; passive renovation; building ventilation; building energy saving; ventilation and cooling; reliability verification

Contents

List of Figures

List of Tables

List of Abbreviations

1.Standard k—ε (SKE)
2. Renormalization Group k—ε (RNG)
3. Realizable k—ε (RKE)
4. Wall Heat Radiation (WHR)
5. Computational Fluid Dynamics (CFD)
6. Large Eddy Simulation (LES)
7. Unsteady-State Reynolds-Averaged Navier-Stokes (URANS)
8. Steady-State Reynolds-Averaged Navier-Stokes (RANS)
9. Heat Transfer Simulation (HTS)
10. Urban Heat Islands (UHIs)
11. Nitrogen Dioxide (NO2)
12. Carbon Dioxide (CO2)
13. Energy Simulation (ES)
14. Building Energy Simulation (BES)
15. Phase-Change Material (PCM)
16. Ground Source Heat Pump (GSHP)
17. Energy Efficiency Ratio (EER)
18. Coefficient of Performance (COP)
19. Domestic Hot Water (DHW)
20. Natural Ventilation Augmented Cooling (NVAC)
21. Dynamic Insulation Material and System (DIMS)
22. Phase-Change Material-Dynamic Insulation Material and System (PCM-DIMS)
23. Exhaust Air Insulation (EAI)
24. Gross Domestic Product (GDP)
25. Night Ventilation (NV)
26. Transparent Radiant Cooling(T-RC)
27. Sick Building Syndrome (SBS)
28. Predicted Mean Vote (PMV)
29. Root Mean Square Error (RMSE)
30. Coefficient of Determination (R2)
31. Physiological Equivalent Temperature (PET)

Chapter 1. Introduction

1.1 Research background

The world's population reached 7.442 billion in 2016 [1]. Industry, agriculture, transport, and infrastructure need to accelerate to meet the needs of this huge population. With the substantial population growth, total energy consumption is also increasing. Commercial, residential, and public energy consumption accounts for approximately 30–40% of global energy consumption [2]. Among the various uses of energy, its use in buildings has become one of the most energy-consuming practices in the world [3]. Currently, carbon emissions caused by the construction and use of buildings will increase by 50% by 2050 [4]. Increased carbon emissions is an important cause of global warming. In this environment of global warming, the requirements for indoor cooling are gradually increasing [5]. In recent years, the rise in sales of air-conditioners, which can be used to cool effectively, has led to a vicious cycle of higher carbon emissions [6]. This situation is more obvious in developing countries, because some of them are in the process of large-scale urbanization. China is a typical example. In China, energy consumption related to construction accounts for 44.7% of the total energy consumption each year, and carbon emissions account for about 30% of the national total [7]. However, these data are still rising. It is estimated that by 2050, China's building energy consumption and carbon emissions will be double the current levels [8].

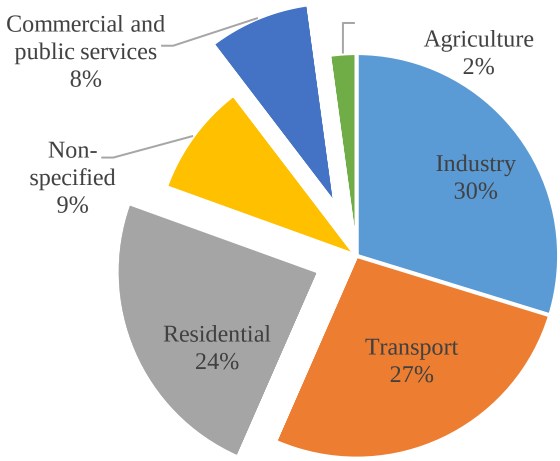

Figure 1-1. Total final consumption (TFC) by sector, World 2016

Under the influence of the rapid development of urbanization, the energy consumption of single families is also increasing annually, and as early as 2011, individual lifetime energy consumption exceeded the total energy consumption of various factories in China [9]. Based on this phenomenon, the issue of energy-saving for family residences has attracted the attention of domestic and foreign scholars. In recent years, China and most countries in Asia have focused on researching various energy-efficient houses, such as low-carbon, green energy-saving, and smart buildings [10]. However, even though scholars and architects have made a lot of effort in this area, the expected goals have not been fully achieved [11].

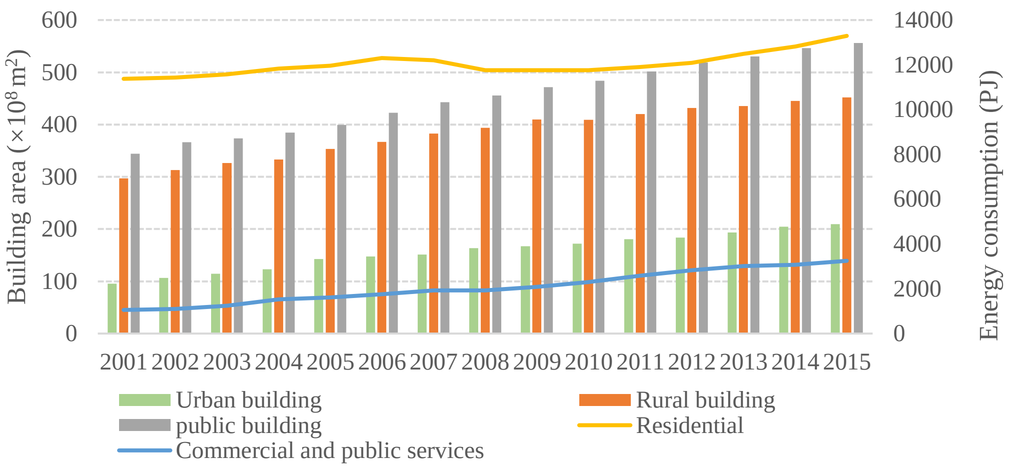

Figure 1-2. Changes in building area and related energy consumption (2001-2015).

Many scholars have paid attention to the energy-saving problem of urban residential buildings. According to the standards of different cities, relevant building codes, laws, and regulations have been formulated to limit certain amounts of energy consumption. However, most villages have a vague awareness of residential energy savings. As of 2016, the rural population in China accounted for 42.65% of the total population [12], so the energy-saving potential of rural houses is also considerable. With the development of the rural economy in China in recent years, housing conditions and quality of life have gradually improved along with the increase in energy consumption. From another perspective, rural residences are essentially different from urban residences. Urban residences are mostly centralized high-rise buildings, while rural residences are mainly independent courtyard buildings. Courtyard residences are usually centered around a patio and surrounded by four buildings. Passive energy-saving in urban high-rise buildings is more difficult, because once the building is completed, the difficulty of renovating will increase significantly. As for independent courtyard houses in the countryside, reconstruction requires relatively less energy, time, and cost, and can be conducted with great freedom [13]. Moreover, rural houses are closer to nature and can make more effective use of passive energy-saving factors brought by the surrounding natural environment. In order to improve the comfort of indoor living in the countryside, this study focuses on establishing a completely new system for the purpose of passive ventilation and cooling of courtyard houses in summer.

According to the current situation of residential buildings in China's rural areas compared with urban areas, there are large differences in basic facilities, with high-energy consumption and low utilization rates. They have a single ventilation method, low clean energy usage, insufficient indoor thermal comfort, and a lack of corresponding industry technical standards [14]. Therefore, it is necessary to apply the related technology and experience of passive energy saving for modern buildings in traditional courtyard-style buildings. However, from the perspectives of protecting regional characteristics, conforming to nature, inheriting culture, improving living quality, and protecting the ecological environment, traditional residential courtyards have their own unique characteristics, which are precisely what modern architecture lacks [15]. With the continuous changing of the social background, modern architecture continues to develop rapidly toward a deeper level, mainly including aspects such as architectural composition systems, material changes, spatial forms, and traditional cultural development [16]. However, due to the inadequacy of related theories and the abuse of technology, the current architecture in the process of transformation has shown the problems of ignoring characteristic regional cultures, abandoning ecological advantages, and adopting uniform design techniques [17]. Therefore, while exploring how to design passive energy-saving equipment in combination with local climate and environmental conditions for traditional residential houses, it is also necessary to introduce ecological energy-saving concepts into modern architectural design, which also has practical value. In terms of academic value, proposing an optimization strategy for a passive energy-saving system for traditional residential buildings also provides some references for future research of modern residential buildings. This has great practical significance for the sustainable development of the new generation of modern rural residential buildings.

1.2 Research purposes

We used complex rural settlements as a study case and adopted a research method of comparing measured data with simulated data to address the following goals of this study:

- Using wind speed, direction, and turbulence intensity as reference factors, discussing the deviation in the results of the three steady-state solvers (SKE, RNG, and RKE), and finding the simulation solver with the smallest deviation.
- Analyzing the causes of deviation in the solver in terms of overall, local, and vertical directions.
- Choosing the most suitable solver for the simulation of complex rural settlement wind environments.

To reduce the energy consumption of traditional residential buildings and improve the living comfort of residents, this study designed a new type of passive energy-saving system. After conducting a multi-faceted comparative analysis of the basic case and of traditional houses after the new system had been added, the following points were considered as the specific objectives of the study:

- By comparing the effects before and after adding thermal insulation walls in traditional residential buildings, we estimated the annual cooling load reduction from using thermal insulation walls in summer.
- The cooling effects of a base case and of a building using the passive system were examined without considering the WHR, aiming to calculate the cooling efficiency inside the building, thermal equilibrium temperature, and reduction of the cooling load for the entire building throughout the year.
- The cooling effects of the new system with and without WHR were compared, in addition to the room cooling rate, thermal equilibrium temperature, and annual cooling load reduction for the entire building.
- Based on comparing the heating effects of a courtyard with or without a glass roof in winter, we estimated the time required for a patio to meet the required heating conditions and reduce the total heating load throughout the year.

The appropriate utilization time for the new passive system over a year was calculated.

According to a local comfort temperature standard, the annual time required to meet the comfort temperature requirement for the base case was estimated, and the annual times required to meet the comfort temperature standard after using the new system with and without WHR were compared.

1.3 Literature review

1.3.1 Settlement ventilation

With the development of CFD technology, more scholars are using fluid simulation to analyze the ventilation performance of a settlement to change and re-establish the microclimate of the area. The wind inside a settlement and the surrounding wind environment can be altered to better cater to the geometric characteristics of the settlement and change the status of the area's thermal environment. Yi et al. [18] proposed an idealized high Reynolds numbers porous media urban model combined with multi-scale computational fluid dynamics (CFD) to quantify urban ventilation and air permeability under geostrophic wind conditions. The air permeability of the city was evaluated based on the hourly rate of air change (ACH) and the age of the air. The contribution of five factors to urban heat islands and air quality was qualitatively and quantitatively analyzed. Chao et al. [19] developed a city-scale indoor and outdoor computational fluid dynamics (CFD) coupling model and defined a novel ventilation index to evaluate the potential of natural ventilation. First, they developed a coupled CFD model to study wind cross-ventilation in high-density cities. Secondly, six key design variables were used to generate 3840 parameter design changes for the evaluation of natural ventilation. Finally, a novel comprehensive index (indoor and outdoor interaction coupling) was constructed to evaluate the wind speed ratio between the indoor area and the outdoor reference area. Luo et al. [20] studied the parameters of the ideal city model based on CFD. Taking Tokyo, Japan; Los Angeles and Phoenix, the United States; and Hong Kong as the research objects, the potential of slope flow for urban ventilation in mountainous areas without background weather was studied.

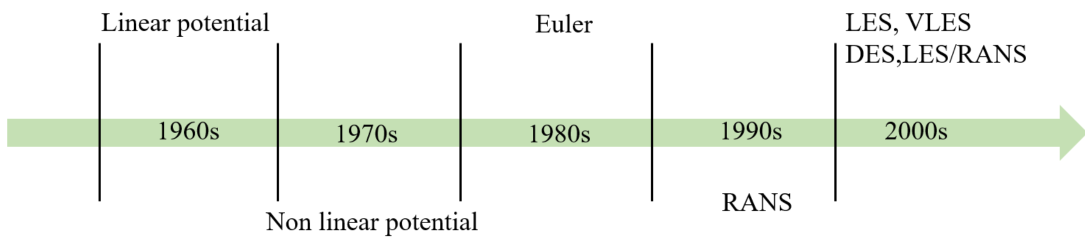

Figure 1-3. Historical progress of CFD research.

Cold alley ventilation is an integral part of the ventilation in urban canyons. In densely populated cities, the possibility that cold alleys exist is higher due to the shortage of land and the small spaces between buildings. Building spacing is a very important factor that urban planners and architects need to consider, because for a given building height, a larger space will induce more wind in the urban canyon, thereby improving the ventilation process [21]. Chen [22] conducted a large-scale outdoor measurement in Guangzhou, China, in the summer of 2017, and suggested that the street aspect ratio and urban heat storage largely determine the urban thermal environment. This research provides direct evidence for how urban structures affect the urban climate, and also suggests the possibility of controlling the outdoor thermal environment by optimizing urban forms and heat storage. Ai [23] used a computational fluid dynamics (CFDs) simulation to study the unilateral natural ventilation induced by wind in buildings near a long street canyon with vertical wind. This research improved the understanding of natural ventilation of urban buildings, providing information for urban planning and building design. In order to improve the heat dissipation in forced convection, Allegrini [24] studied different roof shapes and heights and changed the lengths of street canyon buildings. The results showed that lateral flow can be found in street canyons with uneven building heights, and the air temperature in street canyons is reduced due to improved ventilation. Hadavi [25] proposed that the layout of urban communities will affect the wind flow pattern and permeability in the built environment, and ultimately affect the local thermal comfort and energy consumption of buildings. The penetration rate of wind in low-rise residential buildings was quantified by using CFDs.

1.3.2 Pollutant diffusion path tracking

CFD has also significantly contributed to the tracking of the diffusion path of air pollutants in the settlement and reduction of pollutant concentration. Lingjie et al. [26] proposed a new type of circulation system, using the rubber refining process as an example, to concentrate pollutants and reduce exhaust gas. A circulating ventilation model based on mass balance was established to predict the changes in pollutant concentration in the system, and two control strategies (i.e., continuous or intermittent exhaust schemes) were developed to improve the pollutant capture efficiency of the system. The emission intensity of pollutants in the rubber refining process was measured and used as a boundary condition in the subsequent simulation. CFD simulation was used to optimize the circulating air volume, return air angle, and exhaust volume of the circulating system. Lauriks et al. [27] used CFD to analyze the level and distribution of pollutants in a part of Antwerp's main road artery (Belgium, Europe). Erfan et al. [28] investigated the influence of the cross-sectional shape of a building on the diffusion of air pollutants around the isolated building. Based on detailed wind tunnel experimental data, a CFD model was developed and verified. Compared to the RANS model, the LES model was found to have higher consistency with the experimental results, especially in terms of replicating the pollutant diffusion characteristics related to the interaction of the wind structure. Jiang et al. [29] used CFD to simulate the changes in neighborhood microclimate and pollutant diffusion distribution under different weather conditions and proposed three strategies for the optimization of urban planning to alleviate air pollution. Fabiana et al. [30] investigated the impact of different urban block types on the diffusion of urban pollutants. Using computational fluid dynamics technology, five types of real cities were studied: single, independent buildings, central courtyards, internal courtyards, and determinant layouts. Numerical simulations were conducted using the unsteady-state reynolds-averaged navier-stokes (URANS) equation and the SST model to express the turbulence effect.

1.3.3 Solver accuracy verification

The verification of the simulation accuracy of various solvers in CFD software also plays a decisive role in the study and analysis of wind environments. Tatsuhiro et al. [31] used Hygrabe2D coupled with heat transfer simulation (HTS) to calculate indoor surface temperature, and the convection and convective heat transfer coefficients between regions are calculated using CFD and transferred to heat transfer simulation (HTS). The accuracy of the proposed method was verified. Mohammad et al. [32] focused on carefully separating patches with different thermal characteristics or directions to capture their impact on a cooling device. Their numerical simulations were verified by performing field measurements. The results clarified the key role of wind patterns in reducing or intensifying local urban heat islands (UHIs). The methods provided by Chao et al. [33] can answer questions encountered by wind energy consultants and architects, especially in terms of input boundary conditions, simulation modeling, model verification, and data collection and analysis. Hypothesis testing methods were introduced into the framework to verify and evaluate simulation results. Esther et al. [34] evaluated CFD simulation results using the measurement results provided by a city's air quality monitoring station network and the mobile microsensor network carried by cyclists during their daily commuting. After calculating the annual average concentration of NO_2, the maximum relative deviation between the CFD and the measured data was found to be less than 30%. Tatsuhiro et al. [35] developed a new coupling method of energy simulation (ES) and CFD, verified the effectiveness of the fixed part of the coupling method, and predicted the spatial temperature distribution. Taeyeon et al. [36] used wind tunnel experiments and CFD to analyze the ventilation performance of closed shopping malls, providing useful design information for shopping malls. The scaled-down model of the building was used in wind tunnel experiments to verify the reliability of the CFD method. Based on the structure and arcade design of the mall, 11 design alternatives were proposed, and their performance was evaluated as the air exchange rate using a proven CFD simulation.

1.3.4 Passive cooling of buildings

Looking at the passive design of courtyard buildings, Toe [37] investigated local passive cooling technology, proposed potential applications to improve the indoor thermal comfort of modern brick houses with natural ventilation in Malaysia, and discussed the potential passive cooling technology of brick houses, including night ventilation, roof or ceiling insulation, window and wall shading, a small courtyard concept, microclimate change, and urban heat island mitigation. Dabaieh [38] described the design of a passive refugee house. The scheme used three main passive heating and cooling solutions (earth–air heat exchanger, Trombe wall, and green wall) to suit the Swedish climate. This research was implemented in an urban life laboratory in Lund, Sweden, to verify the simulation results by monitoring the occupancy for 12 months. Dili [39] continuously monitored indoor and outdoor temperature environments by using a customized instrument called a building evaluation system. The thermal comfort parameters of traditional local buildings were quantitatively analyzed. The results showed that the natural passive control system could provide a comfortable indoor environment, regardless of the outdoor climate conditions.

The research of Ding [40] showed that over a 12-month period, the heating energy consumption of modern buildings in China was generally better than in historic buildings, but the cooling energy consumption was much higher. However, historic buildings outperformed modern buildings in terms of energy consumption and carbon analysis. If traditional buildings are replaced with modern energy-efficient buildings, the energy used to construct these buildings will take about 18–41 years to recover. Xu [41] focused on analyzing the characteristics of traditional houses in the Qinba Mountains, selecting two typical houses built with brick and soil, and monitored and simulated the indoor heat, light, and ventilation environment in summer and winter. This study also summarized the advantages and disadvantages of the residential physical environment in coping with climate characteristics. The results showed that traditional native houses could adapt to the local climate well in summer, but in winter, the indoor thermal comfort needs to be further improved. Finally, effective climate adaptation strategies for traditional dwellings have been proposed, such as natural ventilation, heat preservation, and thermal buffer space. Zhang [42] transformed Sichuan Tibetan houses in cold valleys at high altitudes into research objects, adopted T-WALL as a passive heating scheme. The total annual energy consumption of Tibetan houses with the best combination could be reduced by about 72%.

1.3.5 Comprehensive research on settlement environment and passive energy saving of buildings

On the basis of understanding urban canyon wind and the passive design of courtyards, how to effectively use urban canyon wind to improve the performance of buildings and combine the two for passive energy-saving design has also become a focus of scholars. Mitterboeck [43] assessed the microclimate of an urban canyon where there were several different environments. The purpose of this research was to explore whether plants in a city could make identifiable differences in surrounding buildings. Studies have shown that the cooling effect of plants has a positive impact on surrounding buildings. The research results showed that if building ventilation behavior is followed correctly, urban greening has an impact on passive cooling both indoors and outdoors. Kubilay [44] used building materials with different heat and moisture transport characteristics to study the degree of evaporative cooling after rainfall of different intensity. The results showed that increasing rainfall intensity extends the effective period of evaporative cooling, but does not change the decrease in maximum surface temperature. The improvement of thermal comfort of the street canyon depends on the combination of many factors, such as moisture permeability, moisture, and thermal diffusivity of materials. Allegrini [45] used building energy simulation to analyze the influence of neighboring buildings on heat flow and its influence on the demand for cooling and heating of the building space. Allegrini [46] compared the space cooling requirements of independent buildings with those of buildings with urban street canyon configurations. The radiation model of solar radiation and long-wave radiation was used to determine the radiation exchange between buildings. The results showed that neighboring buildings had a greater impact on space cooling. This effect depended to a large extent on the control of shading equipment, and this strategy should be combined with building energy management. Vallati [47] used building energy simulation (BES) to analyze the influence of multiple short-wave and long-wave mutual reflection exchanges between neighboring buildings and evaluated their influence on the heat flux of street canyon buildings. The results showed that these radiation exchanges changed the microclimate of the canyon, thereby affecting the space cooling and heating needs of the building. Valliti [48] analyzed the influence of neighboring buildings on heat flow and quantified the mutual influence of buildings on space cooling and heating demand, proving the importance of considering urban microclimate conditions to predict building energy demand.

In terms of the rational use of the surrounding environment for passive energy-saving in buildings, Fang'ai et al. [49] proposed a new energy-saving design scheme based on using the evaporation of a water system and a glass roof to passively cool and heat courtyard buildings in the Jiangnan region of China. They also improved the lighting capacity of the building and reduced the energy consumption of the lighting. After the design was combined with air conditioners, the total annual energy consumption for one year was 19,528.88 kWh, a saving of 5839.57 kWh (23%) relative to the original case. The design functions for passive solar buildings were proposed by Chandel et al. [50] including changing the building layout, transforming the shading efficiency of the windows, and using solar heating to generate indoor cross-ventilation. Using a local thermal comfort standard as a reference, the e-Quest simulation software was used to simulate the effects of the equipment on cooling and heating, and the reduction in energy consumption was calculated. In winter, the suitable operating temperature range for the device was 15.0 °C to 17.7 °C. Dnyandip et al. [51] classified the passive cooling technologies of buildings in detail and introduced their functions, application scopes, and latest development statuses. They indicated how the cooling load and room temperature affected the passive cooling technology. The results showed that the reasonable use of passive cooling technology could ensure the indoor thermal comfort of the building, while effectively reducing the indoor cooling load. Ahmed et al. [52] used specific experiments and numerical studies to reset a residential ventilation rate and solar chimney design parameters and determined the relationship between the earth–air heat exchanger geometric specifications, pressure, and climatic conditions. Taking Egyptian houses as the main research object, they simulated passive cooling, heating, and ventilation of the rooms. Based on a "TRNSYS" simulation, they found that this correlation could be used to calculate the indoor temperature and load, making it easier for buildings to reach the conditions required for thermal comfort and reducing the building energy consumption and carbon dioxide emissions. Vaseghi et al. [53] proposed a new ventilation strategy for museum buildings based on combining active and passive ventilation so as to comprehensively improve the ventilation efficiency of a museum and used a computational fluid dynamics simulation to verify it. The results showed that even on the coldest day of winter, the building could still meet the temperature requirements for thermal comfort.

1.3.6 Application method of passive energy saving technology

The purpose of reducing the energy consumption of passive buildings is to make the interior as comfortable or as close to comfortable as possible, from which a variety of passive energy-saving renovation methods are derived. There are many types of reconstruction for buildings, and the emphasis varies according to the climatic conditions in the region. For example, in hot regions, the focus of renovation is on how to effectively reduce the indoor temperature of buildings to meet the requirements of comfortable living [54]. In cold areas, the main consideration is to reduce indoor heat loss as much as possible and enhance the thermal insulation performance of buildings [12]. In areas with high air humidity, the focus is on how to effectively maintain smooth indoor ventilation, thereby reducing the humidity inside the building [56]. Regardless of the purpose, as long as there is no active energy supply, making full use of natural conditions to reach or approach the comfort standard will be accompanied by reduced energy consumption. Passive cooling technology mainly includes three aspects: heat protection, heat modulation, and heat dissipation [57].

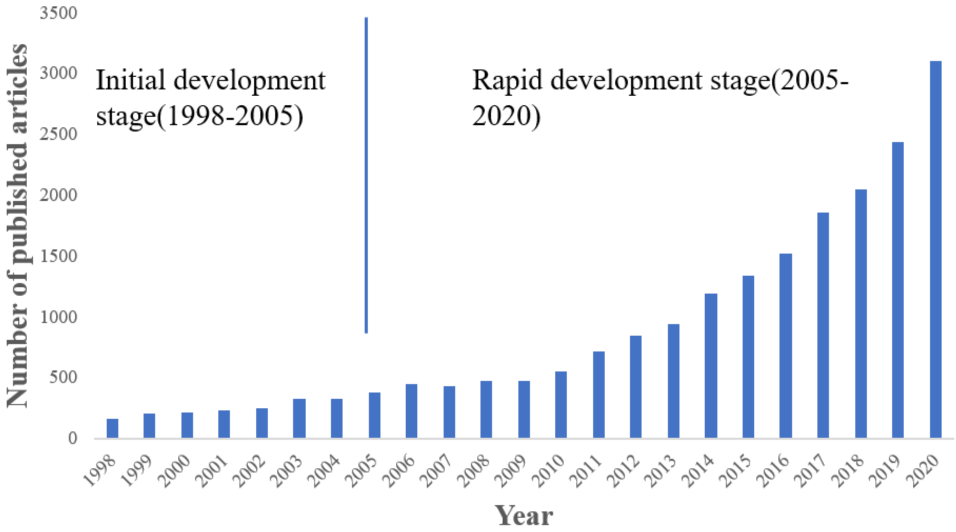

Figure 1-4. Distribution of articles per year (1998-2020).

The main methods of heat protection include reducing the area of solar radiation, increasing the refractive index of light on the roof, and using plants for shading [58.59]. Its purpose is to ease the speed of heat exchange between indoor and outdoor in summer. Taleb [60] proposed an optimization method for studying energy-saving building forms that can minimize the amount of sunlight while preserving the total building area required. In addition, a software system was constructed and optimized on the back end, and a user interface was provided to test different design parameters and visualize the generated building form. The results showed that the optimization tool could reduce sunlight by up to 48% while still meeting different site and building criteria. In addition, new wall materials or wall thickness adjustments can be used to inhibit the building's ability to absorb solar thermal radiation [61,62].

Xu [63] studied the latent heat utilization of phase-change materials (PCMs) and proposed the concepts of relative activation depth and activation time rate for the first time. The PCM parameters are optimized by calculating the relative activation depth and activation time rate. The application background is matched to not only achieve building energy conservation but also make better use of latent heat. Khoukhi [64] analyzed the influence of thermal insulation materials with different thermal conductivity on the thermal performance of buildings in an extremely hot climate, and interpreted the impact of the transient thermal conductivity of thermal insulation layers embedded in typical residential buildings on the cooling effect and energy performance. Some scholars have tried to use plants flexibly to shade buildings or absorb heat through transpiration [65]. Hoelscher [66] proposed that exterior wall greening could reduce the thermal stress of the city through shading, transpiration cooling, and heat insulation. The surface temperature of a green exterior wall is 15.5 °C lower than that of a bare wall, while the surface temperature of the interior wall is as high as 17 °C. The cooling effect depends mainly on the shading, while the lower value is due to transpiration.

Heat modulation involves changing the cooling mode by adjusting the structure of the building itself or finding new ways to change or release the stored heat. Berry [67] provided design parameters related to solar chimneys, and calculated and analyzed indoor air temperature, heating and cooling loads, thermal comfort conditions, energy consumption, energy savings, and the amount of carbon dioxide emission reduction. Zhou [68] , in order to explore the operating characteristics of a ground source heat pump (GSHP) system, used a data acquisition system to monitor it. After that, the measured data were analyzed, including the inlet and outlet water temperature, energy consumption, energy efficiency ratio (EER), coefficient of performance (COP), and ground temperature changes, assuming that the domestic hot water (DHW) system would operate in the next few years. Simulations showed that the operation of the DHW system can effectively reduce the ground temperature and improve system performance. Moosavi [69] focused on the heat and ventilation performance of a newly designed solar chimney, as well as the windshield and water spray system used in two-story office buildings in warm and arid climates. After scaling down the model, a CFD simulation was used to analyze the experimental conditions, which were used to evaluate the cooling and ventilation potential of solar chimneys with and without wind traps. McCartney [70] combined natural ventilation with an unconventional atomization system, and the results showed that a natural ventilation augmented cooling (NVAC) greenhouse could provide a wind speed of 0.38 m/s to improve the air circulation in the greenhouse without using a fan. By using the NVAC design, the average turbulence intensity of the air in the greenhouse was increased to 0.32 m/s, while it was 0.19 m/s under natural ventilation conditions. Guo [71] proposed that by increasing roof sunlight reflectance and night ventilation, the cooling load of buildings could be reduced. The simulation showed that compared with a black roof without night ventilation, the cooling energy consumption of the year was reduced by 27% by combining a cool roof with night ventilation. Compared with a cool roof that did not use night ventilation, the annual cooling energy consumption was reduced by 13%.

Heat dissipation mainly involves transferring the excess heat generated by the building to a suitable radiator. To deal with the excess heat, two factors are mainly considered: the availability of the radiator and the heat conduction efficiency between the radiator and the air, which is the coupling between the two. The surrounding environment can be used as a natural radiator for the building. The type of gas flow and the manner of heat transfer are the keys to determining the heat dissipation efficiency. Zuazua-Ros [72] proposed a third method for heat dissipation in large office buildings: using a hybrid cooling system, or using part of dry heat dissipation panels, or completely replacing the cooling tower. Lule [73], in order to enhance the air exchange of buildings under natural ventilation conditions, used linear heat sources to cover the entire vertical area of the air inlet to study heat dissipation. A constant heat source was used for steady-state and transient experiments, and the heat source was turned off for a period of time during the ventilation process. Infrared thermal imaging was used to obtain the two-dimensional temperature distribution around the vent and predict the volume concentration of the fresh air supply through the fully mixed temperature area. Sánchez [74] designed a new system that can utilize solar and wind energy to accelerate the heat dissipation of air-conditioners. The new system is a combination of cooling towers and solar chimneys that increase air flow without using power. Chen [75] used entransy theory to improve the heat transfer process of the central cooling water system of a building and improve the energy utilization efficiency, taking two kinds of simple central cold water systems as an example to put forward an application of the optimization principle.

The passive renovation of buildings is an effective approach to reducing building energy consumption. Through effective use of the surrounding environment of a building, the transformation of some components of the building can make it more efficient to use naturally generated renewable energy, which is the main means for passive energy saving [76]. For example, the heat transfer rate of the outer wall of a building can be improved by changing the wall material or wall structure [77]. The thermal comfort and ventilation efficiency of a building interior can be improved by using the surrounding environment of the building [49]. In one study, a glass roof was used to increase the heat storage of a courtyard during winter [78].

Aiming to provide a passive design based on the insulation of a building’s exterior wall, Ravi et al. [79] studied a novel wall design that included a phase change material (PCM) layer between two layers of a dynamic insulation material and system (DIMS). In all of the climates and wall orientations studied and analyzed, compared with walls integrated with only DIMS or PCM alone, the walls integrated with PCM-DIMS had higher energy-saving potential. Depending on the climate, a wall integrated with PCM-DIMS could reduce the annual heat gain by 15–72%, and the annual heat loss by 7–38%. Lili et al. [80] used the “Designer’s Simulation Toolkit” energy simulation software to analyze the impacts of the material type and thickness of the external wall insulation layer on building energy consumption in the analysis of a life cycle cost. The economic costs of different insulating materials were studied based on modeling. The results showed that after adding thermal insulation materials to the building envelope, the impact on the cooling load of the building within one year was small, but the impact on the heating load was significant. In the original case, the heating load was reduced by 21.52%, accounting for 3.78% of the total load. Jinbo et al. [81] proposed a new concept called exhaust air insulation (EAI). The main components of the EAI wall were porous materials providing ventilation performance through a ventilation cavity and external enclosure structure. The research results showed that when EAI was used, compared with brick walls, the total heat increase in the EAI walls in summer was reduced by 84.7%; compared with external insulation walls, it was reduced by 67%. The heat storage performance of the wall was greatly reduced by using a thick porous layer and increasing the wind speed. When the wind speed was 0.003 m/s and the thickness of the porous layer was 50 mm, the heat flux of the indoor equipment was almost zero [82]. To explore cost reductions of the exterior wall of the building and reduce the energy consumption, the best thermal insulation materials of different thicknesses were set for the walls, and space was set in the walls to introduce external air into the walls. The results showed that compared with ordinary walls, the energy consumption was reduced by 65–77% under the influences of air gaps with thicknesses of 2, 4, and 6 cm and identified the optimal thicknesses of different insulating materials.

1.3.7 Building energy efficiency

Rural areas are an important part of a country, and the energy consumption of their buildings must be considered. Rural building energy consumption has received extensive attention worldwide, especially in developing countries, where consumption is even more important. Various countries have been exploring reasonable and convenient methods for reducing the energy consumption of rural buildings. The methods include economic means, the introduction of relevant policies, comprehensive data analyses, and the explorations of energy-saving technologies. Satish et al. [83] established a comprehensive database for analyzing the historical characteristics of the energy transfer and consumption patterns of rural and urban households in India. They constructed a per capita energy balance sheet for the urban and rural households in each state for 2004, 2009, and 2011. By comparing the energy consumption values of rural and urban households in low-, medium-, and high-income state and analyzing emission levels, they determined the characteristics of the relationship between energy transfer and income. Martinson et al. [84] used an instrumental variable method to study the impacts of credit on the energy consumption for clean cooking in rural households. The results showed that the impact of the amount of credit received for clean cooking energy expenditures was more pronounced for rural households in the eastern region than for rural households in other regions. The study also explored the importance of credit for energy consumption and provided policy recommendations for increasing the energy consumption for clean cooking. Lu et al. [84] showed that the proportion of non-commercial energy in the agricultural and pastoral areas in Qinghai Province was 52.89% and was affected by the "returning farmland to forest" policy and the "returning farmland to grassland project." In addition, they indicated that the structure of household energy consumption has changed from that based on traditional biomass to that based on a combination of coal and other energy sources. Generally, households with different cultural backgrounds have different energy consumption patterns. Compared with low-income households, high-income households consume more energy, and the energy flows more frequently. Shimei et al. [85] provided a systematic overview of the energy consumption of rural households in China from 1985 to 2013, based on seven energy sources and five end-use requirements. In addition, the energy consumption of rural households was compared based on the volumes, fuel mixes, and demand structures. It was ultimately discovered that biomass continues to account for the main part of the energy supply of rural households in China and that cooking and space heating are the most energy-consuming needs. The overall energy efficiency of rural households was determined as 33%. Marina et al. [86] adopted a "people and pixels" method, based on combining household head interviews with remote sensing analyses of land use and land cover changes. The results of the study showed that although kerosene is the main energy source for cooking and lighting in cities, firewood and flashlights are used more frequently in rural areas, although there are relatively few households selling firewood and charcoal. Yu et al. [87] studied the dynamic relationships between the rural GDP, rural energy consumption, and rural investment, based on a provincial panel data set from 1995–2010. The results showed that it is feasible to promote economic development by accelerating the optimization and upgrading of the rural industrial structure, e.g., by encouraging and promoting the use of green energy. Shuwen et al. [88] estimated the consumptions of biogas, manure, and solar energy in rural households, and established a time series for the actual energy consumption in rural households. The effective energy consumption was measured based on the thermal efficiency of the fuel as found in the existing literature and revealed the main characteristics and trends of energy structure changes. The results showed that in 2015, the per capita actual energy consumption and effective energy consumption reached 546.4 kgce and 142.5 kgce, respectively. Huanguang et al. [89] studied the impacts of rising wage rates on China's rural energy consumption structures. They produced a unique panel data set based on two rounds of surveys conducted for 409 rural households in four provinces. The results showed that the village wage level had a significant negative impact on the traditional biomass energy consumption and a significant positive impact on the electricity and energy consumption. Beatriz et al. [90] proposed a method for using low-cost information and communication technologies to improve the energy efficiency and comfort conditions of public buildings. The results showed inefficient consumption patterns and discomfort, and users were encouraged to take action and to adjust municipal policies. Mohammad et al. [91] studied the adoption of multi-standard decision support tools for transformation projects in four representative climatic environments in Iran. Based on the economic feasibility, environmental impact, and comfort benefits, they defined the best retrofitting strategy for rural buildings. According to the results, in different climate zones, the primary energy demand was reduced by 46% to 55%, carbon emissions were reduced by 40% to 51%, and thermal comfort was improved by 23%. Bao-Jie et al. [92] introduced the current situation regarding energy consumption in rural areas in China, and then noted the problems and challenges in achieving energy efficiency in rural buildings. Measures for reducing the rural energy consumption were proposed based on adaptation to local conditions, including measures based on architectural planning and design, building envelopes, the development and utilization of renewable energy, and energy conservation in daily life. Finally, based on the above analysis, suggestions were proposed regarding policies and standards for improving building energy efficiency. Ronald et al. [93] conducted an extensive literature review on the quantitative energy demands of rural areas in developing countries to study the energy demands and consumption; they determined the various energy requirements and analyzed their typical consumption levels. Weishu et al. [94] proposed a novel passive heating design method called the "On-Top Sunspace" for solving rural heating problems in the severely cold regions of northern China. The results showed that when the roof angle was 28° and the front and rear roof glass-to-roof ratios were 0.5 and 0.6, respectively, the lowest building energy consumption was achieved. Boccalatte et al. [95] used an urban weather generator tool to study the urban heat island phenomenon. The temperature of an urban canyon was calculated based on the location of the city and the geometric shape of a region corresponding to the three European climate zones. The results showed that the urban temperature rose from 0.8 °C in winter to 2.0 °C in summer. When using rural weather data as input, the annual air conditioning demand was underestimated by 10%. Meng Li et al. [96] used rural household survey data from 2005 to 2008 to estimate the proportion of natural gas relative to China's rural energy expenditures, based on the generalized Roy model. The results showed that if the penetration rate of natural gas was doubled, households' fuel expenditures would increase by at least 80%, which could potentially worsen the economic situations of poor households.

1.3.8 Passive ventilation in buildings

Regarding the passive ventilation of buildings, P.M. Sivaram et al. [97] proposed a passive device that used solar energy as the main source of power for passively generating power and improving the ventilation efficiency. The system consisted of a solar photovol-taic system including a chimney and solar distiller. Based on experiments, and using the heat energy obtained by the new equipment, the indoor air was found to change an aver-age of 12 times per hour. The average daily air intake speed as measured on the window was 0.14 m/s. Compared with an independent photovoltaic system, the electrical efficiency of the photovoltaic system in the building-integrated passive solar energy technology increased from 4% to 17%. The solar static performance of the integrated system increased from 3% to 11%. Abayomi et al. [98] proposed a new type of solar chimney system for im-proving the ventilation efficiency of tropical buildings, meeting the corresponding thermal comfort requirements, and managing energy reasonably. It was determined that the new system, as combined with solar chimneys, had an indoor impact in a well-ventilated state. Under the action of the new system, the indoor wind turbines were controlled to change the airflow rate. Rongpeng et al. [99] proposed that a variable air volume system could be used to dynamically optimize night ventilation (NV) and active building air conditioning in an integrated operation. They established a physical model based on differen-tial-algebraic equations, introduced a configuration method to form a nonlinear program, and then used the "General Algebraic Modeling Language" platform to process the solver using the "Interior Point Optimizer." The research results showed that relative to the scheme without NV, using this method could save

23.19–49.31% of the energy consumption under different climatic conditions and could save 14.97–39.70% of energy consumption relative to the NV scheme.

1.3.9 Building glass roof and sun room.

After a glass roof receives direct solar radiation in winter, it can effectively enhance the heat storage capacity of the courtyard, and the heat stored in the courtyard can be used to heat rooms adjacent to the courtyard [100]. Qianjun et al. [101] built a double-slope hollow glass roof and experimentally studied the heat transfer performance of this device under the influence of different slopes in summer and winter. The results showed that the roof slope affected the indoor roof temperature. When the slope of the roof was reduced from 45° to 30°, the temperature of the indoor roof surface was reduced by 12.2%. Zhitong et al. [102] applied a transparent radiant cooling film (T-RC) on a roof glass, which has a low transmittance in the solar spectrum and a selective high emissivity in the atmospheric window (8–13 μm), to reduce a building's energy consumption. The results showed that by combining the cooling effect of the T-RC film in summer and the heating cost in winter, the annual AC energy consumption of an exhibition hall could be reduced by 40.9–63.4%, according to different environmental conditions. Dong et al. [103] proposed that PCMs could be used to fill glazed roofs and compared such roofs with normal glazed roofs. PCM melting temperature and PCM/glass roof slope tests were conducted, with different thicknesses for the elements. The results showed that the maximum energy saving was 47.5% with the use of the new materials.

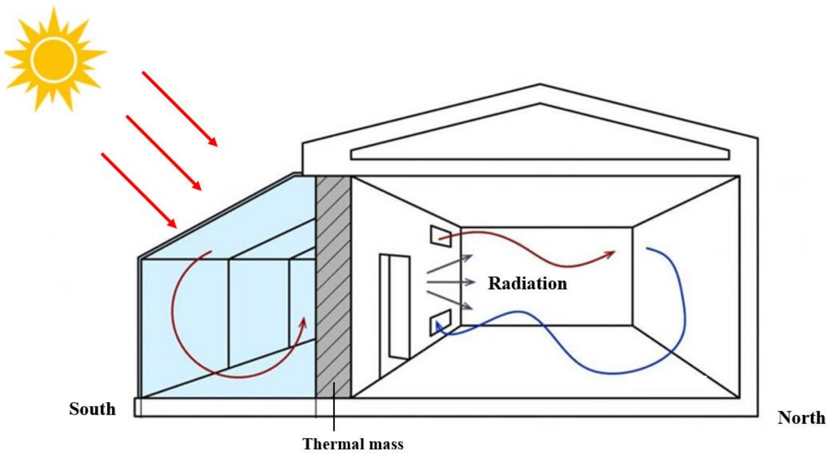

Figure 1-5. The principal of sun room.

1.3.10 Comprehensive review

In previous studies, various methods have been developed for reducing the energy consumption of buildings and to achieve certain results. However, these methods still have problems that need to be solved. The renovation of an exterior wall mainly involves the use of new materials for replacement. Most new building materials are only in the experimental stage and cannot be popularized in time. The transformation of exterior walls also mainly involves the use of new materials for replacement. The time and cost for producing such materials must be further optimized [104]. Moreover, in terms of passive ventilation and cooling design, these materials must be combined with air conditioning. Most of the new equipment still require non-recyclable energy, and therefore, cannot be called completely passive [105]. Other methods merely consider the energy-saving effect of a glass roof, without considering the rationality of the installation and the difficulty of construction [106]. In addition, many technologies mainly focus on urban architecture, and some of them are not applicable to traditional residential buildings. Other passive energy-saving technologies mainly take part of the building as the research object, and there is a lack of relevant research on comprehensive operations [107]. Another shortcoming is that the influence of wall heat radiation (WHR) on the interior is ignored in most of the research processes [108].

1.4 Scientific originality

CFD simulation has become the most widely used research method for the study of settlement wind environment, thermal environment, and air quality. However, most of the main cases studies are cities, with analyses lacking in the rural built environment. Firstly, huge differences exist in the types, layout methods, and street and lane scales between urban and rural buildings. It is not advisable to directly apply urban building environment improvement strategies and coping methods to rural areas. Studies specifically aimed at the rural microclimate are needed to provide a theoretical basis for improving ventilation performance and alleviating air pollution. Secondly, research on the ventilation performance and air pollution of an area often require the macro-control of its overall wind environment. However, most studies on the ventilation performance of settlements are based on ideal geometric models or parts of a city. There are relatively few simulation cases of the overall wind environment of settlements with complex architectural layouts. Finally, for the accuracy of the simulation, the choice of the solver is important. Different solvers have different operation methods and characteristics. In the simulation, the solvers and calculation equations that are most suitable should be selected based on the different research purposes. Therefore, in this study, a village with a complex arrangement of buildings was selected as a study case. According to the building type, layout, and street scale of the case, a detailed model was constructed. Three different steady-state solvers (SKE, RNG, and RKE) were used to simulate the wind environment of the whole village, and we compared the different results with the measured data. Finally, the overall, partial, and vertical deviation ranges of the three steady-state solvers for rural simulations, the reasons for the deviation, and the selection methods of the solvers for different problems were obtained. Our findings provide instructive suggestions for the selection of the solver for the wind environment simulation of complex rural settlements.

We previously proposed a new passive optimization strategy for rural houses combined with cold alley cooling and energy saving and introduced the basic working principle and operating mechanism of a cold alley.

It can be seen from previous studies on the passive cooling of buildings that there are three main cooling measures in summer: introduce cold air from the outside of the building into the space (heat modulation) [109], avoid direct contact between high-temperature outdoor air and indoor air (heat protection) [110], and remove the high-temperature indoor air to the outside of the building (heat dissipation) [111]. The main use of heat modulation is in artificial water circulation, with solar chimneys and atomizers combined with natural ventilation to cool down. When the artificial water circulation system and atomizer cool down, a certain amount of energy consumption is still required to power these processes. It cannot be called a completely passive system; the comparison between the energy consumed and cooling load reduction requires further demonstration. Although a solar chimney can effectively increase indoor ventilation efficiency, it is not obvious for the indoor cooling effect. The use of phase-change materials in heat protection has also had little effect in isolating indoor and outdoor temperatures. The principle of using water for evaporative cooling in heat dissipation is more suitable for desert climates with sufficient sunshine and high water evaporation. Ankang is a city in the subtropical continental monsoon climate and does not meet the climatic conditions of evaporative cooling. The radiator mentioned in [71] is expensive and is more suitable for large public buildings. The cost of renovation needs to be considered for the passive cooling of traditional rural courtyards.

In traditional villages, most of the buildings are leftovers from the Qing Dynasty. The limitations of village planning at that time became the main reason for cold alleys. First of all, the spaces between buildings are too compact, leading to short sunshine time and small areas of solar radiation in the lanes. Second, the overhanging eaves of roofs also act as shields against the sun, also affecting the sunshine in the lanes, leaving them almost without any light during the day. Finally, in a long-term sunless and humid environment, the small space promotes the growth of mosses and ferns, which also take away the surrounding heat during photosynthesis. Under the combined influence of these factors, the temperature in the lanes is lower than the normal outdoor temperature. This kind of lane is very common in villages and is called a cold alley.

In this study, a passive cooling and ventilation system is proposed to lower the indoor temperature and improve the ventilation efficiency of buildings by introducing cold air from cold alleys. This system has three characteristics: heat modulation, heat protection, and heat dissipation. Heat modulation can introduce air from cold alleys to adjust the room temperature; heat protection uses the air wall in front of the wall to isolate the outdoor and indoor temperatures, avoiding direct heat exchange at different temperatures; heat dissipation first introduces cold air into the second floor of the building, then uses the stairwell to convert the heat between the first and second floor, and finally uses hot-pressure ventilation to exhaust the heat from the courtyard.

The entire system completely relies on the accumulation and buoyancy effects of the patio for air circulation, while the indoors relies on hot-pressure ventilation to improve air exchange efficiency. Therefore, the system can run without any power supply, and it is a completely passive ventilation and cooling system. This system is suitable for rural areas with subtropical continental monsoon climates and dense building layouts.

However, in order to improve the ventilation and cooling performance of the cold alley system. This study also has added new energy-saving equipment on the basis of cold alley system. Combining passive energy-saving technology, including cold alleys, with other technologies comprehensively analyzes the efficiency of cooling, ventilation, and energy saving and saves as much energy as possible and takes advantage of passive energy saving as the main purpose.

Firstly, the heat transfer process of the wall in the previous study was analyzed and discussed. We aimed to slow down the wall heat transfer rate in summer and accelerate the heat dissipation of the wall; a thin wall was added along the outer wall of a building, and space was reserved in the middle. The cold air from a cold alley was stored in the space, thereby forming an air wall. The principle was similar to that of a thermos cup, which blocks direct contact between a high-temperature wall and a room. The cold air from the cold alley in the wall could also be used to dissipate the heat generated by the wall receiving solar radiation. The materials used in the new walls were all basic building materials, and no new PCMs were used.

Secondly, the indoor areas and cold alleys were connected to the newly built walls, and air ducts were used to connect the rooms on both sides of the patio. Heat pressure ventilation, the accumulation effect of the patio, and the chimney effect were used to guide the cold air from the cold alley into the room. The cold air from the cold alley could not only lower the indoor temperature, but could also promote air circulation and speed up the air exchange rate in the room. Based on taking the WHR as an independent parameter, a systematic analysis and comparison of whether to consider the WHR status was conducted. This verified the importance of the influence of the WHR on the indoor thermal environment during summer.

Finally, in winter, the air ducts connecting both sides were used as supporting members for adding a glass roof above the courtyard to improve the heat storage capacity of the patio. Solar radiation continuously heated the patio. After a period of time, the patio could transfer heat to the rooms of the building, thereby increasing the indoor temperature. Thus, at this time, the patio was equivalent to a constant-temperature heater. Compared with the cooling and energy saving of separate cold alleys [112], this new system combined four functions, i.e., insulation of the building exterior wall, indoor cooling in summer, an increased ventilation rate, and indoor heating in winter. In addition, it did not use any non-renewable energy. It was a completely passive design in the true sense, as for the first time, a cold alley between buildings was used as the source of cooling and ventilation. This study can reduce the heating and cooling load of the building more than the previous research, and raise the efficiency of indoor cooling and ventilation to a new level. This system integrated mainstream passive energy-saving technologies from recent years and comprehensively applied them to traditional residential buildings, filling the gaps in the comprehensive application of passive designs to rural courtyard houses.

1.5 Research framework

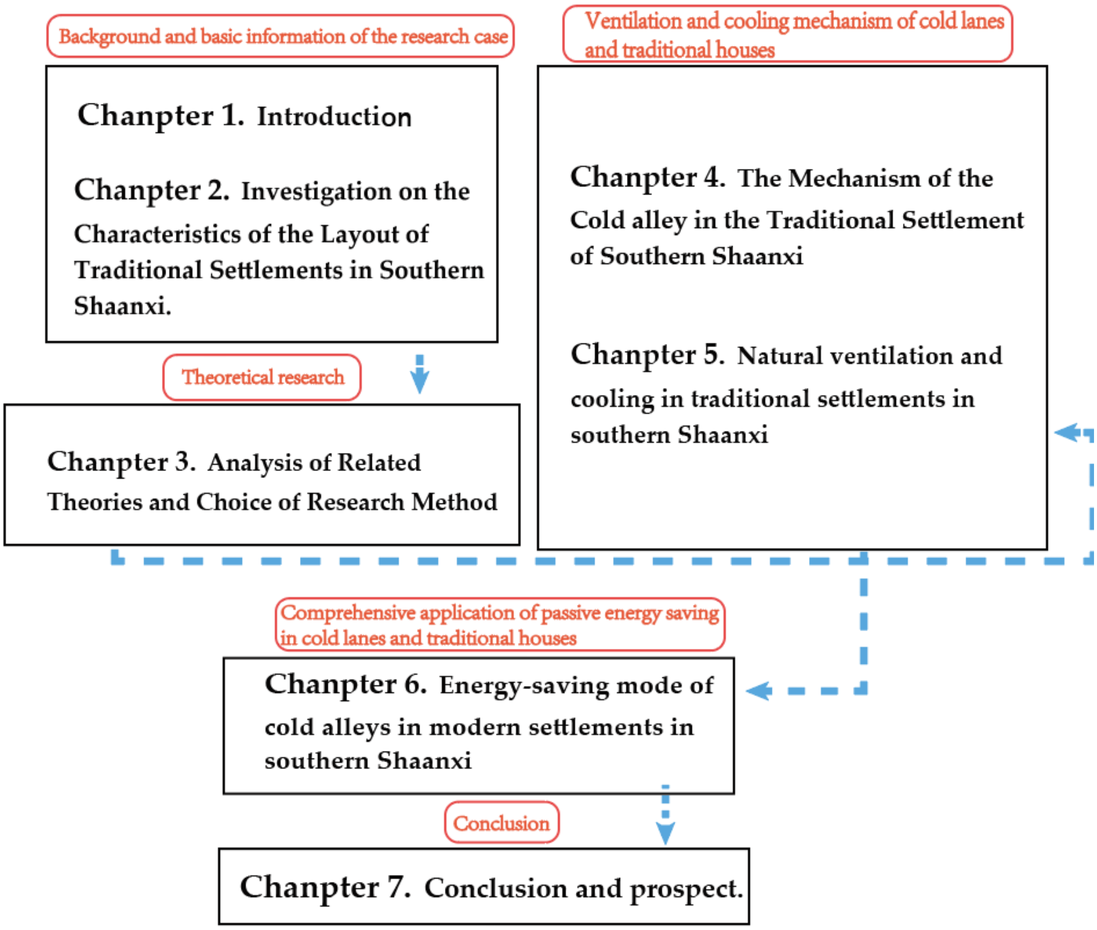

Figure 1-6. Research framework

1.6. Chapter summary

This chapter discusses the background and purpose of the research. Through settlement ventilation, pollutant diffusion path tracking, simulation solver accuracy verification, passive cooling of buildings, comprehensive application of settlement environment and passive energy saving, building energy saving measures, building ventilation, glass roof and sun room settings as the main content, Conducted a literature review. Through the understanding of previous related research, find some methods that can be used for research. Combining the found method with its own research direction, trying to find the correct method to solve the wind environment simulation of traditional Chinese settlements, and how to choose a suitable solver. Discovered the existing problems in traditional settlements and residential buildings about ventilation, cooling, and energy saving in settlements and buildings, and explored the rational use of passive energy-saving technologies in modern buildings in traditional Chinese residential buildings.

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Chapter 2. Investigation on the Characteristics of the Layout of Traditional Settlements in Southern Shaanxi.

2.1 Causes of traditional settlements in southern Shaanxi

2.1.1 Natural factors

Mountains, hills and a small number of intermountain basins, beautiful scenery and relatively closed geographical environment, provide a relatively stable regional environment for residents to live, work, and thrive. It also caters to the psychological needs of a large number of ancient Chinese to avoid wars, live in seclusion, and yearn for a high-quality living environment in order to pursue a peaceful and stable life.

In southern Shaanxi, there are dense lakes and rivers, and abundant water resources provide the necessary conditions for settlements to survive. Unique geographical factors have created a dense distribution of traditional settlements in southern Shaanxi, forming a unique regional landscape. Numerous mountains with different trends, rich water systems, dense vegetation, etc., and unique topography form a subtropical humid monsoon climate with heavy rainfall. The unique natural factors in southern Shaanxi have played a role of nurturing, moisturizing and catalyzing the formation and development of traditional settlements.

2.1.2 Social factors

Due to various social factors such as the patriarchal system, economy, and architectural hierarchy, along with the development of traditional settlements for a long time, it affects the spatial form and internal structure, and the type and function of buildings in the formation of traditional settlements. The spatial form of traditional settlements is planned and laid out centered on ceremonial buildings such as ancestral halls and shrines. The style of traditional dwellings in southern Shaanxi is centered on the hall, the hall and the courtyard are the central axis, and the wing rooms or corridors are arranged symmetrically. As shown in Figure 2-1b, the plane layout is symmetrical and square, which looks orderly. The hall has a high floor height, and there is no wing room above it to reflect the superiority and the inferiority. On the table in the middle of the hall, there is a memorial tablet for the ancestors, and there is a left bottle (representing safe) and a right mirror (representing quiet). This is a yearning for peace and quiet when doing business abroad.

(a) The overall layout of traditional houses.

(b) The internal layout of traditional houses.

Figure 2-1. Residential status. (a) The overall layout of traditional houses. (b) The internal layout of traditional houses.

2.1.3 Human factors

In the Ming and Qing dynasties of China, the strong economic power of southern Shaanxi merchants provided a material foundation for the prosperity of traditional architecture in southern Shaanxi, and ancestral temple buildings became more common and larger in scale [1]. The prosperity of cultural education has also promoted the construction of southern Shaanxi culture and ritual architecture. Qinqiang (a kind of traditional Chinese drama) promoted the prosperity of drama, promoted the development of local cultural and entertainment architecture, and enriched the cultural connotation of traditional architecture. The edification and influence of long-term culture has formed a fusion of culture and life. It reflects the natural ecological view of the traditional architectural culture in southern Shaanxi through the relationship between the site selection and layout of ancient settlements, the construction of houses, the building scale and the landscape and topography. As shown in Figure 2-2, located in the beautiful mountains and clear waters, the ancient architectural settlement in southern Shaanxi presents a perfect combination of dots, lines and faces, green mountains and green waters, rhythm.

Figure 2-2. Settlement layout.

The layout of the ancient architectural settlements in southern Shaanxi relies on the natural topography and is surrounded by mountains and rivers to express people's pursuit of a harmonious and unified view of "architecture-man-nature". The custom of living together in groups has formed a relatively closed appearance, highlighting the defensive function of the building itself. Humanistic factors such as folklore, aesthetics, moral and ethical views, and views of nature have also promoted the formation and development of traditional settlements in southern Shaanxi.

2.2. The geographical location and natural conditions of traditional settlements in southern Shaanxi

As shown in Figure 2-3, southern Shaanxi is located between the Qinling Mountains and Bashan Mountains in southern Shaanxi. The western part of Qinling Mountains and Bashan Mountains is the Hanzhong Basin, and the eastern part is the Ankang Basin. Among them, Hanzhong is located in the southwestern part of Shaanxi, in the western part of the Qinba Mountains, with the Qinling Mountains in the north and Micang Mountain in the south. It is bordered by Ningshan County, Shiquan County, Hanyin County and Ziyang County in Ankang in the east and Qingchuan County, Guangyuan City, Wangcang County, Nanjiang County, Tongjiang County and Wanyuan County in Sichuan Province in the south. Ankang is located in the southeastern part of Shaanxi, with the north slope of Daba Mountain in the south and the main Qinling ridge in the north. The Hanjiang River traverses from west to east, thus entering the border of Hubei. Ankang has unique geographical and geographical advantages, and is located at the junction of the four provinces and cities of Sichuan, Shaanxi, Hubei, and Chongqing. The two landforms are of various types, including mountains, flat dams and hills, but they are mainly mountainous. Compared with the Ankang Basin, the Hanzhong Basin appears to be flat and open in topography. The Ankang Basin is small, with larger undulations and tighter space. In terms of climate, the two places belong to the subtropical continental monsoon climate, with four distinct seasons, abundant rainfall, long frost-free period, good ecological environment and rich biological resources. However, due to the difference in topography between the two, Hanzhong has a milder climate, while Ankang appears to be colder in winter and hotter in summer [2].

Figure 2-3. Map of Southern Shaanxi.

2.3. The cultural and social characteristics of southern Shaanxi

With its special regional environment, southern Shaanxi builds its own regional cultural characteristics in the context of collision and integration in the Hanshui River Basin. In the process of its historical evolution and development, various cultures have appeared on this land successively. They collided, merged, overlapped, precipitated and rearranged and combined, which gave birth to the unique cultural phenomena of this region.

2.3.1 The historical and cultural status of the Han River Basin

Southern Shaanxi is located in the upper reaches of the Han River, and the Han River Basin has been the link between the north and the south and the east and west of China since ancient times, and it is also the axis of the cultural exchange and transformation between the north and the south. It is located in central China, between the Yellow River and the Yangtze River. Its upstream is southern Shaanxi, the Qinling Mountains stand in the north, the Bashan Mountain stretches in the south, and the Han River traverses it, forming a magnificent terrain of "two mountains and one river". In the lower reaches, Han River breaks free from the shackles of the mountains and accepts the tributaries on both sides of the bank, forming an open floodplain, namely the Jianghan Plain, with mighty water and beautiful scenery. In terms of traffic connection, not only the Hanshui River Valley is a corridor between east and west, but the Hanzhong Basin, Nanyang Basin and Xiangfan Basin in the basin are also the corridors for the north-south communication in the western and central regions of China. Surrounding them are the most famous political, economic and cultural centers in ancient China. The northwest is the Guanzhong Plain with Chang'an as the center, the northeast is the Yiluo Plain with Luoyang as the center, the southeast is the Jianghan Plain with Wuhan as the center, and the southwest is the Chengdu Plain with Chengdu as the center. During the period of confrontation between the North and the South in Chinese history, the offensive and defensive of the two sides were mainly carried out in the Hanshui and Huai River basins between the Yellow River and the Yangtze River. The focus of contention was Hanzhong, Xiangfan, Shouchun, and Xuzhou. These four cities were located on the four main traffic arteries connecting northern and southern China in ancient times. In terms of the dangers of the mountains and rivers, Hanzhong and Xiangfan are above Shouchun and Xuzhou. It can be seen that, due to its special geographical location, Hanshui River Basin and even Hanzhong have a very important strategic position in history.

Figure 2-4. Han River.

As shown in Figure 2-4, the Han River Basin is also one of the important birthplaces of human civilization. In the Hanshui River Valley, an almost complete skull fossil was found in Yunxian County, Hubei Province and was identified as Australopithecus. The skull fossil of Australopithecus in Yunxian County was discovered for the first time in China and Asia. It is an extremely important physical material for studying the origin and development of human beings. Ape-man fossils earlier than the "Beijing Man" were also found in the Hanshui River Valley. The human fossils found in Longgu Cave of Meipu in Yunxian County and Bailong Cave of Shenwuling in Yunxi County have been identified as being later than Yuanmou apes and earlier than Lantian apes. Many cultural sites of the Stone Age have also been discovered in the Hanshui River Valley, such as the Paleolithic Culture of Longgang Temple in Nanzheng, and the Neolithic Culture of Lijia Village in Xixiang. Their cultural features and characteristics have the nature of the transition and intersection of the culture of the South and the North. After entering the class society, the Hanshui River Basin, with its unique location advantages, not only continued to serve as the east-west corridor and the north-south link, but also repeatedly served as a strategic base for the unification of the country, which has made important contributions to the great unification of the Chinese nation and the development of regional culture contribute. At present, there is a famous historical and cultural city in the Hanshui River Basin, and it is evenly distributed along the source to the estuary, followed by Hanzhong, Nanyang, Xiangfan, Zhongxiang, Suizhou, and Wuhan, second only to the Yellow River and the Yangtze River among the major rivers in the country. This fully shows that the Hanshui River Basin not only has a rich historical and cultural accumulation, but also occupies an extremely important position in the history of regional cultural development. The Hanshui River Basin is also the axis of the cultural convergence and transformation of China's north and south. The birth and development of culture are closely related to rivers. The river is the main factor in the birth and development of culture. In any country, it is like an organic comprehensive expression of the natural geographical conditions of this area, weather, soil, topography and geological conditions. Human civilization not only originated from rivers, but also spread along rivers. In addition, rivers played an important role in ancient traffic, so rivers naturally became a link between different regions and societies. Chinese civilization is the most typical big river civilization. In terms of the geographical distribution of Chinese culture, there have been two major plates since ancient times: the culture of the Yellow River Basin in the north and the Yangtze River Basin culture in the south. Generally speaking, the southern culture is romantic, beautiful, and fresh, with feminine beauty, while the northern culture is strong, solemn, and masculine [3]. The Hanshui River Basin should be between the north and the south of our country. It is the transition zone of the difference between the north and the south of our country's natural geography. It is precisely because of this special status that Hanshui has become famous. In the ancient times, the outstanding representatives of South and North culture and art, "Chu Ci" and "The Book of Songs", had a profound impact on later Chinese culture. The "Book of Songs", which originated in the Yellow River Basin, and the "Chu Ci", which originated in the Southern Chu region, have different styles. The former is pure and simple, and the latter is romantic and gorgeous, which vividly shows the differences in the characteristics of the two regional cultures. The description in the book vividly reflects the confluence and integration of North and South cultures in the Han River Basin. This also fully demonstrates that the Hanshui River Basin is the axis of cultural integration and transformation between the North and the South.

2.3.2 The cultural characteristics of southern Shaanxi

It is inevitable that southern Shaanxi, which is located in the Han River Basin, exhibits this kind of cultural characteristics. Language is often a tool of cultural dissemination, and the dialects in the upper reaches of the Han River can best illustrate the traces of the intersection of North and South cultures. Due to the fusion of different cultures in the upper reaches of the Han River, the diversity of local languages is caused. The dialects in the south and south of the mountain are mainly Sichuan dialects, while the north of the mountain is mostly Shaanxi dialects [9]. Most of the local dialects in Hanzhong area are close to Sichuan dialects in Chengdu and other places, and belong to the range of southwest dialects. However, the dialects of Yangxian and Chenggu counties are variants after the fusion of Sichuan dialect and Guanzhong dialect. The dialects of Xixiang, Mianxian and Lueyang counties retain fewer features of the Guanzhong dialect, and have a higher degree of closeness to the Sichuan dialect. The Ankang area is more influenced by the Hubei dialect. There is a "dialect island" in Anjiahe, Hancheng District, Ziyang County, and all the people in the "island" speak "Jiangnan dialect". Zhashui and Zhenba counties have settlements of Zhuang and Miao nationalities with more than hundreds of people respectively, and they are known as Zhuang Township and Miao Township. Here is the fusion of Chu and Han cultures, as well as the infiltration of Bashu culture [5]."Chu language", "Sichuan dialect " and "Qin dialect " coexist, while "Jiangnan ", "Miao dialect " and "Zhuang dialect " are still present. The Guanzhong and Northern Shaanxi dialects are generally unified internally to form a clear contrast. In modern Chinese, the names of the rivers "Jiang" and “he” are geographically different. Roughly the Yangtze River is the boundary. The south is called "Jiang" and the north is called “he”. However, people in the upper reaches of Han River call Han River "Han jiang he". This lively popular culture also shows from another aspect that southern Shaanxi is an area where multiple cultures blend and permeate each other [6].

The reason is that there is not only the particularity of location, but also has a great relationship with the cultural orientation of the region. The characteristics of location have been described in the previous article, but from the cultural point of view, this area of southern Shaanxi is mainly influenced by three mature cultural circles, which are Bashu culture, Chu culture and Qin culture. First of all, the regional environment is a prerequisite for the formation of a cultural circle. Qin culture was formed in the Guanzhong Plain of Qinchuan, which is eight hundred miles away, Chu culture was formed in the Jianghan Plain, which was the impact plain of the Han River, and Shu culture was formed in the Chengdu Plain. The formation of these cultures depends on the size of the regional strategic space, and the narrow area of southern Shaanxi, even if there is a relatively large Hanzhong Basin, its disadvantages relative to other places are self-evident. Secondly, whether there has been a stable and powerful regime in the regional environment is also a necessary condition for the formation of a cultural circle. Its existence has a very positive significance for the spread and development of culture. For this point, southern Shaanxi also has inherent shortcomings. For this reason, as far as individuals are concerned, the value identity of the people in southern Shaanxi is much lower than that of the large surrounding cultural circle. Therefore, not only is it much easier to radiate and enter culture in the local area, but the way in which culture enters is also restricted by various factors. This regional difference in influence has caused different cultural choices in the same area. Finally, with the evolution of history, a pattern of coexistence of multiple cultures in southern Shaanxi has been formed. Furthermore, to some extent, it also created the open and tolerant character of the people in southern Shaanxi.

For the infiltration and dissemination of foreign culture, the people of southern Shaanxi have shown a certain degree of selectivity and practicality in the process of historical development. Of course, this choice is based on regional conditions and exchanges, and practicality is also based on economics. If the regional conditions of southern Shaanxi provide the possibility for this multicultural coexistence pattern, then the form and amount of exchanges between different regions in history have determined to some extent the unique cultural pattern and certain psychology of southern Shaanxi. Through field research, we have gradually formed a clearer understanding of the cultural pattern of southern Shaanxi. In terms of cultural influence, Hanzhong mainly focuses on Bashu culture, while Ankang focuses on Chu culture. But as far as the geographical distribution of culture is concerned, with the Han River as the boundary, the influence of Qin culture in the north becomes stronger, and the influence of Bashu culture in the south becomes stronger. And in the east-west direction from Hanzhong to Ankang, following the Hanjiang River, you will find that a growing trend from Shu culture to Chu culture is very obvious. There are many reasons for this, but one very important point is the influence of the routes of human migration and communication on cultural exchanges. Before the Song Dynasty, China's political and economic center was in the north, especially in the Tang Dynasty. When you went to Chang'an, you reached the political and economic center of China, which promoted the cultural and economic exchanges between the north and the south. Then, as a transportation hub between the north and the south, southern Shaanxi has also formed its own cultural pattern in such long-term and stable exchanges. But after the Song Dynasty, China's politics has moved south, and the new economic center has been formed in the southeast of China, which also promoted the cultural and economic exchanges between the East and the West on the Chinese land. As the Han River Basin, the development of shipping also brought southern culture, so as southern Shaanxi is inevitably influenced by Chu culture [7]. At the same time, from the historical evolution of the two places described above, in the Yuan Dynasty, in order to better control Sichuan by the ruling class, Hanzhong formally became part of the land of Shaanxi now. This is of course based on political and military considerations, so it also has a certain impact on the culture of southern Shaanxi. And Ankang, with its geographical advantage of "Qin head and Chu tail", and its economic factors' influence on its culture is self-evident, so naturally it will be deeply influenced by Chu culture in the course of its historical development.

2.4. Layout of the architectural group in the traditional settlement of southern Shaanxi-Shuhe

2.4.1 The climatic conditions of the settlement

Located on the northern edge of the subtropical zone, the ancient town of Shuhe is a climate transition zone between China’s north and south, with Qinling Mountains in the north, blocking the cold air from the northwest to the south, and Bashan in the south, slowing down the warm and humid air flow from the southwest and southeast to the north, playing a role of "heat preservation and moisture protection" effect. Therefore, the climate is warm and humid, with four distinct seasons. The weather in spring is changeable, with uneven cold and hot, high temperature and hot in summer, heavy rainfall, rainy in autumn, and little and unstable river water in winter. The annual average temperature is 15℃-6℃, and the lowest temperature is -9.6℃. The annual rainfall is 800-850 mm, the average rainfall is 831.3 mm, and the relative humidity is 69%. Because the settlements are more concentrated in summer and autumn rainfall, and the monsoons converge frequently, and they are located on higher mountain slopes, the probability of torrential rain has increased, causing the water levels of the two streams to rise, causing flood disasters. The frost-free period of the year is 250-260 days. The early frost in Guzhen begins in November and the late frost ends in March. The annual average sunshine is 1,790.4 hours, and the maximum frozen soil depth is 0.26 meters. The difference in climatic conditions is closely related to the construction of the human settlement environment in the ancient town [8]. The difference in climatic conditions affects the site selection and layout of the settlement, and also affects the architectural layout and architectural style of the settlement. As shown in Figure 2-5a, since the main streets of the ancient town are facing north-south, most of the buildings in the ancient town are facing east-west and are built facing the road. At the same time, because the settlement is built on the west side of the hillside, there is less construction land and dense building layout, which results in poor ventilation and lighting in the living space of the settlement. Therefore, the construction of residential buildings mostly adopts the mode of constructing patios, thereby increasing Indoor lighting meets the lighting needs of residential buildings. As shown in Figure 2-5b, the ancient town of Shuhe has a humid climate and heavy rainfall in summer, so long cornices are used in the design of residential buildings. The climatic conditions have caused the construction of the human settlement environment in the ancient town of Shuhe to present rich construction elements, resulting in the formation of a unique human settlement environment in the ancient town.


Figure 2-5. Ancient town of Shuhe.

2.4.2 Topography of the settlement

Geographical conditions are the natural basis for all human activities and survival. It will profoundly affect the development of local humanities and history, especially the site selection, settlement, and settlement of early humans, which play a decisive role. They will also affect all the remains of human activities, of course ancient towns, buildings, and streets are not listed. The origin and prosperity of the ancient town of the Shuhe are one of the key elements of the spatial form of the ancient town due to its geographical features. Choosing a site at the confluence of the Han River and the Shuhe is a kind of wisdom of the local ancestors. They have a broad vision and look at the Han River basin, which together with the culture deduced by Han River, constitutes the main body of Chinese civilization. In the historical process of interdependence between the ancient town and the Han River Basin, with its unique regional environment, it accepted, nurtured, selected, and integrated various cultural phenomena and finally built its own unique regional cultural characteristics through historical precipitation [9]. And this kind of cultural characteristics, the people of Shuhe, used the form of architecture to fully explain it.

Shuhe Town is located 53 kilometers east of Xunyang City, and its geographic coordinates are 109°42' east longitude and 32°57' north latitude. According to qinling Mountains in the north and Bashan mountains in the south, it is located in the transportation hub of two provinces and three counties, adjacent to Hubei Bixi County. The geographical advantage of transportation is obvious. It can reach Xunyang, Hanzhong and Sichuan along the Hanjiang River. It goes down the Han River eastward to Hankou in the Jianghan Plain, and it is only a few kilometers to the provincial capital of Xi'an by land [10]. Its surface features are incompletely developed hilly landforms in the lower part of the mountain. The geological structure is mainly composed of limestone, Korean rock, and schist. The soil parent material is mostly Quaternary red clay, loess, and loess. Type and strata belong to the Lower Silurian.

Due to the influence of various conditions such as unique topography and surface conditions of Ankang traditional dwellings, topographic winds in local areas are formed, which affects the ventilation of residential areas to a certain extent [11]. In the traditional Ankang houses in the mountains, the valley winds exist in the basin and mountain terrain, and the wind environment in this area is often affected by the ups and downs of the terrain. Mainly manifested in the situation of the valley wind during the day and the mountain wind at night, resulting in the circulation of the valley wind in a small area. According to the law that the circulation wind is weaker than the valley wind on the windward slope and the valley wind on the leeward slope is weaker than the mountain wind, the residential area on the windward slope should ensure the combination of the rear high and the front low residential area, and the residence on the leeward slope The site should ensure a combination of buildings with low rear and high front to make the living environment more suitable.

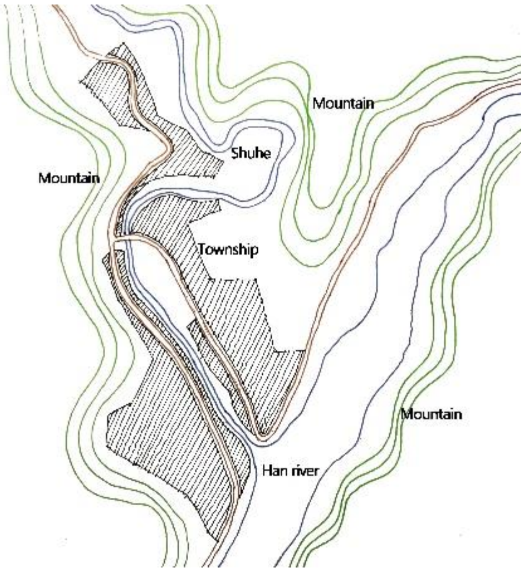

Figure 2-6. Topographic map of Shuhe.

As shown in Figure 2-6, the ancient town of Shuhe is located on the northwest bank of the confluence of the Han River and the Shuhe, on the upper reaches of the Han River basin. The two rivers converge on the south side of the town. Zhangzhong Mountain at the southern foot of the Qinling Mountains is the origin of the Han River system. The waters of the Han River flow in Shaanxi and Hubei provinces, and merge into the Yangtze River system in Wuhan City, Hubei Province. The main stream of the Han River is about 1577 kilometers long and is the largest tributary of the Yangtze River. As the upper reaches of the Han River is located in Shaanxi, the Han River has many tributaries flowing through Shanxi, and the main planar shape is dendritic. The Shuhe is an important tributary of the Han River flowing through Shaanxi. The Shu River is a tributary of the north bank of the Han River. It originated in Hujiayan, Yunxi County, Hubei Province. It is a first-level tributary of the Han River. It has a total length of 67.1 kilometers and a drainage area of 592 square kilometers. Flowing through the borders of Yunxi County in Hubei Province and Xunyang County in Shaanxi Province, the ancient town of Shu e is located at the intersection of Han River and Shu River. Han River and Shuhe provide abundant water resources for the ancient town, and Han River and Shu River are also the living water for residents of the ancient town. Transportation and other major sources. Since the ancient town of Shu River is close to the Han River, whenever the rainy season comes in summer, the water of the Han River will flood the streets of the ancient town. The long-term and flowing floods have brought greater threats to the lives and property of the residents of the ancient town. There are four major floods recorded in the history of Shuhe Town. The flood disaster in 1983 was the largest flood in the ancient town of Shuhe in modern times. This red flood disaster caused great damage to the ancient town. During the Wanli reign of the Ming Dynasty, the ancient town experienced a flood disaster. This time the water level of the disaster was as high as three feet. Due to perennial flood disasters, most of the buildings in the ancient town were destroyed in the flood. This also led the ancient town to choose the location of the hillside area where "near the water is not close to the water, but the ditch defense province" during the construction of the town area, in order to reduce the disasters caused by floods. The waterway wind is formed based on the different thermal properties of the land and water surface of the river, and is an indispensable and important feature in the traditional houses of Ankang. The residential house can rely on water and land wind to complete the organization of ventilation, reduce the height of the houses along the bank, ensure the open layout, reduce the restriction on the ventilation air flow, and the houses far away from the bank should be appropriately raised to achieve a low-to-high wind pressure gradient [12].

2.4.3 Settlement location

In ancient society, "feng shui" has always been one of the traditional Chinese folk culture, accompanied by the prosperity and development of Chinese society [13]. However, the agricultural society has always been covered with a veil of mystery, but it has actually played a good guiding role in building houses for ordinary people and the formation of villages. The geographical environment of the Shuhe area itself is relatively closed, the settlement spatial form is linearly distributed, and the buildings of the ancient town are surrounded by mountains and water. The self-sufficiency of traditional agriculture is particularly suitable for this "two mountains and one river" environment. The mountains and rivers are naturally divided into mountains, plains, slopes, and rivers, which not only ensure daily water planting and salary, but also provide a good living environment. The cold wind in winter is blocked by the back-mountain pattern, and the surface water welcomes the cool summer breeze. The north-south layout is the layout form adopted by most buildings in the ancient town. This layout and orientation can maximize the sunshine, which is especially important for the ancient towns sandwiched between mountains [14]. The slope is gentle, so that residential buildings can be arranged along contour lines, which can effectively organize drainage and resist water errors in the rainy season. This is particularly important for the people of the Shu River who have suffered from floods since ancient times. This is the design idea that appeared in the early stage of the development of the ancient town and passed on all the way. The natural and primitive living concept of the people of the Shuhe coincides with the traditional concept of Fengshui. In the process of gradual development and construction, the roof and dragon veins gradually formed in the main street of the old street.

Seeing the mountains and seeing the water is a beautiful vision for the location of towns and people's needs for the external natural environment. The initial settlements of ancient humans were caused by the requirements of humans for defense, production, and life in the settlements. The enclosed space formed by the mountains can effectively block the cold wind and form a good microclimate. At the same time, it can also form a safe defense with superior conditions for settlements [15]. The ancient Chinese have attached great importance to the environment of mountains and waters in the selection of urban sites since ancient times. They selected towns to be built on the terraces with mountains and waters. Such places are usually rich in products and abundant in water resources, which can meet the demand for food and water. At the same time, the surrounding mountains and forests can be used as a shelter. Careful selection of sites in the waterfront areas is also to reduce the natural disasters of floods and droughts in cities and towns. Therefore, a good natural mountain and water environment has become a prerequisite for people to consider when choosing a city site. The ancient town of Shuhe is surrounded by mountains (Hejia Mountain, Siliangzi Mountain, Dong Mountain, Yunlong Mountain), and the two rivers (Han River, Shu River) are surrounded by each other. The town is surrounded by Hejia Mountain in the west and Siliangzi Mountain in the north. The two mountains are surrounded by Yunlong Mountain in the south and Dongshan mountain in the east, forming a form of surrounded by mountains as a whole and forming a natural defensive barrier for the town. The slopes of Hejia Mountain and Siliangzi Mountain are relatively gentle, the terrain at the foot of the mountain is flat, and the soil is hard, and there are fewer disasters such as landslides or soil erosion. They are suitable for long-term living. Shuhe ancient town is adjacent to Shuhe River in the east and Hanjiang River in the south. Shuhe River in the north and south and Hanjiang River in the east and west surround the town.

On the premise of meeting the production and living needs of the town, it can also serve as a natural security defense barrier to protect shuhe ancient town. The town is surrounded by Hejia Mountain, Siliangzi Mountain, Dongshan Mountain and Yunlong Mountain, showing the form of surrounded mountains[16]. The town is located at the junction of mountains and plains, which is also known as the "land surrounded by mountains" in the site selection of landscape concept. It has the topographic advantage of "high but not dry, living under and not washed out". At the same time, the ancient town is adjacent to the Han River and shu River, and the site is located in the northwest bank of the Han River and Shu River. The Han River and Shu River surround the ancient town, which is known as "the land surrounded by golden cities" in the site selection of landscape concept [17]. The high mountains block the flow of heating and cooling from the north and south, and effectively regulate the microclimate of the ancient town. The water flow also provides abundant resources and superior traffic conditions for the ancient town of Shuhe. The landscape pattern surrounded by mountains and dependent on the two waters organically integrates the ancient town of Shu River with the natural landscape environment, forming an integrated landscape of "mountain-water-city" on the premise of meeting the production, life and security defense of the ancient town. This also reflects site selection concept of respecting nature and adapting measures to local conditions has been achieved in the ancient town of Shuhe.

2.4.4 The spatial pattern of the settlement

The traditional urban planning thought advocates the planning concept of "rules in the city, and guidelines in the roads", which emphasizes a well-mannered structure, a centered and upright axis, and a square and neat road network [18,19, 20]. The spatial pattern of villages and towns is different from traditional planning concepts. Its spatial pattern has the naturalness that is highly compatible with the natural environment and the spontaneity of different development models formed by the free settlement of people. The development of settlement space in villages and towns pays more attention to its practicality and comfort, so that the spatial pattern between each village and town has its own characteristics and is different [21]. The spatial pattern of villages and towns not only shows its integration with the natural environment and spontaneous growth, but also shows its obvious cohesion [22]. Due to the harmonious neighborhoods relationship between village and town residents and the family network of clan relatives, the spatial pattern of villages and towns develops more cohesively. Due to its unique geographical location, the ancient town of Shuhe has a unique spatial pattern, and due to the multi-culture of the ancient town, the spatial pattern of the ancient town has a certain cultural connotation. The ancient town is backed by mountains and water, bordering on the Shu River and on the slopes of the mountain, thus forming a unique belt-shaped spatial form. At the same time, because the ancient town is located under the east and west mountain valleys, the ancient town presents a good landscape pattern of "mountain-city-water-mountain". The ancient town is located on the slope of the mountain, and the buildings in the entire town are arranged in accordance with the contour of the mountain, thus forming a unique stepped architectural layout.

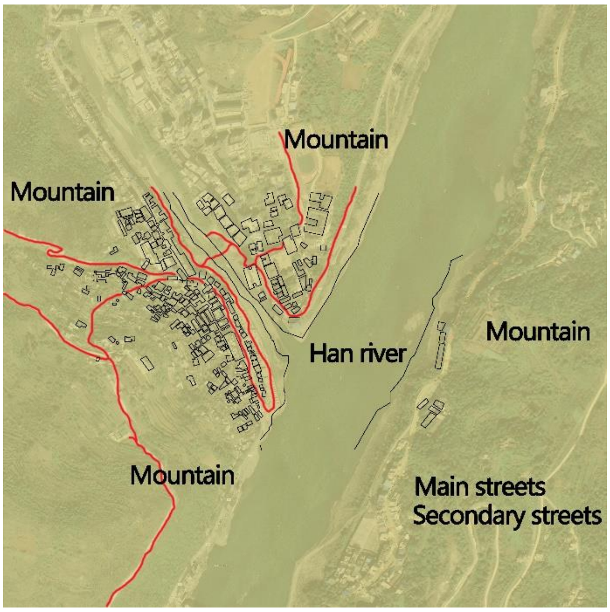

Figure 2-7. Mountain-water-city.

The urban landscape is the basis for the survival of the town, and at the same time it is closely integrated with the town's culture with a unique language [22]. The growth of the settlements in the ancient town of Shuhe gave its unique regional culture to nature through symbolism. In the landscape, the ancient town is integrated with the natural landscape environment, creating a poetic landscape. The construction of cities and towns in ancient China paid special attention to combining the surrounding natural mountains and rivers, and considered "mountain-water-city" as a whole. In the long-term process of urban human settlement construction in ancient China, the pattern of "mountain-water-city" was used as the essence of urban spatial pattern design [23]. It harmoniously unifies the urban spatial pattern with the natural mountain and water environment and the human landscape environment, so as to find the characteristics of order and visual beauty displayed in the construction of the urban human settlement environment from a large-scale perception range. Due to its unique geographical location, the ancient town of Shuhe is integrated with the surrounding natural environment as a whole, forming a unique landscape pattern of east-west, north-south spatial environment with "mountain-city-water-mountain" as the space base. The north side of the ancient town is adjacent to Hejia Mountain, the east side is bordered by the Shu River, and the east mountain is the commanding height of sight across the Shu River, forming an east-west “mountain-city-water-mountain” landscape pattern of the ancient town. The ancient town is adjacent to Siliangzi Mountain on the north side, Hanjiang River as the boundary on the south side, and Yunlong Mountain is the commanding height of sight across the Hanjiang River to the south, forming a north-south "mountain-city-water-mountain" ancient town landscape pattern [24]. From the landscape pattern of the ancient town of Shuhe, we can find that the spatial pattern of the ancient town is to integrate the ancient town into the surrounding natural landscape environment, and the ancient town is regarded as an integral part of the entire landscape environment. Through the development of the human settlement environment for hundreds of years, the ancient town of Shuhe merges the ancient town into this beautiful natural landscape, thus forming a unique "mountain-city-water-mountain" symmetrical landscape pattern. As shown in Figure 2-7, the "mountain-water-city" space of Shuhe ancient town is a kind of harmonious order beauty, which not only shows the coexistence of the ancient town and natural landscape environment, but also shows the integration of natural landscape environment and cultural landscape. The integration of mountains, rivers and cities in Shuhe ancient town takes mountains, waters and cities as a whole independent system, truly realizing the integration of landscape and city in the construction of the ancient town's human settlement environment [25,26,27].

2.4.5 The spatial axis of the settlement

The axis is an important symbol of urban spatial artistic achievement. As an important factor in the construction of urban human settlements, the space axis of ancient Chinese towns is an important support for the interaction and organization of the humanistic space within the town, and is also an important construction method for the connection between the town and the natural landscape pattern [29]. The spatial axis is the benchmark of urban space, the main structure that determines the urban spatial form, and the foundation for the formation of urban space. Macroscopically, the spatial axis of Shuhe ancient town takes the surrounding natural landscape environment as the base, the landscape city as the space element, and the cultural space with internal characteristics of the ancient town as the ornament [30]. All elements are interconnected and interact with each other, forming the spatial axis of the ancient town based on the natural environment and dotted with cultural space.

In ancient China, "dialectical orientation" was emphasized in the process of town construction, and the spatial axis of the town was always in the same direction as the overall orientation of the town. However, due to the external constraints of terrain conditions, some mountain towns can’ t meet the conventional ideal orientation facing south, but more generally, the overall orientation and spatial axis of the town in the construction conform to the mountain terrain, forming the ideal orientation of water on the back of the mountain. Its space construction pays more attention to the echo relationship with the surrounding natural landscape space [31,32]. The formation of the spatial axis of the ancient town of Shuhe is the result of the formation of the spatial pattern of the ancient town and the formation of the surrounding landscape pattern. Through the analysis of the spatial pattern and landscape pattern of the ancient town, it is found that the ancient town of Shuhe has two spatial axes: east-west and north-south. The spatial form of the ancient town of Shuhe presents the status quo of north-south zonal development as a whole [33]. The streets and lanes inside the ancient town are also constructed in accordance with the north-south direction. Therefore, it can be found that the north-south spatial axis is the main development axis of the ancient town. The overall formation is based on the natural landscape pattern and the humanistic space as an important node of the spatial axis. The east-west spatial axis of the ancient town is the "virtual axis" of the ancient town, which is the development axis corresponding to the north-south axis in the spatial pattern [34]. The whole is perpendicular to the Shu River and parallel to the Han River. The two spatial axes of the ancient town of Shuhe formed a spatial pattern that can reflect the unique culture of the ancient town’s residential construction in the blend of natural environment and regional culture [35].

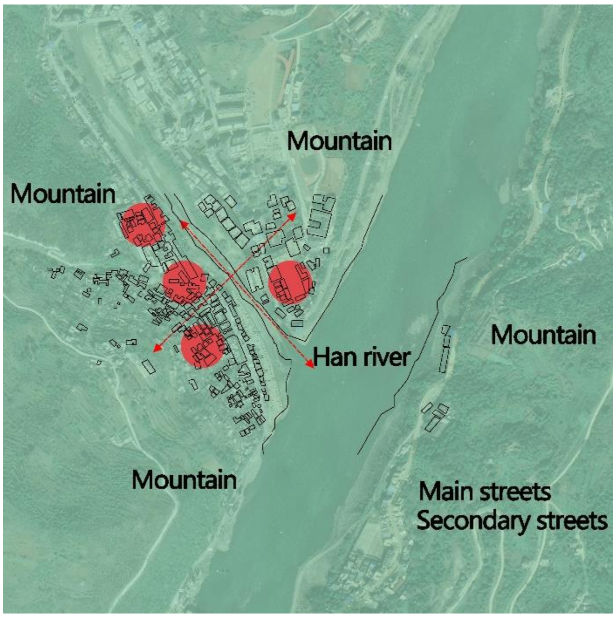

Figure 2-8. Axis map of Shuhe.

As shown in Figure 2-8, the ancient town of Shuhe is located in the valley topography surrounded by mountains. The superior natural landscape environment and characteristic regional culture have created the unique spatial pattern of the ancient town, thus deriving the spatial axis with the characteristics of the ancient town of Shuhe. The north-south space axis of the ancient town is a cultural space axis based on the landscape pattern and focusing on the humanistic space. On the macro level, the spatial axis of the ancient town is the commanding height of the north-south line of sight with the large-scale mountains on the north and south sides as the axis, which determines the overall orientation of the ancient town [36]. The ancient town is located in the valley of mountains and rivers, forming a unique spatial axis of the ancient town of Shuhe, so that the ancient town and the natural environment complement and balance each other. It reflects the close connection between the spatial pattern of the ancient town of Shuhe and the natural landscape pattern. The determination of the spatial axis of the ancient town also played a very good role in shaping the regional culture of the ancient town. On the basis of the macroscopic spatial axis, Shuhe Ancient Town arranges the important cultural and religious buildings of the ancient town on the north-south axis, so that the space axis of the ancient town and the humanistic axis are combined. The humanistic axis of the ancient town is centered on the Huangzhou Guild Hall, which connects the north-south Yangsi Temple, the ancient wharf, the mosque, the Huoshen Temple and other important buildings (structures) to form an important spatial landscape axis of the ancient town [37].

2.4.6 The spatial structure of the streets and lanes of the settlement

If the settlement form of the ancient town of Shuhe is taken as the external body of the ancient town, then the street space as the basic framework of the ancient town is the bloodline skeleton of the ancient town. Street space is not only an important passage space in the ancient town, but also an important space medium for commodity transactions in the development of the commerce and trade economy in the ancient town of Shuhe. The street space is a typical representative of the traditional residential space in the ancient town of Shuhe. It is also an important place of communication in the life of the citizens of the ancient town of Shuhe. It carries the traditional life and memory of the residents of the ancient town. The streets and lanes of the ancient town not only serve the function of transportation, but also have the functions of commerce, culture, entertainment, and display. At the same time, it can also reproduce the historical and cultural atmosphere of the ancient town, which can reflect the historical context of the ancient town [38]. In this section, the study takes the street space as the research object of the living space, so as to analyze the characteristics of the human settlement environment of the ancient town of Shuhe in more detail.

The ancient town of Shuhe has complex topography and landforms. The ancient town is located on the hilly landform. The overall street and lane spatial form is greatly affected by the topography. The topography and landform of the ancient town largely determines the street and lane spatial form of the ancient town. The main streets and lanes of the ancient town were constructed in accordance with the contours of the mountain, and the secondary streets and lanes used steps to connect the main streets and alleys with different heights [39]. The overall construction adopts the construction method of artificial overlap, and the overall construction is in a form that conforms to nature and changes freely. The streets and lanes of the ancient town vary freely according to the terrain and terrain, and the streets vary in width and width, winding and changing freely. The ancient town's ancestors handled the street and lane Spaces with different height differences flexibly. The buildings were built according to the street and lane, with ups and downs and well-proportioned. The main street and lane were connected with the secondary lane by steps to form a rich and varied street and lane space. The architecture of the ancient town has a degree of advancing and retreating, and the space that has been retreated has become an important space for residents to rest and stop. The streets and lanes change freely with the ups and downs of the terrain where the ancient town is located. Walking in the streets and lanes of the ancient town seems to give people a kind of fun. Along with the mountain topography, the architectural layout of the height difference is generated, forming a layout of high and low, layered buildings, making the streets and lanes of the ancient town have a sense of space and layering.

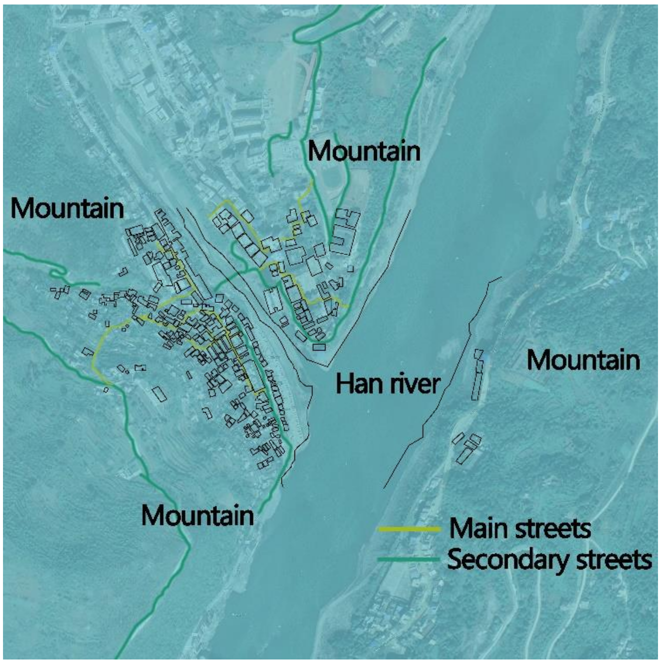

Figure 2-9. The streets of Shuhe.

As shown in Figure 2-9, the streets and lanes of the ancient town of Shuhe have a relatively complete organization system. Large and small streets and lanes are connected to each household, making the transportation system of the ancient town systematic and complete. In the heyday of the economic development of the ancient town of Shuhe, a cohesive commercial main street started from the east gate of the ancient town and extended to the northwest border.

The main street of the ancient town carried multiple functions such as commercial trade and transportation. Due to economic development and the gathering of foreign population, the ancient town has produced a secondary street connected by the assembly hall buildings. It is connected with the residential space streets of the ancient town, and its main functions are residence and transportation. The main street and secondary street of the ancient town are connected with other life streets, organizing and improving the internal transportation network of the ancient town. The streets and lanes of the ancient town of Shuhe have evolved over a long period of time, mainly affected by topography, lifestyle, customs and other factors, and are the most important basic framework in the ancient town system [40]. The streets and lanes of the ancient town are affected by the natural environment. The main street and the secondary street are formed along the direction of the Shu River and Hejia Mountain, parallel to the Shu River. Other streets and lanes are vertical or parallel to the main and secondary streets as branches, thus constructing a street and lane system with linear characteristics. Due to the topography of the town, its main and secondary streets are not in the form of long straight lines, showing a plane shape with staggered height difference and winding transition. The streets and alleys of the ancient town are connected with the main and secondary streets with flexible layout, which better reflects its function and pays more attention to its life. It reflects the active adaptability of the streets and lanes of the ancient town to the topography, and the street system of the ancient town is in line with the natural environment. Among the streets and lanes system of the ancient town, the streets and lanes dominated by Yong'an Lane are the main streets of the ancient town, which pay more attention to commercial and transportation functions. Take the streets and alleys in front of the convention hall buildings as the secondary streets of the ancient town, which pays more attention to the functions of leisure, life, clubs, etc. The other lanes are mainly majiapo Lane on the south side of mosque, shijia Courtyard on the south side and extending westward to the old site of Lei Gong Guan through the old site of bank, Ganyi Lane on the north side of Hengyu Gongzhen, streets and lanes on the north side of Huangzhou Guild Hall, streets and lanes on the south side of Yangsi Temple and connecting dongmen West Road of ancient town. They pay more attention to living and walking transportation. Therefore, the overall street structure of Shuhe ancient Town presents a system of "one main street and five horizontal lanes at a time".

The streets and lanes of Shuhe Ancient Town are mainly composed of three levels of streets and lanes, namely the main street, the secondary street and the laneway [41]. The main street, named Yong 'an Lane, starts from the east gate of the ancient town, extends northward to Chengzhong Gate and Shijia Courtyard, and then continues northward to connect with the old Mulu ancient Road. The road width is about 5 meters. There are mostly commercial shops on both sides of the main street. The commercial shops in Shuhe ancient Town are divided into two floors. The first floor is used as a commercial facade and the second floor is used as a warehouse for storing materials. This kind of building is called "Super Building" in the ancient town. The main street is an important area for commercial activities in the ancient town of Shuhe. It follows the mountainous terrain and runs from northwest to southeast. The main function is to provide the ancient town with material transportation, resident communication and commercial development. It is an important commercial street in the ancient town that integrates leisure, entertainment, traffic and transportation. The second street is a street with life as its main function. It starts at the foot of the mountain outside the south gate of the village, passes through the south gate to Yangsi Temple, Huangzhou Pavilion, and the mosque, and from the west side of the mosque to the back mountain. On both sides of Zhenxi Road. The pavement width is about 1.5 meters and is a slate pavement. The second street is a winding street, mainly used to serve the guild halls, public buildings and residential houses on both sides of the street. There are many roadways in the ancient town of Shuhe, scattered scattered in the ancient town, used to connect the main streets and provide the residents of the ancient town with the function of walking through. The roadways of the ancient town are scattered high and low, and the space is abundant. The main streets of the ancient town are arranged according to the contour line of the mountain, and the height difference is different. Therefore, the steps are skillfully used to connect the laneways and the main streets, enriching the street space of the ancient town, and making the ancient town form a network road structure. The main streets are Majiapo, Yong 'an, Kanyi, Huangzhou Bian, Yangsimiao, Frozen lvbian and Xingwenqiao. The most important ones are Majiapo Lane, Ganyi Lane, Huangzhou Pavilion Lane and Yangsimiao Lane.

2.4.7 The street scale of the settlement

Place spirit refers to a space with a special style. Pleasant spatial scale and sense of spatial enclosure are the necessary factors and external conditions that constitute the "spirit of the place". Therefore, an in-depth study of the spatial scale of the streets and lanes of the ancient town of Shuhe can grasp the feelings of people's space and better explore the wisdom of constructing the residential space of the ancient town of Shuhe. The topography of the ancient town of Shuhe is complex. The ancient town was built according to the high line of the mountain. The whole building is located on terraces of varying heights, with varying heights and rich changes. Most streets and lanes in the ancient town are relatively narrow, with only a few main streets and lanes reaching five meters wide, and the remaining lanes are mostly 2 to 3 meters wide [42]. In order to satisfy the transportation and other functions of the ancient town, the main streets and alleys in the ancient town have wide roads. Most roadways are used as life traffic roads in ancient towns, and the narrower pavement can ensure a good living environment and traffic environment. The streets and lanes in the ancient town have different widths and can change freely, making the inner space of the ancient town simple and not monotonous. Set the street width to D and the building height to H, and use the street aspect ratio (D/H) to measure people's feelings about the street-scale space. When D/H> 1, as the ratio decreases, it will give people a sense of proximity, when the ratio is equal to 2, it will give people a sense of spaciousness. When D/H<1, it will give people a sense of depression as the ratio decreases. When D/H=1, it is a relatively pleasant space, and the ratio of 1 is also a turning point for the feeling of space. The ratio of street width (D) to building height (H) in the ancient town of Shuhe is more varied. The D/H in the same street is also different and varied. The streets in the ancient town give people different feelings through different spaces. Due to its complex terrain and mountains, the ancient town of Shuhe has less construction land area. Therefore, there are few wide streets and lanes in the ancient town, and most of them are laneways with spatial characteristics reserved between houses and buildings. Through the investigation and analysis of the internal streets and lanes of the ancient town, the spatial scales of the streets and lanes of the ancient town are divided into five types, which are analyzed in turn and the feeling of walking is summarized. The height-to-width ratio (D/H) between the roadway building and the street in front of the pawn shop is less than 0.5, but as a street leading to the house, it gives a strong guiding character. When walking from the streets to the main street of the ancient town, there will be a sense of changes in the level of street space. Another kind of roadway with traffic as the main function as the inside of the ancient town. For example, Ganyi Lane, Xingwen Lane, etc., the height-to-width ratio (D/H) of the building to the street is also less than 0.5. The reason is that many buildings on both sides of the roadway were rebuilt by the residents of the ancient town in the later period, which increased the height of the building, thus increasing the height of the buildings on both sides of the roadway. Therefore, passing through it will give people a strong feeling of depression. The roadways such as Majiapo Alley and Nianzigou Alley in the ancient town have a height-to-width ratio (D/H) between the building and the street, which is also greater than 0.5 but less than 1. However, due to the large difference in building height on both sides of the roadway, one side is high and the other side is low, so although D/H is more appropriate. But the higher side gable will give people a more depressing feeling. The more pleasant spatial scale of the streets and lanes of the ancient town belongs to the main street of the ancient town. Its D/H=1, the height of the buildings on both sides and the width of the street form a suitable scale, giving people a comfortable and pleasant feeling. The streets of ancient town 2>D/H>1 are mostly partial sections of other streets. For example, Nianzigou Alley, Yongan Alley, etc., the space experience will give people a sense of spaciousness. But as you walk in it, when you walk into a space with a different scale, it will give people a sense of level change. As shown in figure 2-10, the streets and lanes of Shuhe Ancient Town are abundant in spatial scale, but most of the laneways are relatively pleasant in spatial scale. Although a small number of streets with larger or smaller scales give people a sense of spaciousness and depression, the streets and lanes of the ancient town are all connected together. Therefore, walking in it will feel the free change of the streets and lanes of the ancient town, and the feeling of the streets and lanes with abundant levels [43].

(a) Wide lane (b) Narrow lanes

Figure 2-10. Different alley Spaces: (a) Widely Lane; (b) Narrow lanes.

2.4.8 Street organization of the settlement

Based on the topography of the ancient town, the spatial organization of the streets and lanes of the ancient town has become an important spatial feature of the ancient town. Due to the integration of the overall space and topography of the ancient town, its internal street space and topography have formed a certain correlation, and the whole and topography have formed a variety of different organizational methods. The topography of the ancient town is analyzed by on-site survey and other methods, and it is analyzed that the spatial organization of the streets and lanes of the ancient town is mainly divided into levels, steps, and ramps [44]. The organization of streets and lanes is handled in different ways, which reflects the wisdom of high-level human settlement construction that the residents of the ancient town fully adapt to the natural environment.

The organization of horizontal intersection is because the intersecting streets and lanes are on the same level or terrain with a small elevation difference. The street and lane space system is organized by direct intersection between streets and lanes The streets and lanes of the horizontal intersection are mostly on the east side of the ancient town [45]. Since the east side of the ancient town is close to the Shu River, the terrain is relatively slow and relatively flat, and the early residential space of the ancient town is located here. Therefore, including the main commercial streets and alleys of the ancient town (Yong'an Lane), secondary streets and alleys (front streets and alleys such as Yangsi Temple and Huangzhou Guild Hall), and other streets and alleys connecting the main street and the secondary street, all adopt horizontally intersecting spaces [46].

(a) Ramp (b) Step

Figure 2-11. Streets organization: (a) Ramp; (b) Step.

The organizational form where steps or ramps intersect. The streets and lanes of the ancient town are large and small. Due to the influence of the terrain, the height differences of the lanes in the ancient town are different. In order to meet the basic functions of roadway traffic, all roadways in the ancient town of Shuhe are connected by ramps or steps, which perfectly solves the construction of the internal transportation network system of terraces or mountain towns. Most of the ramps in ancient towns are used for the connection between the main street and other roadways, while the steps are mostly used for connections between roadways with large terrain differences [47]. The steps inside the ancient town can be roughly divided into two categories due to their different functions: One is the connecting steps used to solve the height difference between the streets and lanes, and the other is the entrance steps used to enter the house beside the streets [48]. As shown in Figure 2-11 the two steps connect the streets and lanes system of the ancient town through different applications, so that the streets and lanes of the ancient town have a rich spatial form and a sense of spatial hierarchy. This kind of spatial organization is because the intersecting streets and lanes are in different terrain height differences, and the streets and lanes are built by building steps or ramps to connect the streets and lanes. The organization of streets and lanes that use steps or ramps intersects is mostly located in the living space west of the second street of the ancient town. Due to the rapid economic development and population expansion of the Shuhe Ancient Town in the later period, the internal land of the ancient town was compact, and some buildings were built along the mountain terrain. The buildings are at different height differences, so they are connected by steps or ramps to facilitate the passage of residents.

2.4.9 Street function of the settlement

The street and lane system is one of the important material form elements of the ancient town of Shuhe, and the important skeleton of the ancient town [49]. In the street and lane system of the ancient town of Shuhe, in addition to its basic traffic function, it also carries the social life of the ancient town. The streets and lanes of the ancient town of Shuhe have multiple functions. According to the systematic analysis of the street and lane system of the ancient town, the functions of the street and lane system in the ancient town of Shuhe can be summarized into the functions of transportation connection, commercial economy, leisure communication, and life attachment. This constitutes the unique street space of the ancient town [50].

Traffic connection function. Traffic is the basic function of the street and lane system in ancient towns and an important part of the function of the street and lane system. The primary function of the street and lane system of the ancient town of Shuhe is the traffic connection function. The main street of the ancient town is the main street in the street space of the ancient town. It carries the functions of streets and lanes such as the inside and outside of the ancient town, as well as traffic connections. Therefore, the streets and lanes of the main street are relatively wide to meet the important basic functions of the ancient town's traffic. The secondary streets and alleys of the ancient town and other streets are used as the internal traffic of the ancient town and serve as the traffic of the residents in the ancient town. The interconnection of the streets and lanes makes the traffic connection function of the streets and lanes of the ancient town more perfect to meet the basic needs of the residents for the road traffic connection function.

Business economic function. The ancient town of Shuhe takes commodity trade as the main economic pillar, and the business culture is an important reason for the formation of the real ancient town’s street space system. The ancient town was a small residential settlement in the early days. Due to its important geographical location, early merchants going up and down north and south would pass through the ancient town and temporarily stop, thereby promoting the development of the ancient town’s commodity economy. The main streets and lanes of the ancient town were also formed due to the promotion of commodity trade. The main street of the ancient town, as the carrier of the commodity trade development of the ancient town, carries the economic development of the ancient town. On both sides of the main street of the ancient town, there used to be commercial trading places such as money houses and guild halls, which is enough to see the important commercial and economic functions of the main street of the ancient town. The ancient town has developed from its original prosperity to its decline. Nowadays, the commercial atmosphere of the main street of the ancient town has been greatly reduced, and its commodity economic function has gradually degraded, and it has become a protected area together with the ancient town.

The important function of street space during leisure and communication, it carries the life of the residents of the ancient town, and is the memory and inheritance of the life of the ancient town residents. In addition to the basic traffic functions of the streets and lanes of the ancient town of Shuhe, the most important function is the function of leisure and communication. Affected by the topography and topography, the ancient town has less construction land, resulting in fewer public activity venues in the ancient town. As a result, there are fewer public event venues in the ancient town, so the streets and lanes of the ancient town have become the most important outdoor event venues for the residents of the ancient town. The main streets and alleys of the ancient town are mostly commercial stores along the street, which are the working places of the residents and the places of life and leisure for the residents of the ancient town. The residents of the ancient town extend the living space from indoor to outdoor, and become the most important living and entertainment space of the residents, carrying the leisure and social life of the residents of the ancient town. Except for the main streets of the ancient town, most of the other streets inside the ancient town carry the life functions of the ancient town. The daily life of the residents of the ancient town, such as communication, recreation, and laundry, takes place in the streets and lanes, making the streets and lanes of the ancient town full of residents' life. In addition to the leisure and communication functions of commerce and life, the streets and lanes of ancient towns are also an important part of the folk culture. The folk culture that the ancient town has accumulated over thousands of years is displayed in the streets and lanes through physical activities. Various folk activities in the Shuhe, such as the social fires and folk dances, and the weddings and funerals of the residents, have left memories in the streets and lanes [51].

Subsidiary function of life. The street space also has the auxiliary functions of the residents of the ancient town, including the function of ventilation. Shuhe is located in the northern margin of the subtropical zone, and is close to waters such as the Shu river and Hanjiang. Therefore, the streets and lanes have become the ventilation corridors, playing the role of ventilation in the town. The shading function is also an important function of the street space. As the Shuhe is located in southern Shaanxi, the summer is relatively hot. Therefore, As shown in Figure 2-12a, the twists and turns, rich layers, and small-scale streets and lanes of the ancient town are suitable for the residents' summer heat prevention and cooling effect, and provide residents with a shelter from the sun [52]. As shown in Figure 2-12b, in addition to the function of ventilation and summer heat, the drainage function is also an important auxiliary function of life in the streets. As the ancient town was built at the confluence of the Han River and the Shu River, the terrain is low and suffers from floods all the year round. Therefore, the open ditches and culverts on both sides of the streets and lanes in the town assume the drainage function of rainwater and flood.

Figure 2-12. The street and lane system.

2.5. The characteristics of the traditional houses of the settlement

Traditional houses are the most important part of the ancient town, and the houses represent the local culture. It combines the most distinctive local folk customs, spiritual beliefs and other cultures, which can be reflected in traditional residential buildings. The traditional residential buildings in the ancient town are based on practical functions and cultural factors, such as former commercial houses and pure residential houses.

2.5.1 Changes in architectural forms with different functions

The dwellings of "former business and then house" are the most representative buildings in ancient town [53]. These buildings are mostly concentrated on both sides of the main street of the ancient town and are constructed in the form of courtyards. The front part facing the street is used as a shop, and the back is used as a residential function. This type of residential buildings mostly use a two-story bucket-type wooden structure. The first floor is used as a shop, and the second floor is used as a warehouse for storing materials and commodities. Generally, the height of the first floor is 2.3 meters, and the height of the second floor is 2.5 meters. This type of building is mainly made of wood, and the facade wood panels can be removed. When the shop opens for business, the wooden boards are removed, closed and then reinstalled on the wooden doors, thus forming a unique style of residential buildings. The former-shanghai-style residential houses are generally one-entry or two-entry courtyards, which are similar to the traditional courtyards of southern Shaanxi. The courtyard has a symmetrical layout as a whole, with street-facing shops and main buildings one behind the other on the central axis, with east and west wing rooms on the left and right. Since the ancient town is located on the platform as a whole, the terrain has a relatively large difference in elevation. Therefore, when constructing residential courtyards, the buildings in the same courtyard may be at different heights. Residents use steps to deal with, this kind of building is also the characteristic architectural culture of the ancient town.

Hall building. The building of the guild hall originated in the Qing Dynasty. As the ancient town relied on water transportation and other transportation hub functions during this period, the economy of the ancient town was unprecedentedly prosperous [54]. Merchants gathered in the ancient town, and merchants from all over the country moved to the ancient town to do business and buy land. Merchants from the same place formed a chamber of commerce and built a fellow village hall. The representative guild hall buildings in the ancient town mainly include the Sanyi Temple of the Shaan Gang, the Huangzhou Pavilion of the Yellow Gang, the Mosque of the Hui Gang, the Wuchang Pavilion of the Wu Gang, the Wanshou Palace in Jiangxi, the Yangsi Temple of the Ship Gang, and the Huangzhou Pavilion of the Huang Gang. The Hunan Guild Hall, and the Fire Temple of the local gang, etc. In addition to the function of gathering together in the same town, the guild hall building of the ancient town also carries the function of public leisure and entertainment, and is an important public space. For example, the square space in front of the Yangsi Temple is an important place of religious belief in the ancient town. The boatmen in the past had to come to the Yangsi Temple to make money and worship every time they went into the water to bless safety and prosperity. Until now, local residents still come here to burn incense and pray for blessings on the fifteenth day of every month. These square spaces have assumed the religious, ceremonial, and gathering functions of the ancient town, and become the most important public space in the ancient town.

Residential houses. Shuhe is a place with many immigrants and merchants, so the residential buildings in the ancient town are also concentrated with the characteristic culture of various places [55]. Various cultures blend with each other and are displayed in the residential buildings. The dwellings of the ancient town are influenced by the cultures of Bashu, Jingchu and Guanzhong. The building facades often use horse head walls with regional characteristics. The horse head wall in Shuhe is different from the horse head wall in Anhui and other places. The horse head walls on the houses in the Shuhe are rich in styles, generally two-fold or three-fold, mainly in the shape of a horizontal ladder. There is also a semicircular shape at the top, while the horse head walls in Anhui and other places are mostly regular rectangles with many layers. The styles of the horse head walls in the two places are also distinctive and have distinctive local characteristics. Residential houses in ancient towns also mostly adopt the form of one-entry, two-entry or three-entry courtyards. The plane form mainly includes a font type, patio type, courtyard type and so on. The residential buildings in the ancient town are mostly scattered on the hillside of the back mountain, and the building materials are made of wood or stone. The main function of this type of building is the residential function. As the ancient town is located at the confluence of the Shu River and Han River, floods often occur. Therefore, the residents of ancient towns raise the building as a whole, build a platform of about half a meter, and build steps at the entrance to reduce the damage caused by floods. Another major feature of the residential buildings in the ancient town is that every family will build a back door. This is because the natural environment often leads to floods. Therefore, if the residents of the ancient town encounter a flood, they will transfer materials and property through the back door, which has become a feature of the ancient town's residential architecture.

2.5.2 Changes in architectural form at different heights

As the height difference changes, the functions and forms of traditional buildings gradually change. With the gradual increase in height difference, the functions of traditional buildings gradually tend to be singular. Shuhe is located on the platform at the foot of the Hejia Mountain. It is laid out layer by layer along the height difference of the mountain. The architectural form and function also gradually change with the height difference of the terrain. The main street of the ancient town with Yong'an Lane as the main street, as an important commercial space of the ancient town, is an important factor in the social and economic development of the ancient town. According to the analysis of the topography of the ancient town, the spatial shape map of the ancient town and the topographic analysis map are superimposed. It can be seen that the commercial building space of the ancient town is mainly located between 249.80-264.00 meters in elevation, and the terrain is relatively flat. The reason is that the population of the ancient town was relatively small in the early days, and the ancient town relied on water transportation to develop the commerce and trade economy. Therefore, the buildings located on both sides of the main commercial street of the ancient town are mostly commercial buildings, mainly composed of "front-commercial and back-style commercial houses" combining commercial and residential buildings. With the rapid social and economic development of the ancient town, the population of the ancient town has gradually increased. Shuhe has become an important commercial town in southern Shaanxi, and a large number of foreign merchants have moved to it. From this derives the guild hall building dominated by fellow merchants. The guild hall of Shuhe has a semi-public architectural function, and is an important place for gatherings of fellow villagers in the ancient town, which also adds a major regional characteristic to the ancient town. The guild hall buildings of the ancient town present a north-south development space along the contour lines of the mountain, which also forms an important secondary street in the ancient town that focuses on life. The guild hall buildings in the ancient town are mainly located on the contour line of the mountain on the west side of the main street, at an elevation of 264.10-278.40 meters. Due to the increase in the population of the ancient town, the land of the ancient town has become compact. Therefore, most of the residential buildings in ancient towns are built in places with large elevations. As the height difference increases, the architectural function of the ancient town gradually changes from a commercial and residential function to a single residential function, and the architectural function gradually becomes single.

(a) "L" shapes architectural form (b) "-" shapes architectural form.

Figure 2-13. The architectural forms of the ancient town: (a) "L" shapes; (b) "-" shapes.

With the increase in topographical height difference, the architectural form of the ancient town gradually tends to be simplified. As shown in Figure 2-13, the architectural forms of the ancient town mainly include courtyards, "L" and "-" shapes. With the economic development of the ancient town and the increase in population, the land within the ancient town has gradually become compact. Therefore, the building types of the ancient town also gradually change with the gradual increase in topographical height difference. Transformed from a large courtyard to an "L" and "-" residential building with a smaller area. This also enriches the building types and adds to the characteristics of the ancient town.

2.6. Chapter summary

This chapter first expounds the causes of settlements in southern Shaanxi through three aspects: natural factors, social factors, and human factors. A detailed description of the geographical location and natural conditions of southern Shaanxi in China. Introduced the formation process of the cultural characteristics and social structure of Southern Shaanxi in China. Subsequently, Shuhe Town, a representative settlement in southern Shaanxi, China was taken as the main research object. From a macro perspective, the layout of the building groups and the organizational structure of the streets and lanes of Shuhe Town are analyzed. Finally, it takes the buildings in the settlements as an independent research content to illustrate the characteristics of traditional residential buildings in southern Shaanxi.

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Chapter 3. Analysis of Related Theories and Choice of Research Method

3.1. Theoretical research

3.1.1 Wind environment characteristics and its influencing factors

The natural ventilation of the building refers to the rational building layout and internal space organization of the building. Promote the air flow inside and outside the building to achieve the purpose of ventilation of the building space. [1] When there is a pressure difference on both sides of a building's opening, air will flow through the opening under the action of the pressure difference, which is the basic mechanism of natural ventilation. There are two main types of dynamics for the pressure difference formed in the opening of the building, wind pressure and thermal pressure. Natural ventilation is also divided into natural ventilation under the action of wind pressure and natural ventilation under the action of heat pressure according to the different causes of formation [2]. But in the actual situation, the two effects exist at the same time, but sometimes the wind pressure ventilation is the main one, and sometimes the Heat pressure ventilation is the main one.

3.1.1.1 Natural ventilation under wind pressure ventilation

Natural ventilation under the action of wind pressure means that when the air from the outside blows towards the building, the turbulence is generated due to the obstruction of the building, which will generate positive pressure on the windward side of the building. At the same time, a local pot flow is generated on the side and leeward side of the building to generate negative pressure, and a pressure difference is generated between the windward side and the leeward side [3]. If there are suitable openings and indoor airflow channels between different sides of the building, the outdoor airflow will pass through the building under pressure. This is the basic principle of wind pressure.

The wind pressure difference is related to many factors such as the environment around the building, the layout of the building, and the angle of the incoming wind. A good external environment and proper building layout can produce a better external wind environment and create good conditions for ventilation inside the building [4]. When the building is a conventional rectangle, when the incoming wind blows vertically to the building, it will form a positive pressure on the windward side of the building, and a negative pressure on the leeward side, creating more conditions for indoor ventilation. Reasonable arrangement of the layout and form of the building, to create a good wind pressure difference, and according to the wind pressure difference adjust the opening of the outer wall of the building and the internal airflow channel, can form through the building inside the natural wind. In addition, according to the Bernoulli fluid principle, as the fluid flow speed increases, the static pressure of the fluid will decrease.[5] Conversely, if the fluid flow velocity decreases, the static pressure of the fluid will increase. Using this principle rationally, a passage for airflow is reserved in the building. When the wind flows through the passage, the static pressure of the air in the passage is reduced, which can drive the flow of surrounding air. The reserved air duct needs to have a certain length to achieve the effect of driving the air flow. This kind of ventilation method is suitable for use in the building space with large depth.

3.1.1.2 Natural ventilation under heat pressure ventilation

Natural ventilation under the action of heat pressure refers to the use of the air temperature difference near the openings of different heights in the building to form a thermal difference to promote air flow, which is what we often call the "chimney effect". When the average temperature inside and outside the building is inconsistent or there is a difference in air temperature near the openings at different heights of the building, the air density will also be different, resulting in a difference in air pressure, which drives the flow of air. The heat pressure is determined by the temperature difference between the indoor and outdoor air and the height difference between the inlet and outlet [6]. The greater the temperature difference between indoor and outdoor, the greater the height difference between the entrance and exit, and the stronger the effect of hot foot ventilation. The key to promoting the building's thermal pressure ventilation is to create a local temperature difference through the creation and organization of the spatial shape, or to increase the height difference between different openings, so as to form a good natural ventilation under the action of heat pressure. Compared with the natural ventilation under the action of wind pressure, the natural ventilation under the action of heat pressure is more suitable for the unpredictable external wind environment. In architectural design, vertical passages inside the building, such as atriums, stairwells, etc., can be used to form Heat pressure ventilation, and controllable openings can be set [7]. Flexible changes according to the external conditions promote the outflow of hot air inside the building and form natural ventilation.

3.1.1.3 Natural ventilation under the combined action of wind pressure ventilation and Heat pressure ventilation

In the actual situation, wind pressure and heat pressure do not exist alone. The ventilation of buildings is generally the result of the combined action of wind pressure and heat pressure. The two pressures sometimes work in the same direction, and sometimes work in opposite directions [8]. The size of the pressure difference is affected by factors such as wind speed, wind direction, indoor and outdoor temperature difference, and opening height difference. But the air flow through the opening of the building is not proportional to the pressure difference, but proportional to the square root of the pressure difference.

When wind pressure and heat pressure work together, the air flow through the building is not a simple algebraic sum when the two act separately, but is smaller than the sum of the two. Air pressure ventilation and Heat pressure ventilation are closely linked in the building and complement each other. Usually in building design, the parts with small depth of the building can be directly ventilated by wind pressure [9]. In the parts of the building where the depth is relatively large, the combined effect of wind pressure and heat pressure can be used to achieve the ventilation effect. However, in the design, it is necessary to avoid the opposite directions of wind pressure ventilation and heat pressure ventilation and offset each other.

3.1.1.4 Auxiliary natural ventilation

In buildings with poor external wind environment or large buildings, relying solely on wind pressure and heat pressure cannot meet the demand for natural ventilation. In this case, a certain air treatment method (solar chimney, etc.) can be added to promote ventilation [10]. The main direction of this research is also to use passive auxiliary natural ventilation as the main utilization method for the purpose of energy saving and to reduce the indoor temperature in summer. Improve the heat storage capacity of the building in winter, increase the overall ventilation rate of the building, and reduce the cooling and heating load of the building [11].

3.1.2 The advantages of natural ventilation

For buildings and people, natural ventilation is divided into three categories: thermal comfort ventilation, healthy ventilation, and cooling ventilation. Thermal comfort ventilation is to increase the heat dissipation of the human body by accelerating the speed of the air around the person, and at the same time prevent the discomfort caused by the moist skin. Healthy ventilation is the use of gas flow to bring fresh outdoor air into the room, replace the polluted indoor air, and maintain the cleanliness of the indoor air [12]. Cooling ventilation is a ventilation method that uses outdoor airflow to take away indoor heat through the building when the outdoor air temperature is lower than the indoor air temperature, such as night ventilation to cool down.

3.1.2.1 Natural ventilation and thermal comfort

The American Society of Heating, Refrigeration and Air-Conditioning Engineers stipulates in the standard ASHRAE 55-2004: "Thermal comfort" is a state of consciousness that people are satisfied with the environment. There are six main factors that affect human thermal comfort, namely: four environmental variables: temperature, humidity, wind speed, and radiation temperature, and two human variables, namely the amount of human activity and clothing. Among the six influencing factors of thermal comfort, wind speed has a greater impact on thermal comfort. A better wind speed can prevent discomfort caused by damp or warm skin [13]. At the same time, it can promote the convection and evaporative heat dissipation of the human body, take away excess heat, and achieve the thermal comfort of the human body. When the indoor temperature is lower than the skin temperature, the wind speed has a greater impact on thermal comfort, because the low temperature climate can take away the heat in the body. When the indoor temperature is equal to or higher than the skin temperature, the wind speed has little effect on thermal comfort. Humidity, clothing, and amount of activity determine the comfort of a person. In the state of low humidity or quiet people, a smaller wind speed is more appropriate, but when the humidity or metabolic rate is high, a larger wind speed can promote evaporative heat dissipation and convection, and improve comfort [14]. Different wind speeds have different effects on the human body. Through investigation, most people feel comfortable when the indoor wind speed is 0.25/m/s-1.0m/s. When the wind speed is greater than 1.5m/s, most people think that the wind speed is too large and uncomfortable. The reasonable organization of natural ventilation can reduce the human body's perception of the indoor thermal environment, and the human body's requirements for thermal comfort will be relaxed. Under the influence of a certain indoor wind speed, even if the humidity rises and the relative humidity increases, the human body still feels comfortable [15].

3.1.2.2 Natural ventilation and cooling and energy saving

The specific heat capacity of the air is low. When there is no ventilation in the building, the temperature of the indoor air is close to the surface temperature of the building. Ventilation is performed when there is a temperature difference between indoor and outdoor of the building, and outdoor air enters the room and exchanges heat with the inner surface of the building [16]. The indoor temperature is ventilated when the outdoor temperature is high, which can reduce the indoor temperature. When the indoor temperature is lower than the outdoor temperature, the indoor humidity can be increased. Generally, the room temperature at night in summer or spring and autumn buildings is higher than the outdoor temperature, and night ventilation is often used to cool down. When using ventilation to cool down, it is necessary to consider the conditions of the climate area where the building is located, as well as the type and use characteristics of the building [17]. For residential buildings, you should avoid opening windows during the day to prevent outdoor high-temperature gas from entering the room. For office buildings, ventilation and cooling can be carried out when the night is free, which can greatly reduce the energy consumption of cooling in summer. In dry and cold conditions, the outdoor temperature is low, and the humidity and water vapor are also low at night. In such cases, the building should control the penetration of cold air and restrict the outdoor air from entering the room [18]. Under humid and hot conditions, the flow of air can promote the evaporation of sweat and the heat dissipation of the human body, and improve human comfort. Natural ventilation can reduce indoor humidity without consuming non-renewable energy, take away moist gas, make the human body feel comfortable, and help reduce energy consumption and pollution.

3.1.2.3 Natural ventilation and living health

After the emergence of the energy crisis, out of consideration of energy conservation, the airtightness of the building was greatly improved, and the indoor space was relatively closed. As a result, the amount of indoor ventilation is insufficient, and incidents of indoor air pollution occur frequently [19]. The emergence of sick building syndromes such as headache, dizziness, nausea, and difficulty concentrating caused indoor air quality to receive great attention in some developed countries in the late 1970s. At present, with the widespread use of air conditioners in Chinese buildings and the increase in airtightness of buildings, the ventilation rate of buildings has decreased, toxic substances such as formic acid and benzene emitted by indoor decoration materials, coupled with man-made carbon dioxide and other exhaust gas cannot be discharged for a long time, it seriously pollutes indoor air quality and endangers people's health. In order to protect people's living health, the country has successively introduced relevant legal standards. Such as "Ambient Air Quality Standard" (GB3095-1996), "Indoor Air Quality Standard" (GB/T18883-2002), "Technical Points for Healthy Housing Construction", etc. People spend most of their lives indoors, so indoor air quality is closely related to people's health. Modern buildings must not only have good comfort, but also pay attention to indoor environmental quality. After experiencing the new coronavirus incident, indoor air quality has been raised to a new height and has become an important indicator for evaluating building quality. To improve indoor air quality, in addition to reducing pollution sources, the use of natural ventilation to supplement fresh air must also be emphasized [20]. Ventilate the room in time to reduce the concentration of pollutants in the indoor air and maintain indoor health.

3.1.3 The basic way of residential ventilation

Building ventilation can introduce outdoor fresh air to dilute it when the concentration of indoor carbon dioxide or air pollutants is too high, which is beneficial to human health. EUROVEN, a European scientific organization, has been committed to studying the impact of ventilation on the health and comfort of users in civil buildings. Studies have shown that when the fresh air volume of an office building is less than 251/ (s· person), the probability of suffering from Sick Building Syndrome (SBS) will increase, which will affect the work efficiency of the staff. When the ventilation frequency of residential buildings is higher than $0.5h^{-1}$, the infection rate of house dust mites can be effectively reduced [21]. Therefore, the European building standards pay much attention to the ventilation performance requirements of the building, and $0.5h^{-1}$ is generally used as the lower limit of indoor air changes. China's "Indoor Air Quality Standards" set the indoor fresh air volume to be at least $30m^3$/ (h· person). In the HVAC code, there are classification restrictions on houses with different per capita living area. The larger value of the two can be used in specific design. For example, in the case of a common household with three households, a per capita housing area of $30m^2$ and a floor height of 3m, the ventilation frequency required by the former is $3*30m^3$/ (h· person)/($270m^3$) = $0.33h^{-1}$, which is less than 0.5 h^{-1}, the minimum number of indoor air changes is $0.5h^{-1}$.

In addition, building ventilation is also an important way of heat exchange between indoor and outdoor environments. When the outdoor temperature is too cold or too hot, ventilation will introduce a large amount of cold or heat into the room, increasing the heating and air conditioning load. However, when the outdoor room temperature is suitable during the transition season, the use of ventilation can effectively improve the indoor thermal environment and reduce the use of air-conditioning equipment. Therefore, ventilation is closely related to the level of building energy consumption. In addition to protecting the health of people, building ventilation design must also meet energy-saving requirements [22]. There are three main forms of building ventilation: window ventilation, air infiltration ventilation and mechanical ventilation. The first two are actually natural ventilation, but in more cases, natural ventilation generally refers to window ventilation.

3.1.3.1 Open windows for ventilation

From ancient times to the present, the residents of southern Shaanxi have had the habit of opening windows for ventilation. Under normal circumstances, if the window area is sufficient, the ventilation frequency after opening the window can reach 10h-1. For some building shapes and exterior window forms that are conducive to natural ventilation, it can even achieve a ventilation intensity of 20^{-1} or more. And there is almost no cost, which is basically unattainable by other methods. However, the disadvantage of natural ventilation lies in its lack of controllability, and it is difficult to control the air volume, wind direction, and air supply temperature [23]. Due to the lack of a filter mechanism for fresh air, window ventilation can only be limited by the conditions of the outdoor environment. It is not suitable to open windows for ventilation under humid, rainy, typhoon, haze or air pollutant concentrations. For a long time, residents in areas with hot summer and cold winter generally use continuous natural ventilation throughout the day as one of the main means of cooling in summer. However, in the case of continuous sunny days in summer, continuous natural ventilation throughout the day will cause a large amount of outdoor hot air to enter the room, especially in the afternoon, causing the room temperature to rise rapidly and a large amount of heat storage indoors. The room temperature of a house with continuous natural ventilation throughout the day can reach up to 36°C during the day, and the average daily room temperature is around 31-34°C. The indoor thermal environment is extremely harsh. This shows that natural ventilation alone cannot meet the comfort requirements of residents in areas with hot summers and cold winters. In addition, when the indoor heating and air-conditioning equipment is turned on, opening windows for ventilation will cause a lot of waste of energy. At this time, the indoor fresh air demand cannot be provided by opening windows for ventilation.

3.1.3.2 Air infiltration ventilation

When the doors and windows of a building are normally closed, indoor and outdoor air can still penetrate through the gaps between doors and windows, door and window openings, electrical junction boxes, pipeline penetrations, etc [24]. The ability of the building to resist such air penetration is called airtightness. Air infiltration is a kind of passive natural ventilation, which can supplement the fresh air to a certain extent, but there is still a big difference between this infiltration and the fresh air required by health standards:

- The air infiltration distribution cannot be uniform. The upper floors of multi-storey or high-rise buildings are generally seepage areas without fresh air supply, and the amount of air infiltrated by the lower floors is often large.
- Air infiltration is carried out all the time, and it cannot be purified. When the outdoor air is particularly dirty, it will increase the pollution of the indoor air.
- Air enters the enclosure structure or thermal insulation structure through the gap, causing humidity damage, causing water vapor condensation or mold, and affecting the indoor air quality and the durability of the enclosure structure.

In addition, air infiltration is also an important factor affecting the level of building energy consumption. In winter and summer, air infiltration introduces cold and heat into the room at all times, resulting in an increase in energy consumption for heating and air conditioning. Relevant studies have shown that the heat loss caused by air infiltration accounts for 25%-50% of the building's heat load [25]. China’s airtightness research started late. In terms of Chinese architectural characteristics, the airtightness of the walls is good, but the airtightness of the exterior windows is very poor. Steel windows and wooden windows were widely used in early buildings, and the gap width could reach 1.5-2.0mm. The Chinese Academy of Construction Sciences has conducted relevant research and testing on the overall air tightness of existing buildings in my country. The results showed that there was serious air leakage in buildings before 2000, and the average number of air changes under 50pa pressure reached 12.4^{-1}, which far exceeded the limit of European standards. In hot summer and cold winter areas, the reference building indoor ventilation frequency set by the current energy-saving standards is $1.5h^{-1}$. The value of $1.0h^{-1}$ for energy-saving buildings also reflects the poor airtightness of buildings in this area to a certain extent.

However, improving air tightness is not always beneficial to building energy consumption. When the frequency of air permeation and ventilation is less than $0.5h^{-1}$, the fresh air volume of natural ventilation is not enough to meet the minimum requirements for human health, and only mechanical ventilation can be increased, resulting in ventilation power consumption [26]. After considering this part of the power consumption, it is found that for the hot summer and cold winter areas, the total building energy consumption does not decrease but rises as the airtightness of the building increases. With the introduction of the Passive House concept into my country, the airtightness of buildings has received unprecedented attention. More and more scholars directly regard high air tightness as a necessary condition for ultra-low energy buildings. However, the relationship between building air tightness and energy-saving effects in hot summer and cold winter areas and its reasonable value range still need to be further analyzed and verified.

3.1.3.3 Mechanical ventilation

As the sealing effect of modern buildings is getting better and better, and natural ventilation is sometimes restricted by factors such as outdoor bad weather and noise, fresh air systems have been commonly used for indoor ventilation in foreign countries. At present, the common fresh air system can be divided into various forms such as unidirectional flow, bidirectional flow, duct type and no duct. The advantage of mechanical ventilation is that the ventilation is organized. After a reasonable pipeline design, there will be no short-circuit ventilation, air flow disturbance, waste gas in the bathroom and kitchen, etc., and it is not affected by the external environment [26]. Various filters can be installed to remove harmful substances in the air and improve the quality of fresh air. In addition, the two-way flow fresh air system can also be equipped with a heat recovery device, so as to make full use of the heat or cold in the return air to heat or cool the fresh air introduced into the room to achieve the purpose of energy saving. The heat recovery device is divided into two types: sensible heat exchange type and total heat exchange type. Sensible heat refers to the heat required to increase or decrease the temperature when the phase change does not occur, while the latent heat refers to the heat absorbed or released during the phase change. Total heat includes both of the above. Hot summer and cold winter areas have higher humidity throughout the year, and the outdoor air in summer is more humid. When using the total heat exchange type, it can not only recover heat, but also play a role in indoor humidity regulation. In contrast, sensible heat is more suitable for this area.

Mechanical ventilation is another product of humans’ pursuit of a higher indoor environment. The combination of it and the high air-tightness of buildings is an important way to achieve the so-called "constant oxygen, humidity, and static". In developed countries in Europe and America, natural ventilation has gradually replaced natural ventilation as the main ventilation measure [27]. However, the disadvantage of mechanical ventilation is that its initial investment is high, and both filters and heat exchangers require routine maintenance, cleaning or replacement. Considering noise and cost, the design air volume of mechanical ventilation is generally controlled at 0.5^{-1}-$1.0h^{-1}$, which is far less than the intensity of window ventilation.

Once indoor air pollution sources are brought into the room, the number of people increases significantly, or other emergencies, mechanical ventilation alone may not be able to effectively adjust the indoor environment, causing discomfort. In addition, Chinese residents have long been accustomed to opening windows for ventilation, and the acceptance of mechanical ventilation may not be very high in the short term.

3.1.4 Basic principles and dominant equations of CFD simulation

3.1.4.1 Governing equation

Xuelin Z. et al. [28] proposed the flow field setting equation in the calculation domain when using CFD for air flow simulation. The advantages and disadvantages between the Navier–Stokes (RANS) equation and large eddy simulation (LES) are discussed in detail. The paper proposes that the RANS simulation may be computationally more economical, time-saving, and more versatile, but RANS cannot resolve fluctuating flow variables, so turbulence components must be removed from the simulation. In addition, they cannot simulate vortex shedding, and they usually overestimate the turbulent kinetic energy near the stagnation point and the flow recirculation of the airflow. LES can solve the governing equations of eddy currents larger than the sub-grid scale and can minimize the above-mentioned shortcomings of RANS. Using LES to simulate turbulence can provide more realistic flow data, including flow intermittent and separation in and around buildings, but this requires a lot of additional calculations. In this study, it is necessary to view the flow data during the simulation at any time and calculate the time for the indoor temperature to reach a steady state. In order to make the simulation more accurate, LES was finally selected as the main simulation method.

The flow field in the computational domain was modeled as an instantaneous, three-dimensional Navier–Stokes equations for a confined, incompressible viscous flow of a Newtonian fluid using Equations (1)– (3) [29]:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial u_i}{\partial t} + \frac{\partial}{\partial x_i}\left(u_i u_j\right) = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(2 v s_{ij}\right) \tag{2}$$

$$\frac{\partial c}{\partial t} + \frac{\partial}{\partial x_j}\left(c u_j\right) = \frac{\partial}{\partial x_j}\left(D\frac{\partial c}{\partial x_j}\right) \tag{3}$$

where u_i and x_i are the instantaneous velocity and position vectors; p is the instantaneous pressure; t denotes time; ρ denotes density; v is the kinematic molecular viscosity; c is the instantaneous concentration; D is the molecular diffusion coefficient or molecular diffusivity; and s_{ij} is the strain-rate tensor as defined in Equation (4):

$$s_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_i}{\partial x_j}\right) \tag{4}$$

3.1.4.2. Large Eddy Simulation (LES)

LES applies a filter function to filter scales smaller than size Δ from the variables in the Navier–Stokes equations. The rearranged Navier–Stokes equations with the filtered variables, denoted by the tilde, can be expressed as:

$$\frac{\partial \tilde{u}_i}{\partial \tilde{x}_i} = 0 \tag{5}$$

$$\frac{\partial \tilde{u}_i}{\partial t} + \frac{\partial}{\partial x_j}\left(\tilde{u}_i \tilde{u}_j\right) = -\frac{1}{p}\frac{\partial \tilde{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left(2v\tilde{s}_{ij}\right) - \frac{\partial \tau_{ij}}{\partial x_j} \tag{6}$$

$$\frac{\partial \tilde{c}}{\partial t} + \frac{\partial}{\partial x_j}\left(\tilde{c}\tilde{u}_j\right) = \frac{\partial}{\partial x_j}\left(D\frac{\partial \tilde{c}}{\partial x_j}\right) - \frac{\partial q_{c,ij}}{\partial x_j} \tag{7}$$

where $\tilde{s}_{ij}$ is the rate of the strain tensor and τ_{ij} and $q_{c,ij}$ are the subgrid-scale (SGS) Reynolds stresses and the subgrid-scale mass fluxes, respectively. τ_{ij} is estimated using the Wall-Adapting Local Eddy-viscosity (WALE) model (Equations (8) and (9)) in this study:

$$\tau_{\mathrm{ij}} - \frac{1}{3}\tau_{kk}\delta_{ij} = -2\mu_t\tilde{s}_{ij} \tag{8}$$

$$\mu_t = \rho L_s^2 \frac{\left(s_{ij}^d s_{ij}^d\right)^{3/2}}{\left(\bar{s}_{ij}\bar{s}_{ij}\right)^{5/2} + \left(s_{ij}^{-d} s_{ij}^{-d}\right)^{5/4}} \tag{9}$$

In Equation (8), μ_t is the SGS turbulent viscosity and τ_{kk} is the isotropic part of the SGS stresses. In Equation (9), L_s is the mixing length (Equation (10)) and s_{ij} is the rate of strain (Equation (11)):

$$L_s = min\left(kd, C_{to}V_{cell}^{1/3}\right) \tag{10}$$

$$s_{ij}^d = \frac{1}{2}\left(g_{ij}^{-2} + g_{ij}^{-2}\right) - \frac{1}{3}\delta_{ij}g_{kk}^{-2}, \text{where } \bar{g}_{\mathrm{ij}} = \frac{\partial \bar{u}_i}{\partial x_j} \tag{11}$$

3.1.4.3. Calculation of the radiation and convection heat transfer coefficient

According to the research of Mengying Z. et al. [30], the surface to surface (S2S) model is used to calculate the radiative heat transfer. The size in the simulation was the same as the real building. The measured average temperature of each wall was used as the boundary condition. CFD can directly calculate the angle of view coefficient with the wall. The subsequent h_r was calculated based on Equation (12), this radiation analysis method has been verified by Yang et al. [31] and used by Gao et al. [32]. Then, h_c is calculated by Equation (13).

$$h_r = \frac{q_r}{(T_{air} - T_{wall})} \tag{12}$$

where h_r (W/ (m^2 ·K)) is the radiant heat transfer coefficient, q_r (W/m^2) is the radiant heat flux, and T_{air} (K) and T_{wall} (K) are the surface of the hand and the wall surface temperature, respectively.

$$h_c = \frac{q_{Total} - q_r}{T_{air} - T_{amb}} \tag{13}$$

where h_c (W/ (m^2 ·K)) is the convective heat transfer coefficient, q_{Total} (W/m^2) is the heat flux required to keep each area of THM at 308.15 K, and T_{amb} (K) is the ambient temperature.

3.1.4.4. Surface to Surface (S2S) Heat Radiation Equation

∇q_r in the energy equation is the divergence of the radiative heat flux, which was described by the surface to surface (S2S) model:

$$q_{r,m} = \varepsilon_m\sigma T_m^4 - (1-\varepsilon_m)\sum_{n=1}^{N} F_{m,n}\, q_{r,n} \tag{14}$$

where $q_{r,m}$ is the energy flux leaving the surface m, ε_m is the emissivity, σ is the Stefan–Boltzmann constant, $q_{r,n}$ is the energy flux leaving the surface *n*, and $F_{m,n}$ is the view factor between surface *n* and surface *m*, described as follows:

$$F_{m,n} = \frac{1}{A_m}\iint \frac{cos\theta_m cos\theta_n}{\pi r^2}\delta_{mn}dA_m dA_n \tag{15}$$

where δ_{mn} is determined by the visibility of dA_n to d_m. δ_{mn} = 1 if dA_m is visible to dA_n and 0 otherwise.

3.1.4.5. Calculation program

ANSYS FLUENT uses the finite volume method to solve the governing equations. The COUPLED algorithm is used for pressure-velocity coupling and basing on the least square method for gradient discretization. The body force weighting scheme was used as a spatial discretization method of pressure. Second-order algorithms were used for momentum, turbulence, and energy equations.

3.1.5 Comfort evaluation index

Indoor thermal comfort is closely related to the indoor and outdoor thermal environment. The indoor thermal environment is a kind of indoor microclimate that is integrated by four parameters: indoor air temperature, indoor air relative humidity, wall surface thermal radiation temperature (usually expressed by the average radiation temperature of the surrounding solid surface) and airflow velocity [33]. Different combinations of various indoor microclimate factors form different indoor thermal environments. Thermal comfort is people's subjective perception of thermal environment, which belongs to the category of physical environment. At the same time, it also involves the physiological adaptations reflected by the organisms formed under the long-term specific and relatively cruel thermal environment. Psychological adaptation to the objective thermal environment changed due to personal experience and expectations, and in a natural ventilation environment, people change the body's heat balance through intentional or unintentional actions. Such as changing clothes, increasing the amount of exercise, fanning, turning on the fan, opening and closing doors and windows and other environmental control methods to adapt to the thermal environment and other behavioral adaptations [34].

Due to the specific climatic conditions in different regions, people's physiques show tolerance to cold and heat in a long-term life. The variables that determine the human body's feeling of cold and heat mainly involve six aspects. The amount of activity and clothing of the person and the four indoor environmental variables (air temperature, air relative humidity, average radiation temperature and air flow rate). Other factors such as race, gender, age, health status, body shape, personality, and mood affect people's feelings, but they have no obvious effect on the average cold and hot feelings of most people in a stable state.

The research on human thermal comfort is one of the earlier research topics in the field of architecture, with many results. Among the evaluation standards for human thermal comfort, ISO-7730 and ASHRAE 55-1992 are currently widely used standards for evaluating and predicting indoor thermal comfort in the world [35,36]. The comfort zone calibrated by ASHRAE 55-1992 is a comfort zone that meets at least 80% of the population. The index PMV-PPD proposed by ISO-7730 for predicting human thermal sensation (Table 3-1), through a large number of experimental studies, on the basis of investigation and statistics, proposed the PMV-PPD index [37]. It is currently a comprehensive evaluation method for evaluating indoor thermal environment parameters and human body conditions (human activities and clothing) on human thermal comfort. It reflects the relationship between various factors more comprehensively and objectively. Another concept related to thermal comfort is thermal sensation. It refers to the subjective feeling of the physical, physiological and psychological comprehensive effects produced by the heat and moisture exchange between the human body and the environment.

Fanger thermal comfort calculation formula:

$$PMV = (0.303e^{-0.036M} + 0.028)[(M - W) - H - E_C - C_{res} - E_{res}] \quad (1)$$

$$PPD = 100 - 95e^{-(0.03353PMV^4+0.2179PMV^2)} \quad (2)$$

In formula:
M-human metabolism heat production rate [W/m²].
W- Human body's required heat rate [W/m²].
H- dry heat loss [W/m²].
EC-skin evaporation heat transfer [W/m²].
Cres- breathing convection heat transfer [W/m²].
Eres- breathing evaporation heat transfer [W/m²].

Table 3-1. PMV-PPD comfort index

Hot sensation	cold	cool	Slightly cooler	neutralize	Slightly warmer	warm	hot
PMV	-3	-2	-1	0	1	2	3

The ISSO-7730 standard recommends PPD≤10% as the design basis, that is, the thermal environment satisfied by more than 90% of people is a comfortable environment, and the corresponding PMV=-0.5-+0.15 at this time. The state with the PMV value of 0 is actually the state with the best thermal comfort. In order to achieve the thermal comfort index "PMV=-0.5-+0.15", the building interior can only be achieved by air-conditioning. This is due to factors such as gender, age, health, race, body shape and personality. Under certain activity conditions, proper skin humidity and perspiration rate can make people feel comfortable. Therefore, a PMV between -1-+1 can be rated as comfortable, and a value higher or lower than this value can be rated as uncomfortable, the corresponding PDD ≤ 30%. The thermal comfort range proposed by ISO-7730 and ASHRAE 55-1992 standards are shown in Table 3-2 [40].

Table 3-2. The thermal comfort range proposed by ISO-7730 and ASHRAE 55-1992 standards

standard	summer				standard	Winter			
	to ℃	va m/s	Met M/m²	Rcio m²·K/W		to ℃	va m/s	Met M/m²	Rcio m²·K/W
ISO7730	23.0-26.0	0.25	70	0.08	**ISO7730**	20.0-24.0	0.15	70	0.155
ASHRAE 55-1992	19.5-23.0	0.25	70	0.08	**ASHRAE 55-1992**	20.2-24.6	0.15	70	0.155

3.2. The investigation research

3.2.1 Investigation and research of settlement research cases

The study area is the Ankang area of Shaanxi Province, China. It is the southern part of Shaanxi, with the Qinling Mountains in the north and Daba Mountain in the south. The Han River flows from west to east. The Ankang area is a typical two-mountain and a river. The fold-belt of the Qinling Mountains runs east-west. Therefore, the Ankang area is mostly mountainous, with sub-alpine, mid-mountain, low-mountain, basin and other landforms. The traditional villages in the Ankang area are mostly distributed in the flat terrain on both sides of the river or built on the hillside, while a few are built entirely on the top of the mountain, and farmland is reclaimed for work in the relatively gentle slope of the mountainside. At the same time, the distribution of traditional villages is also inseparable from factors such as climate conditions and natural resources.

The above not only directly affects the distribution of traditional villages, but also has an impact on the cluster-like layout and spatial form of traditional villages. The traditional village groups located on both sides of the river and built on the mountain are mostly belt-shaped, with a belt-shaped road network structure as the planning structure. In Ankang City, 46 traditional villages were finally selected for investigation. It is a typical and representative village as shown in Table 3-3:

Table 3-3. Overview of the spatial form of villages and towns

Village name	region	Layout form	Floor plan
Zhongshan Village	Zhaowan Town, Xunyang County	Strip layout	
Hongjun Village	Hongjun Town, Xunyang County	Strip layout	
Changxing Village	Houliu Town, Shiquan County	Discrete layout	
Panlong Village	Hengkou Town, Hengkou District	Lumpy layout	
Wanfu Village	Chiyan Town, Xunyang County	Radial layout	
Dongshahe Village	Zhongchi Town, Shiquan County	Radial layout	
Shuhe Village	Shuhe Town, Xunyang County	Strip, tandem layout	

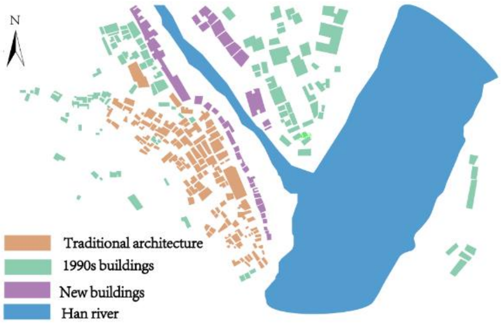
Based on the above information, the overall spatial form of the traditional village and the layout of the buildings in the village should be fully considered when selecting the survey site. Among the many traditional villages in Ankang, the spatial and microclimate characteristics of the survey objects are divided into flat land type, valley type, and river valley type, and then selected according to the research purpose. Among them, valley-type villages are affected by various forms of wind, such as valley wind and land water wind, and are most likely to form a characteristic regional microclimate, which is representative. Therefore, Shuhe Town, Xunyang County, Ankang City is the research object.

3.2.1.1 Settlement study case building distribution status

Before field surveys, classify the buildings in the settlement according to the time they were built, and understand the location of the traditional buildings in the entire settlement. Grasp the division of functional partitions as much as possible to facilitate the purposeful data measurement in the future. Figure 3-1a shows the distribution of buildings in the entire village, which reveals the layout of the distribution of buildings in the village. Figure 3-1b shows that the buildings in the village are classified according to the age, and they are divided into three categories, namely Qing Dynasty buildings, 80-90s buildings and newly built buildings. Because Shuhe Town is a tourist village, the core tourist area is the distribution area of Qing Dynasty buildings, so the daily flow of people is the largest within its architectural layout (Figure 3-1f). Therefore, the research on the ventilation performance here is particularly important. Therefore, in the data measurement, the distribution area of Qing Dynasty buildings is taken as the key test area. In the 1990s building (Figure 3-1d) and the modern new building (Figure 3-1e), only a few test points were selected.

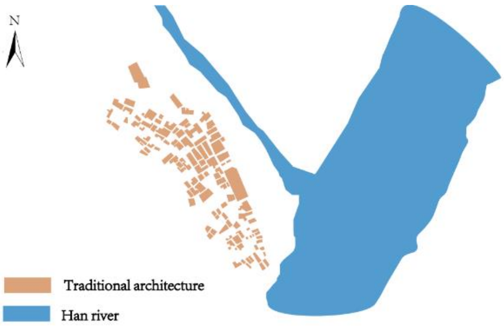
(a) Satellite maps.

(b) Overall building distribution.

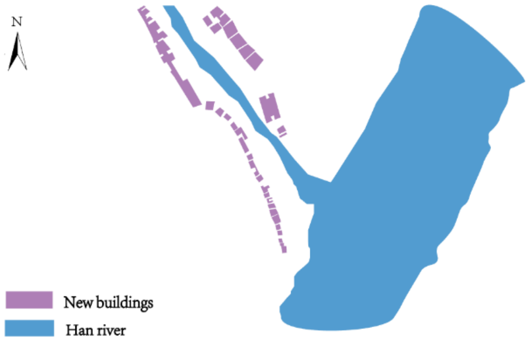


(c) Distribution of buildings in different periods.

(d) 1990s buildings.



(e) Traditional architecture left over from the qing dynasty.



(f) new buildings.

Figure 3-1. The distribution of buildings in the village: (a) Satellite maps; (b) Overall building distribution; (c) Distribution of buildings in different periods;(d)1990s buildings;(e) Traditional architecture left over from the qing dynasty; (f)new buildings.

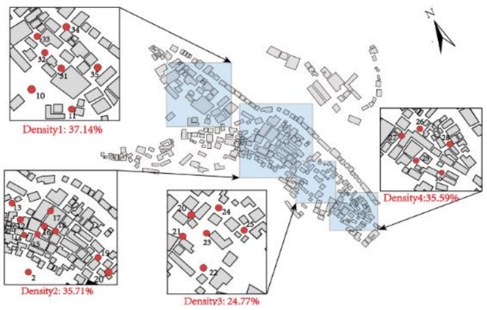
3.2.1.2 Analysis of the cold air storage capacity in cold alleys

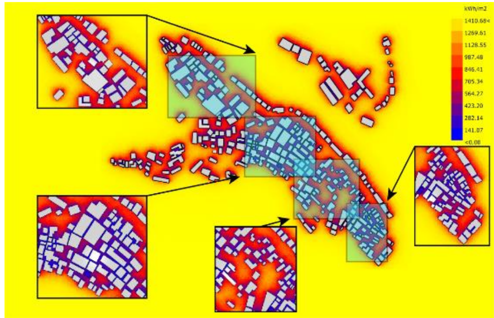
After investigating the local climate and measuring the study cases, it is also necessary to analyze the cold air storage capacity of the cold alleys. The ability of cold alleys to store cold air includes two aspects. First of all, considering the narrow size of the streets of the cold alleys, the bottom of the cold alleys does not have the ability to receive a lot of solar radiation, which will cause the temperature of the bottom of the cold alleys to be different from the average outdoor temperature, so it is necessary to analyze its sunshine duration and the intensity of solar radiation. Secondly, the ability to store cold air is also related to the air flow in the cold alleys, so the wind environment in the cold alleys must be analyzed.

a. Sunshine and temperature analysis in cold alleys

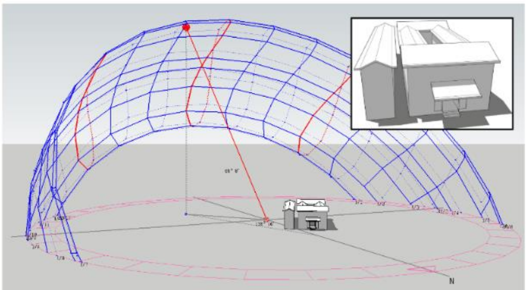
To understand the distribution of streets in Shuhe in more detail and facilitate subsequent research on the solar radiation and ventilation performances of the streets and lanes, in this study, the entire village was roughly divided into different building densities, as shown in Figure 3-2a. For the four areas, the building densities were 37.14%, 35.59%, 35.71%, and 24.77%, respectively. With the gradual decrease in density, the sizes of the roads and lanes in these four areas were divided into four gradually decreasing levels. To obtain a more detailed understanding of the temperature and ventilation conditions of the streets and lanes at different scales, a total of 30 points were selected as actual measurement points in the streets and lanes of areas with different densities so as to facilitate data comparison and analysis.

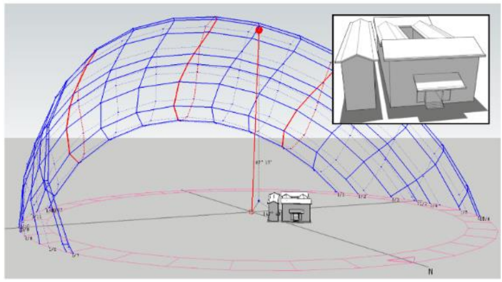
Figure 3-2b shows the solar radiation intensity of Shuhe over a year. It can be seen that as the density of the buildings increases, the amount of solar radiation received in the streets and lanes gradually decreases. In the densest areas (37.14%, 35.59%), the annual solar radiation in the streets and lanes is between 141.07 kwh/m^2 and 282.16 kwh/m^2. This means that almost all of the streets are in a state of no sunlight throughout the year. Figure 3-2c, d, e shows the sunshine conditions of the streets and cold alley during a day. It can be seen that there is only a short period of sunshine (from 12:00 to 13:00) in the day, and that the area receiving solar radiation is only 1.58 m^2. The temperatures of the cold alley and outdoor air are the closest at 5:00 in the morning, at approximately 26.2 °C. With the passage of time, the difference between the two temperatures increases, reaching a peak at 17:00. At this time, the temperature in the cold alley is 33.1 °C and the outdoor normal temperature is 38.8 °C; thus, the difference reaches 5.7 °C (Figure 3-2f).



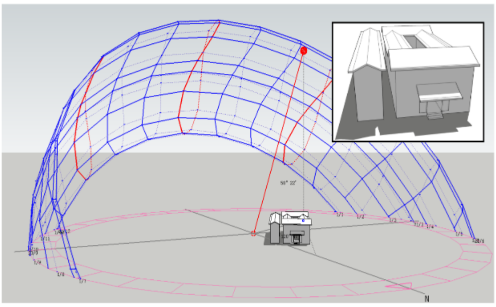


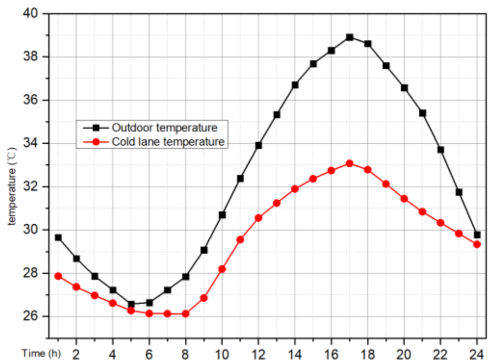
(**a**) Building density zoning of the main village. (**b**) Village solar radiation analysis.





(**c**) Daylighting in the cold alley at 11:00. (**d**) Daylighting in the cold alley at 12:00.



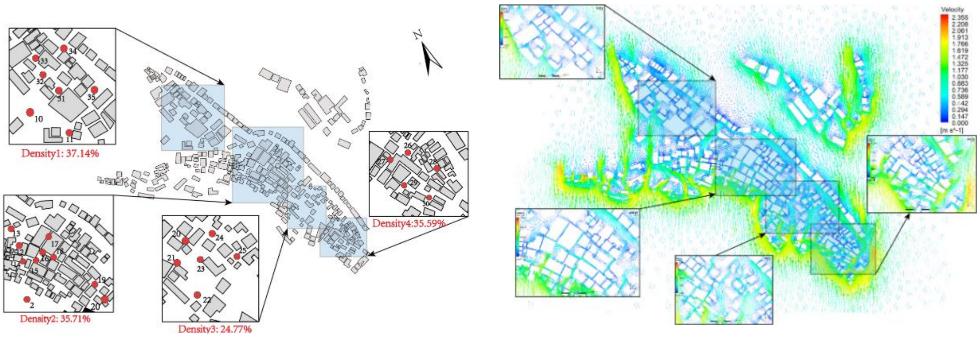


(**e**) Daylighting in the cold alley at 13:00. (**f**) Comparison of cold alley temperature and outdoor normal temperature.

Figure 3-2. Analysis of solar radiation and temperature in the cold alley. (a) Building density zoning of the main village. (b) Village solar radiation analysis. (c) Daylighting in the cold alley at 11:00. (d) Daylighting in the cold alley at 12:00. (e) Daylighting in the cold alley at 13:00. (f) Comparison of cold alley temperature and outdoor normal temperature.

b. Ventilation in the cold alley

The reasonable use of natural ventilation is a very important method for the passive ventilation and cooling of buildings. This can increase the ventilation frequency in the building, reduce the temperature, and improve the comfort of residents; moreover, it can also save a certain amount of energy consumption. Therefore, in this study, the cold air in the cold alley was introduced into the building rooms, and street ventilation values of different sizes of streets were analyzed. As shown in Figure 3-3, the airflow velocity in the streets is positively related to the size of the street, as the air is blocked by other surrounding buildings. In the narrowest street (cold alley), the wind speed is only 0.147 m/s. Because there is no horizontal airflow, the cold air in the cold alley is not easily lost, showing that the cold alley has good heat insulation and that the main method of air flow is Heat pressure ventilation. Heat pressure ventilation can be used as a necessary condition for the passive cooling of buildings. Moreover, as the air flow accelerates, the ventilation efficiency in the room will also be greatly improved.



(**a**) Building density zoning of the main village. (**b**) Ventilation situation of different streets.

Figure 3-3. Ventilation analysis of village streets. (a) Building density zoning of the main village. (b) Ventilation situation of different streets.

Through actual measurements of the various data of the case study and analysis of the laneways of different widths in the village, it was concluded that the cold alleys received a small amount of solar radiation during the annual sunshine period; thus, their temperatures were lower than the normal outdoor temperature. Owing to the hindrances of other buildings in the village, the horizontal ventilation capacity was weak, so the cold air in the alley could be preserved.

3.2.2 Investigation and research of architectural cases

Figure 3-4a shows the basic case of this research, which is an enclosed courtyard surrounded by four two-story buildings. The height of the first floor in all buildings is 3 m, and the height of the second floor is 2.8 m. The courtyard space is 9.2 m, and the depth is 22.9 m. The outer retaining wall is a blue brick masonry structure, and all of the buildings have sloped roofs. A sloped roof can play a role in shading and drainage. This is a typical Chinese traditional arrangement centered on the courtyard, and the courtyard is representative of those in Shuhe.

(a) Research case situation.

(b) Situation in a cold alley.

Figure 3-4. Research case and cold alley. (a) Research case situation. (b) Situation in a cold alley.

Shuhe is mainly composed of ancient buildings from the Ming and Qing dynasties. It is 160 m wide from east to west and 735 m long from north to south, covering an area of approximately 9.78 hectares. The street node system mainly comprises three levels: main streets, roadways, and street nodes. The streets comprise three vertical main streets and five horizontal lanes, which run through the entire village and town. The layout of the streets and lanes is dominated by broken lines. The laneway and main street intersect vertically, and the laneways are connected to each other by alleys to form a complete street lane system. The middle street, as the main axis, is the core of urban development. The scale of the roadway is relatively narrow, and the width of the narrowest street is less than 2 m, fully reflecting its subordination to the main road. The narrow lanes effectively reduce the traffic volume, allowing the residents in the lanes to obtain a comfortable living environment. The street scale of a traditional building follows ancient heritage and is narrow and compact. Most of the roadways are too narrow, leading to insufficient sunlight, less direct solar radiation, heavy rainfall, and moist ground; these promote the growth of mosses and ferns, and the photosynthesis of such plants can absorb the surrounding heat. Under the comprehensive influences, the temperature in this type of tunnel (which we call the "cold alley") is lower than the outdoor temperature (Figure 3-4b). As an auxiliary road, a cold alley comprises high and low pedestrian steps for connecting the main streets as a whole so that the roads of the entire ancient town are connected to a network interconnection system.

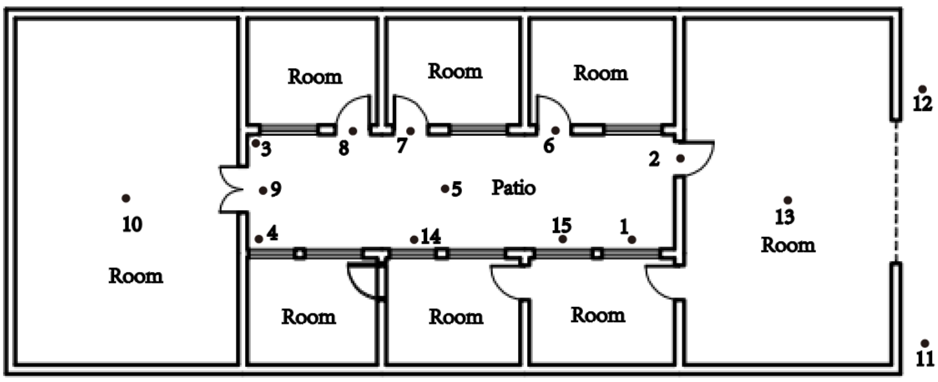


Figure 3-5. Distribution of building measurement points

The test point distribution of the research case is shown in Figure 3-5. A total of 15 points are arranged, and points 11 and 12 are points outside the courtyard. Point 2 leads from the entrance room to the courtyard. 6, 7, 8, 14, and 15 are the test points of the building windows in the courtyard. Points 6, 7, 8, and 9 are test points at the entrance of the building. 10 and 13 are selected points inside the building. 1, 3, 4, and 5 are the test points at the four corners and the middle of the courtyard, respectively.

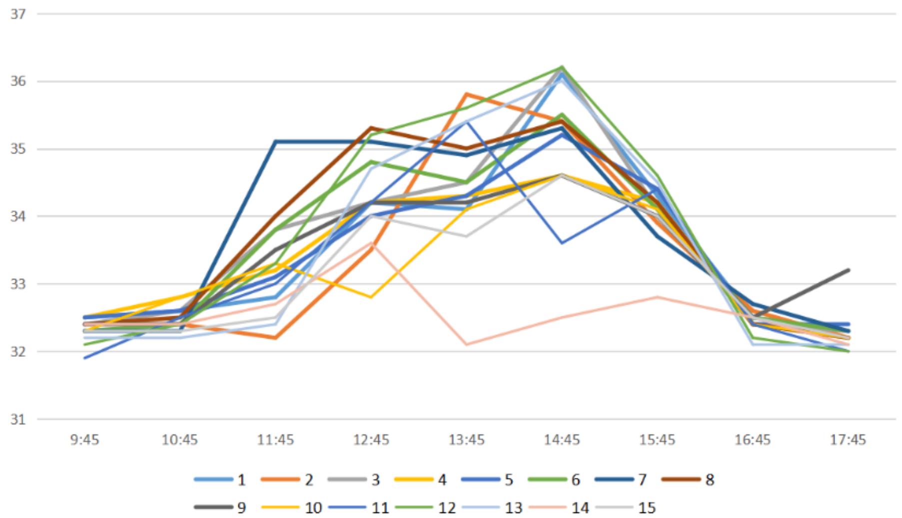


Figure 3-6. Building temperature

The temperature change of the selected courtyard is shown in Figure 3-6. The overall temperature change range during the test period is between 36.2~32.1℃. The temperature is highest at 14:45 in the afternoon. During the period of the highest temperature, it can be seen that the temperature at most points in the courtyard is higher than that of the outdoors. Because of the occlusion of the interior of the courtyard, the point on the left side of the courtyard is in the architectural projection, and the temperature is generally lower than that of the point on the right.

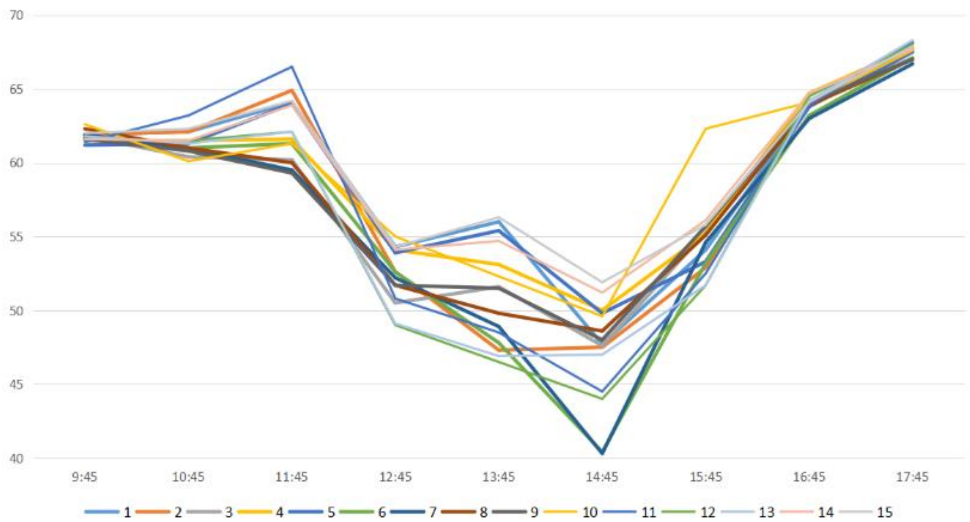


Figure 3-7. Building relative humidity

The humidity line chart of different measuring points of the building in different time periods is shown in Figure 3-7. The temperature is the highest in the time period of 12:45~15:45, so the air humidity is the smallest. The air humidity in the morning and evening is relatively high. At 14:45, when the air humidity is at its minimum, the air humidity inside the courtyard is still higher than that outside. The humidity inside the courtyard building is also relatively high, which is all caused by poor air circulation.

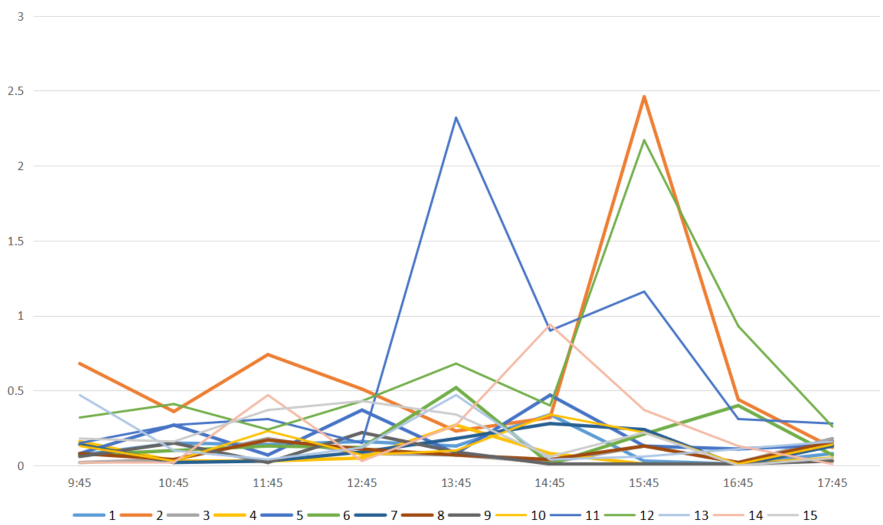


Figure 3-8. Building wind speed

The broken line graph of wind speed at different measuring points in the building during different time periods is shown in Figure 3-8. It can be seen that the wind speed changes at points 11, 12, 2 and 6 are the largest. Because points 11 and 12 are test points outside the courtyard, the external space of the courtyard is relatively fluid. Point 2 is the entrance to the courtyard, and the wind tends to form a "crack" at the entrance, so the wind speed at Point 2 also changes significantly. Point 6 is just downwind of Point 2. Affected by Point 2, the change in wind speed is also relatively large. The wind speed changes at the other points are relatively small, and the wind speed inside the courtyard is generally lower than that outside the courtyard. The wind speed at the door and window of the building is slightly higher than that in the interior, but the magnitude is not very large.

3.3. Simulation and comparative analysis research method

3.3.1 Choice of numerical simulation solver

3.3.1.1 Data measurement and model setting.

Before the field survey, the buildings in the settlement were classified according to the time of construction to understand the location of the traditional buildings in the whole settlement and to grasp the division of functional zones, so as to facilitate the data measurement in the following research. Due to its unique Qing Dynasty architectural features, Shuhe has attracted a large number of tourists from all over the country in recent years and has become a famous tourist village in Shaanxi. The core tourist area is the area with Qing Dynasty buildings. In this area, the daily flow of people is the largest (Figure 3-1e), so research on the ventilation performance here is particularly important. Therefore, when measuring wind speed and turbulence intensity, the distribution of Qing Dynasty buildings was regarded as the key test area. In the modern and 1990s buildings, only a few test points were selected. The distribution of test points is shown in Figure 3-10a. Shuhe is located on the northern edge of a subtropical zone, in a climate transition zone between China's north and south. To the north of the village is the Qinling Mountains, blocking the cold air from the northwest to the south. The Ba Mountain in the south slows the warm and humid airflow from the southwest and southeast to the north and provides heat preservation and moisture protection. The weather in spring is changeable, with uneven hot and cold. The summer is hot, with large amounts of precipitation. It is rainy in autumn, and the river water is scarce and unstable in winter. As shown in Figure 3-10c, the highest temperature in the village during the year is 39.2 °C, and the lowest temperature is −4.7 °C. The annual rainfall is 800−850 mm, the average precipitation is 831.3 mm, and the relative humidity is 79%. Due to the concentrated rainfall in summer and autumn, the frequent monsoons, and the higher mountain slopes in the village, the probability of torrential rain has increased, causing the water levels of the two streams to rise, causing flood disasters. The annual average sunshine is 1790.4 h, and the maximum frozen soil depth is 0.26 m. Due to the high temperature and frequent rainfall in summer, the air humidity inside the village is directly higher. Accurate simulation of natural ventilation is particularly important for this entire village. Therefore, in this study, we chose to measure wind environment data during the peak tourist season, which has high temperatures and heavy rainfall (June 22, 23, and 24). We compared the measured data with the simulated data to verify the accuracy of the three CFD model simulations. As shown in Figure 3-10a, a total of 35 points were selected for field measurements in the study area of the village. The test time was from 9:00 a.m. to 7:00 p.m. according to the number of tourists, and data were recorded every ten minutes. Because we mainly considered the values at the height of the tourist crowd, we focused on analyzing the height of the human body when standing and sitting. Therefore, height was controlled within the range of 0–3 m, and measured separately at 0.5, 1.0, 1.5, 1.7, 2.0, 2.5, and 3.0 m. Table 3-4 introduces the detailed information of the instruments used in the field measurement, and Figure 3-9 shows the average wind speed at the height of 0–3 m at 35 measuring points.

Table 3-4. The detailed information of the instruments.

Instrument	Model	Precision	Measuring Range	Use
Hot wire anemometer		0.01 m/s	0.1–30 m/s	Measure wind speed
Infrared rangefinder		±1.0 mm	0.05–150 m	Measure distance

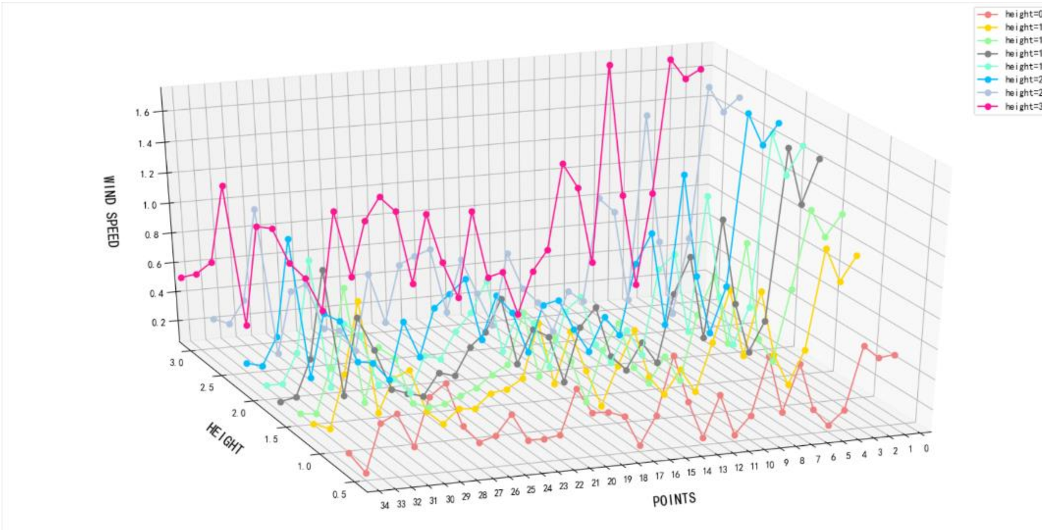


Figure 3-9. Measured wind speed values at 35 points.

The calculation of turbulence intensity adopts the method provided by [41]: The turbulence intensity, also often referred to as turbulence level, is defined as:

$$I = \frac{\mu'}{U'} \tag{1}$$

where μ' is the root-mean-square of the turbulent velocity fluctuations and U is the mean velocity (Reynolds averaged).

If the turbulent energy, k, is known μ' can be computed as:

$$u' \equiv \sqrt{\frac{1}{3}\left(u'^{2}_{x} + u'^{2}_{y} u'^{2}_{z}\right)} = \sqrt{\frac{2}{3}k} \tag{2}$$

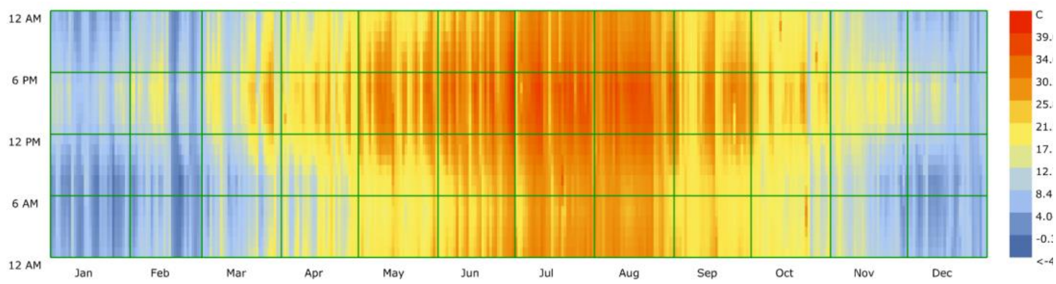
U can be computed from the three mean velocity components U_x, $U_y$and $U_z$as:

$$U = \sqrt{U_x^2 + U_y^2 + U_Z^2} \tag{3}$$

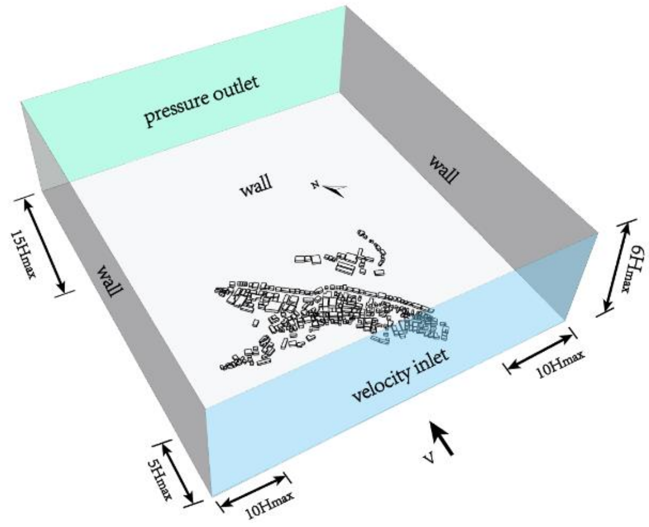
As shown in Figure 3-10d, the simulation geometry was established in the CFD model at a ratio of 1:1 after field measurement. The simulation mechanism of the external atmosphere is based on the methods provided in [42,43,44]. This method has undergone many experimental applications. The height was six times that of the tallest building in the village, the distance between the air outlet and the air inlet was five and fifteen times that of the tallest building, and the height and width were ten times that of the tallest building. The boundary conditions of the entrance, including the average wind speed value and turbulence intensity, were established based on the measured data, and the aerodynamic roughness length was determined by the measured average wind speed. In the inner area, an accurate model was established. The roughness of the bottom area and the wall was set to 0, which is regarded as a smooth and frictionless surface. A zero static gauge pressure was set in the exit area. The mesh was divided into a local density method (Figure 3-10e). The mesh used the proximity and curvature in the surface grid to divide the model into 9,357,352 units. Another advantage of using proximity and curvature is that the details inside the village can be processed more finely so that the simulated results are more accurate.

(**a**) Distribution of measuring points.

(**b**) Scope of the study case.



(**c**) Outdoor temperature distribution of study cases throughout the year.



(**d**) Study case boundary conditions.

(**e**) Meshing of study cases.

Figure 3-10. (a) Distribution of measuring points. (b) Scope of the study case. (c) Outdoor temperature distribution of study cases throughout the year. (d) Study case boundary conditions. (e) Meshing of study cases.

3.3.1.2. Setting and verification of the air inlet wind speed

The wind speed of the air inlet required for the simulation was determined using the measured data. As shown in Figure 3-11a, the average wind speed of the three green points was taken as the wind speed of the air inlet during the simulation. Before this, it was necessary to compare the wind speed at the three green points. If the wind speed difference between the three points was too large, it could not be used as the basis for the wind speed at the air inlet. Figure 4 shows the results of the comparison: the average wind speed at the height of 0.5–3.0

m at the three points at the air inlet of the study case. The difference between the No. 1 and No. 2 points is 4.635%, the difference between No. 1 and No. 3 points is 1.3%, and the difference between No. 2 and No. 3 points is 4.82%. The values are all within the deviation range, so we determined the three sets of data could be used as the basis for determining the inlet wind speed.

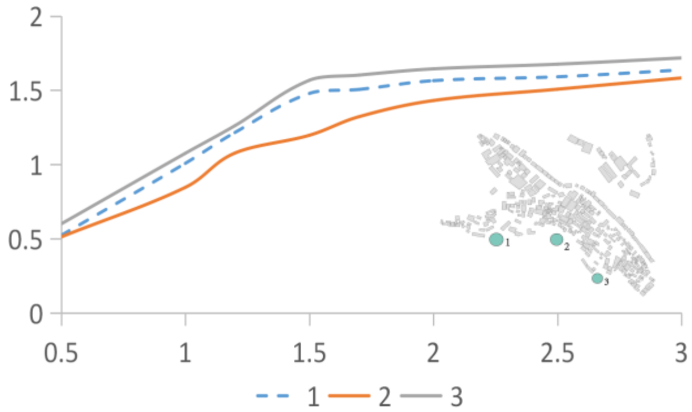
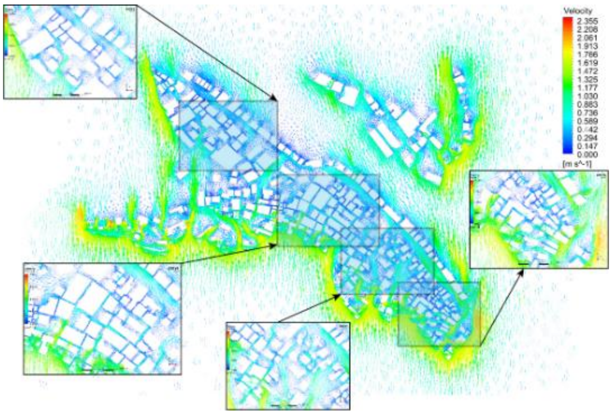


Figure 3-11. Deviation analysis of the 3 points at the air inlet.

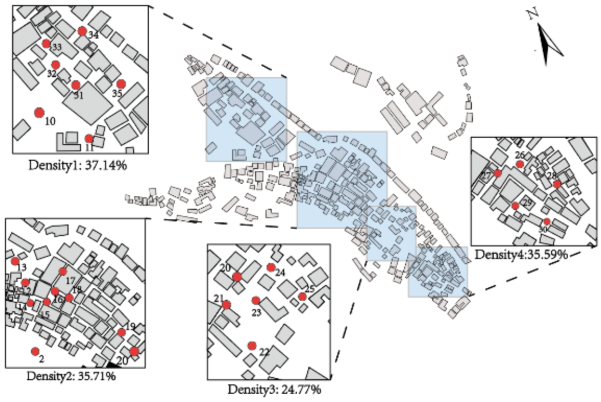
3.3.2 Results and discussion

3.3.2.1 Comparison of measured data and Simulated data inside the village

Before conducting a detailed comparison between the measured and simulated data, we first performed a rough simulation of the overall wind environment of the village. As shown in Figure 3-12a, we found that the airflow rate in the village is affected by the width of the street, which depends on the building density of the area. As the data at a single measurement point may not be able to represent the characteristics of the overall wind environment in the area, the whole village was divided into four parts according to different building densities. The wind speed values of all measurement points in each area were weighted and averaged, and the calculated values were compared with the results produced by the three different solution methods to increase the representativeness of the data. As shown in Figure 3-12b, the building densities of the four areas are 37.14%, 35.59%, 35.71%, and 24.77%. The gradual decrease in building density, street size, and lanes in these four areas was also divided into four different levels, which decrease in sequence.



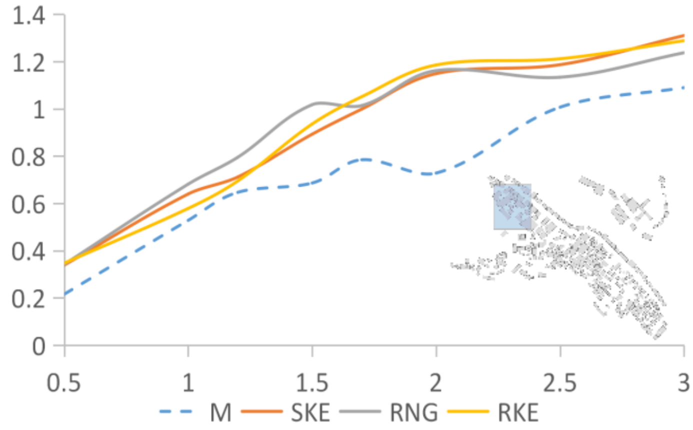
(a) Wind environment of study case.



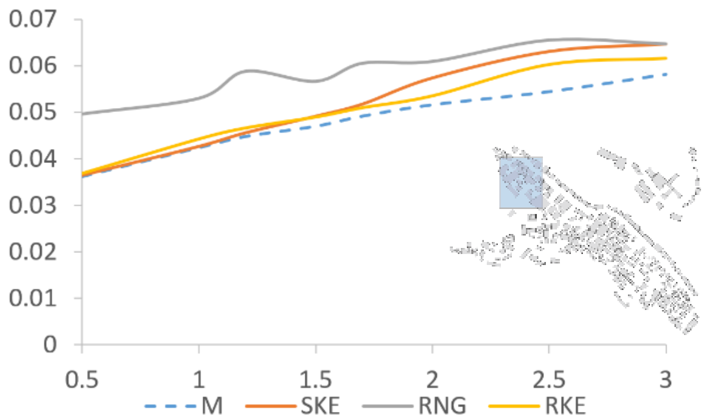
(**b**) Study cases are divided by different building densities.

Figure 3-12. (a) Wind environment of study case. (b) Study cases are divided by different building densities.

Figure 3-13 shows the comparative analysis of the wind speed and turbulence intensity values at seven points in the area where the building density is 37.14% and the data simulated by the three solution methods. The abscissa is the wind speed, and the ordinate is the height. The wind speed at the measuring point increases with the increase in height. After comparison, we found that different solution methods led to different deviation values between the simulated and measured data. As shown in Figure 3-13a, the simulation results of the three solution methods are all higher than the actual measured values. The SKE calculation result is the closest to the measured value, and the overall numerical distribution is about 9.74% higher than the measured value. The calculation results of RNG and RKE are 14.24% and 13.79% higher than the measured values, respectively. As for the turbulence intensity, Figure 3-13b shows that the calculation results of the three are slightly higher than the measured values, and the deviations are 11.66% and 17.2%, and 8.52%, respectively. The value simulated by RNG is significantly higher than those of SKE and RKE.



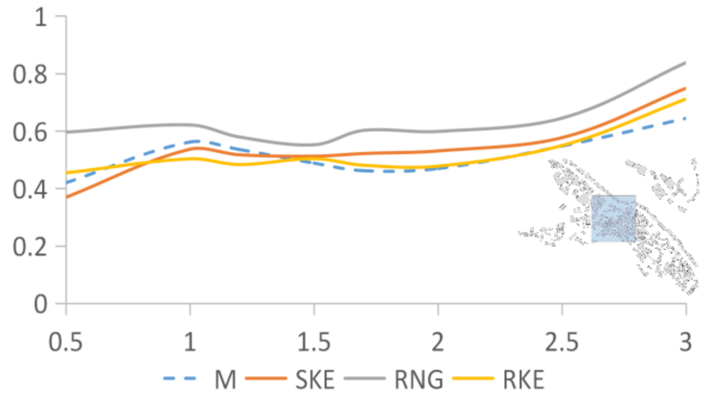
(a) Wind speed comparison between SKE, RNG, RKE, and measured data.



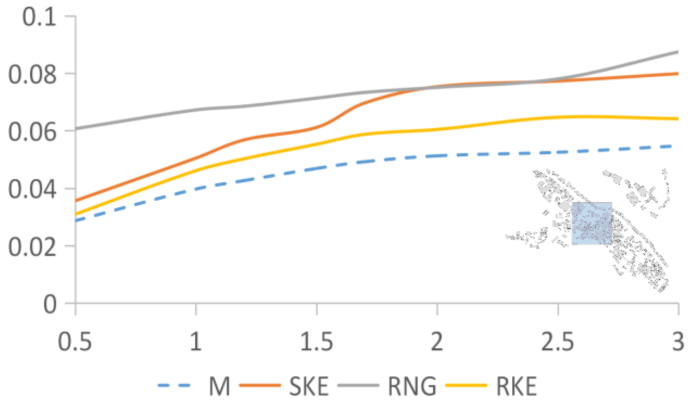
(**b**) Comparison of turbulence intensity between SKE, RNG, RKE, and measured data.

Figure 3-13. Analysis of measured and simulated data produced by SKE, RNG, and RKE in an area with a building density of 37.14%. (a) Wind speed comparison between SKE, RNG, RKE, and measured data; (b) Comparison of turbulence intensity between SKE, RNG, RKE, and measured data.

Figure 3-14 compares the measured and simulated data of the 35.71% building density area, which expresses the relationship between the values simulated by SKE, RNG, and RKE and the measured values. The wind speed and turbulence intensity data solved by RNG are higher than the measured values, SKE, and RKE. As shown in Figure 3-14a, the wind speed data from the SKE and RKE simulations are consistent with the measured data. The deviation values are 20.53% and 26.26%, respectively. The deviation between the numerical value simulated by RNG and the measured result is 45.21%, but the movement trend of the curve is similar to the previous two. For the turbulence intensity (Figure 3-14b), the value produced by RNG is significantly higher than the other three curves, and the deviation is the largest, at 17.04%. The fit of the other two sets of data is above 95%, the deviation of SKE is 2.28%, and the deviation of RKE is 0.77%.



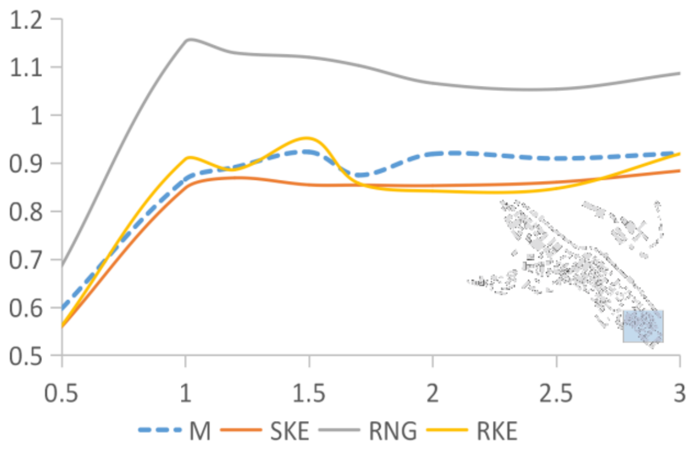
(**a**) Wind speed comparison between SKE, RNG, RKE, and the measured data.



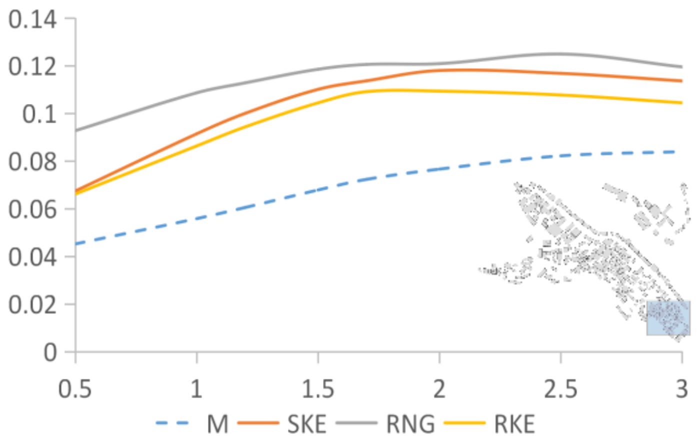
(**b**) Comparison of turbulence intensity between SKE, RNG, RKE, and the measured data.

Figure 3-14. Analysis of measured values and data simulated using SKE, RNG, and RKE in an area with a building density of 35.71%. (a) Wind speed comparison between SKE, RNG, RKE, and the measured data. (b) Comparison of turbulence intensity between SKE, RNG, RKE, and the measured data.

In the area where the building density was 35.59%, as shown in Figure.3-15a, the values produced by RNG are still higher than those by the other two solving methods. The data simulated by SKE and RKE are very close to the measured data. The difference between the wind speed value obtained by SKE calculation and the measured value is 3.28%, and the average distribution of wind speed is slightly lower than the measured value overall. The value obtained produced by the RNG calculation is higher overall than the measured value by 13.28%, and the value obtained by the RKE calculation is generally higher than the measured value by 21.43%. However, for turbulence intensity (Figure.3-15b), the results obtained by the three solution methods are consistent. Both the numerical value and the movement trend of the curve are similar to the measured values. The deviations between SKE, RNG, and RKE and the measured value are 14.1%, 17.27%, and 19.05%, respectively.



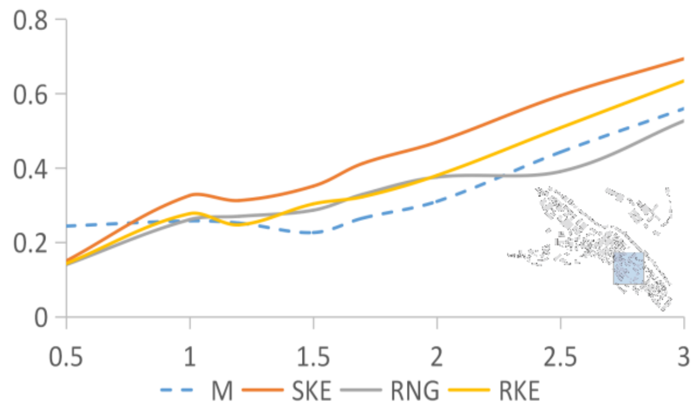
(a) Wind speed comparison between SKE, RNG, RKE, and measured data.



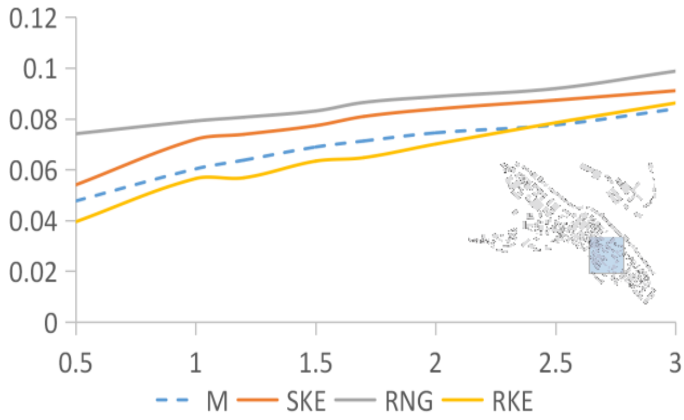
(**b**) Comparison of turbulence intensity between SKE, RNG, RKE, and measured data.

Figure 3-15. Analysis of measured and simulated data of SKE, RNG, and RKE in an area with a building density of 35.59%. (a) Wind speed comparison between SKE, RNG, RKE, and measured data. (b) Comparison of turbulence intensity between SKE, RNG, RKE, and measured data.

Figure.3-15 compares the measured and simulated values in the area with a 24.77% building density. When the building density is between 30% and 40%, the values produced from the RNG solution are always higher than those from SK and, RKE and the measured data. However, Figure.3-16a shows that when the building density drops to 24.77%, the values produced by RNG are close to the other three sets of data. Even at a height of 2–3 m, the wind speed is lower than the other three sets of data. This shows that the accuracy of the RNG solution method may be affected by building density. When the building density is higher than a certain value, using RNG will reduce the accuracy of the simulation. SKE's deviation in the average wind speed is 20.35%, that of RNG is 26.29%, and that of RKE is 12.74%; Figure.3-16b depicts the turbulence intensity data and motion trends corresponding to different solutions. The three sets of simulated and measured deviations are small, 2.38%, 6.46%, and 2.68%, respectively, and the motion trends also fit well.



(a) Wind speed comparison between SKE, RNG, RKE, and measured data.



(**b**) Comparison of turbulence intensity between SKE, RNG, RKE, and measured data.

Figure 3-16. Analysis of the measured values and the values simulated by SKE, RNG, and RKE in an area with a building density of 24.77%. (a) Wind speed comparison between SKE, RNG, RKE, and measured data. (b) Comparison of turbulence intensity between SKE, RNG, RKE, and measured data.

According to the density of the four selected areas, the deviations in the measured and simulated values of the average wind speed and turbulence intensity are listed in Tables 3-5 and 3-6, respectively. From the data comparison, we found that the accuracy of the values simulated by RNG, whether the average wind speed or turbulence intensity, is the lowest. The deviation in the average wind speed is 24.76%. For the turbulence intensity, the deviation value is 12.33%. Conversely, in the simulation of average wind speed, the numerical deviation obtained using SKE is the smallest, at 13.47%. In the simulation value of turbulence intensity, the solution method with the smallest deviation is RKE, with a deviation value is only 6.06%. The deviation evaluation index refers to [45,46,47,48], and the error range is determined to be 15%. It can be seen that in the horizontal wind speed simulation value, only the deviation of SKE is within 15%. However, for the turbulence intensity, the three solvers are all within the deviation range.

Table 3-5. The deviation between the measured and simulated average wind speed for different building densities

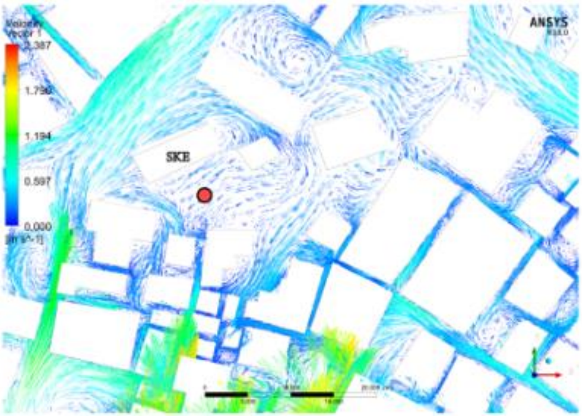
	SKE	RNG	RKE
Density1 (37.14%)	9.74%	14.24%	13.39%
Density2 (35.71%)	20.53%	45.21%	26.26%
Density3 (35.58%)	3.28%	13.28%	21.43%
Density4 (24.76%)	20.35%	26.29%	12.74%
Mean Deviation	13.47%	24.76%	18.46%

Table 3-6. The deviation between the measured and simulated turbulence intensity for different building densities.

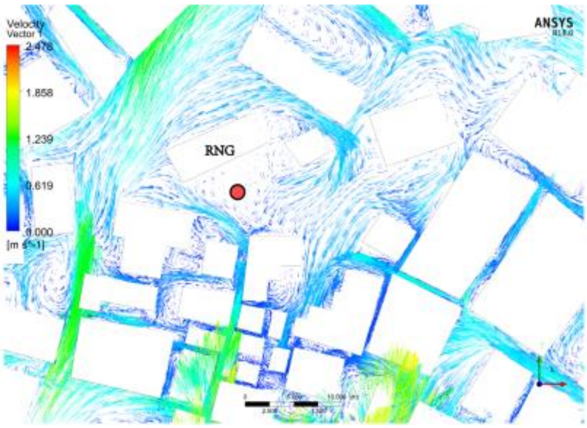
	SKE	RNG	RKE
Density1 (37.14%)	11.66%	8.52%	1.72%
Density2 (35.71%)	2.28%	17.04%	0.77%
Density3 (35.58%)	14.11%	17.28%	19.05%
Density4 (24.76%)	2.38%	6.48%	2.68%
Mean Deviation	7.61%	12.33%	6.06%

3.3.2.2 Reasons for RNG deviation

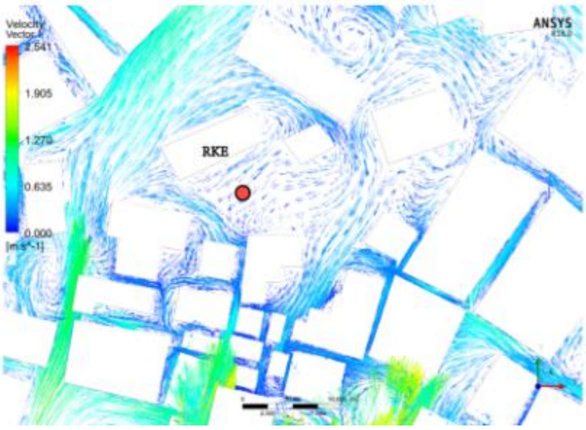
To determine the reason for the larger deviation in RNG, we used 3 of the 35 measuring points for further observation. These three points were points 13, 16, and 25. Taking point 13 as an example, when using SKE (Figure.3-17a) and RKE (Figure.3-17c) to solve the problem, the distribution of wind environment at point 13 is not particularly different, and the air movement trajectory is relatively smooth. However, for RNG (Figure.3-17b), there is a vortex at point 13 and the measurement point is located in the static pressure zone at the center of the vortex, and there is almost no airflow. Therefore, comparing the three solution methods with the measured values, the deviation of the average wind speed values of SKE and RKE are all within 15% (Figure.3-18a, e). However, when using RNG simulation, a large deviation occurs at these three points; as shown in Figure 11c, the simulated value and the measured value could not be fitted at all. However, for the simulated turbulence intensity (Figure.3-18d), the deviation produced by RNG is only 12.54%. Therefore, we assumed that the RNG solver is not accurate enough for the simulation of wind speed, but its simulation of turbulence intensity can be used as a reference.



(a)SKE-simulated wind environment distribution at point 13.

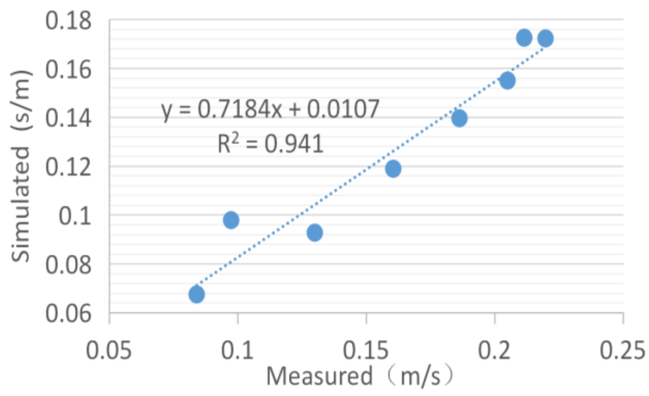


(b)RNG-simulated wind environment distribution at point 13.

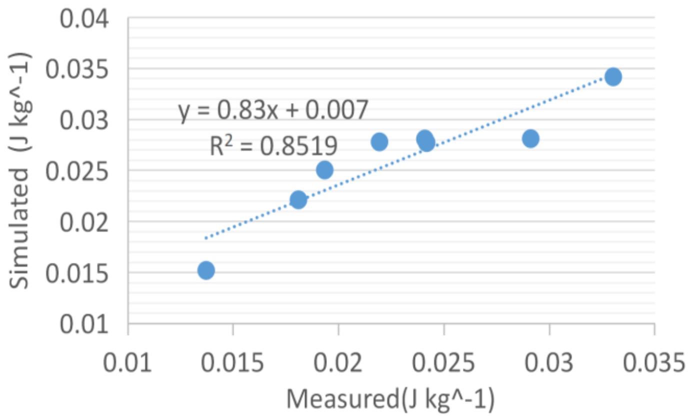


(c)RKE-simulated wind environment distribution at the point

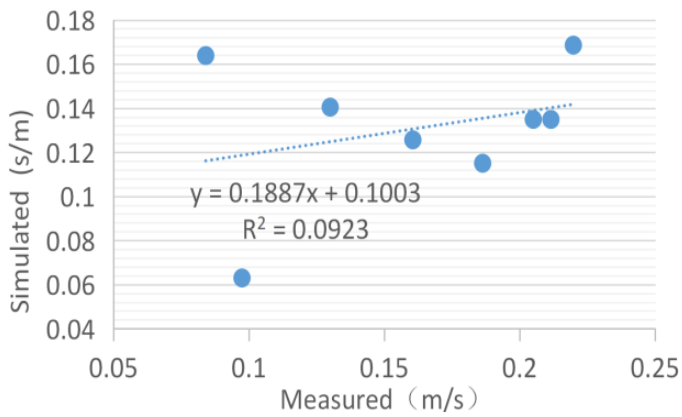
Figure 3-17. SKE-, RNG-, and RKE-simulated wind environment distribution at point 13. (a) SKE-simulated wind environment distribution at point 13. (b) RNG-simulated wind environment distribution at point 13. (c) RKE-simulated wind environment distribution at the point.



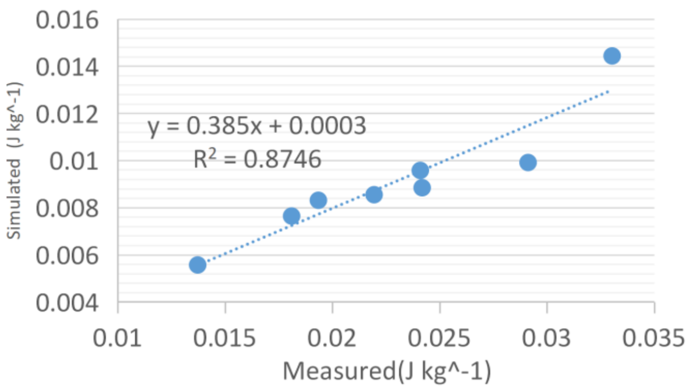
(a)Comparison of wind speed between SKE and measured data.



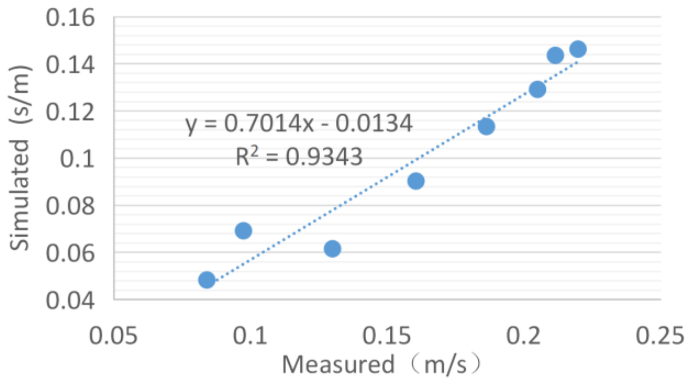
(b)Comparison of turbulence intensity between SKE and measured data.



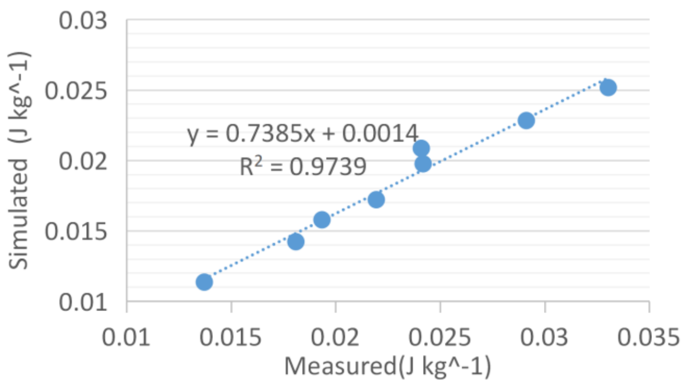
(c)Comparison of wind speed between RNG and measured data.



(d)Comparison of turbulence intensity between RNG and measured data.



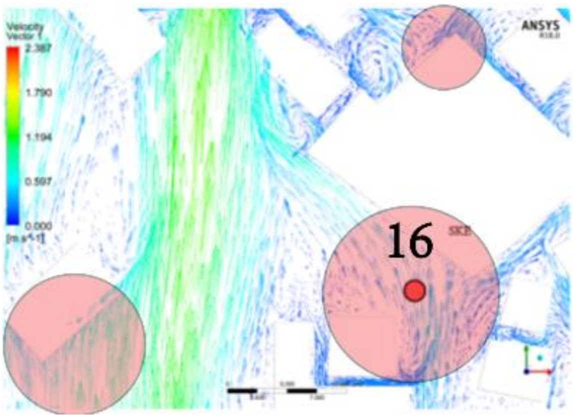
(e)Comparison of wind speed between RKE and measured data.



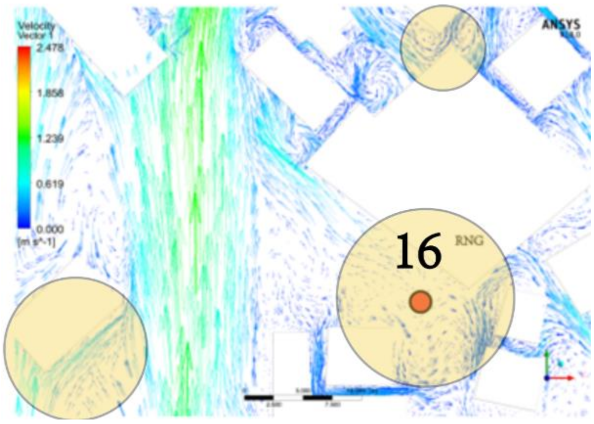
(f)Comparison of turbulence intensity between RKE and measured data.

Figure 3-18. Analysis of measured and simulated data of SKE, RNG, and RKE at point 13. (a) Comparison of wind speed between SKE and measured data. (b) Comparison of turbulence intensity between SKE and measured data. (c) Comparison of wind speed between RNG and measured data. (d) Comparison of turbulence intensity between RNG and measured data. (e) Comparison of wind speed between RKE and measured data. (f) Comparison of turbulence intensity between RKE and measured data.

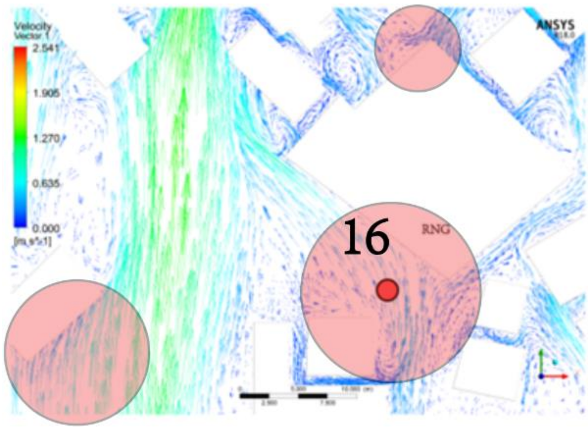
Points 16 and 25 also showed the same problem. Figure.3-19b depicts the difference in the data from the RNG solution. The location of point 16 also has a static pressure zone, and the wind speed value approaches 0 m/s. However, with SKE and RKE, the air is flowing uniformly, and the wind speed at this point is accelerated due to the gap effect. The RNG solution results in the other two areas are significantly different from those produced by SKE and RKE. Figure.3-19d,f shows the wind environment distribution calculated by the three solvers around point 25. Similarly, a large number of vortices are generated in the result using RNG, and the air fluidity does not conform to the conventional logic, which is the reason for the large deviation.



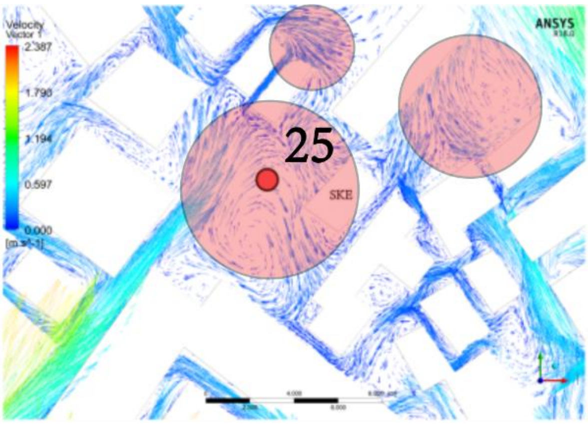
(a)SKE-simulated wind environment distribution at point 16.



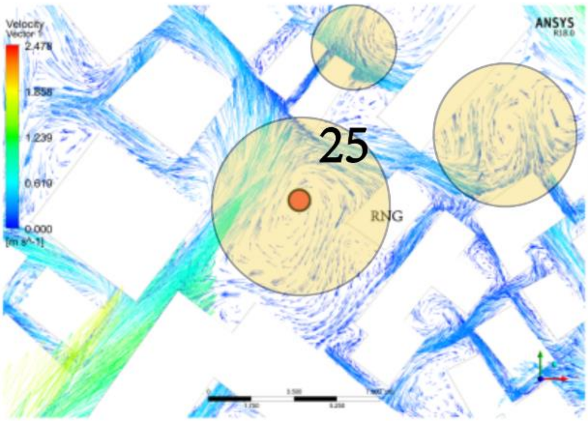
(b)RNG-simulated wind environment distribution at point 16.



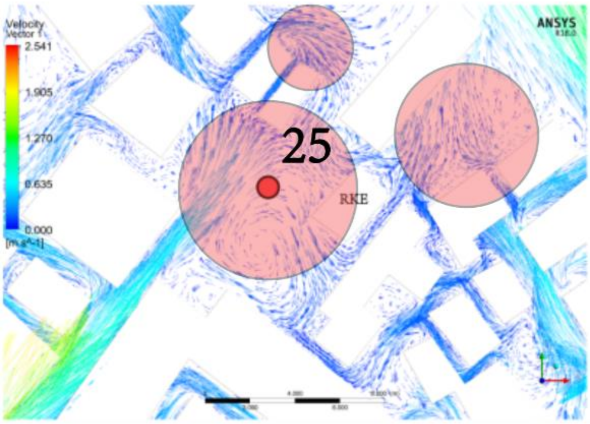
(c)RKE-simulated wind environment distribution at point 16.



(d)SKE-simulated wind environment distribution at point 25.



(e)RNG -simulated wind environment distribution at point 25.



(f)RKE-simulated wind environment distribution at point 25.

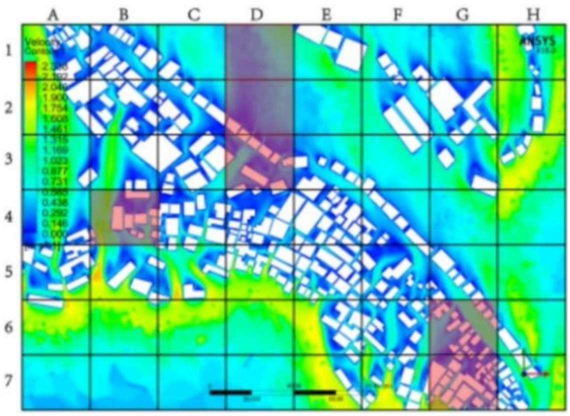
Figure 3-19. SKE-, RNG-, and RKE-simulated wind environment distribution at points 16 and 25. (a) SKE-simulated wind environment distribution at point 16. (b) RNG-simulated wind environment distribution at point 16. (c) RKE-simulated wind environment distribution at point 16. (d) SKE-simulated wind environment distribution at point 25. (e) RNG -simulated wind environment distribution at point 25. (f) RKE-simulated wind environment distribution at point 25.

3.3.3. Comparison of wind environment distribution in the overall village

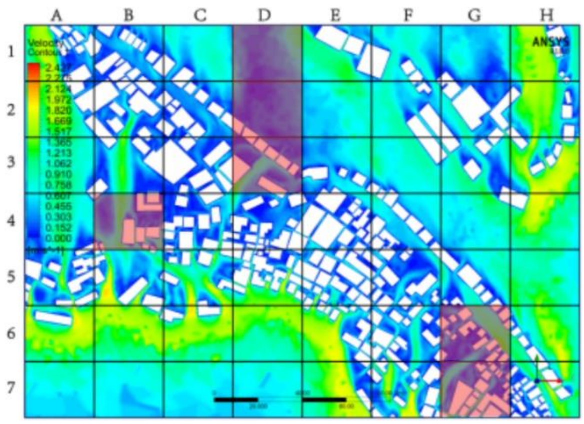
The three different solvers with different calculation methods led to differences in the simulation results. In the above, we mainly discussed the actual wind environment state at each measurement point in the village and the deviation after simulation. The values simulated by SKE and RKE are close to the measured values, but when RNG was used for simulation, a relatively large deviation occurred. Next, we discuss the comparison between the deviation generated when using the RNG solver for simulation and the use of SKE and RKE. We calculated the accuracy and deviation range of RNG’s simulation of the overall wind environment of the village.

3.3.3.1. Horizontal contrast

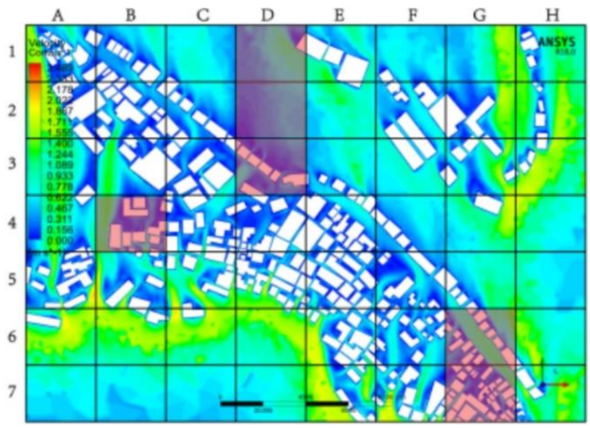
Figure.3-20 shows the difference between the overall internal village wind environment layout simulated by the three solvers, and the turbulence intensity distribution in the area using the same calculation settings and parameters. In Figure.3-20a–c, the green area represents the active part of the airflow, and the blue area indicates that the airflow frequency is relatively low. In Figure.3-20d–f, the cyan area indicates that the turbulent kinetic energy is larger, and the blue area indicates that the turbulent kinetic energy is smaller. The intensity of turbulence can provide an important reference standard for expressing the age of the air; notably, in the CFD simulation of outdoor ventilation, the age of the air distribution inside the village is usually.



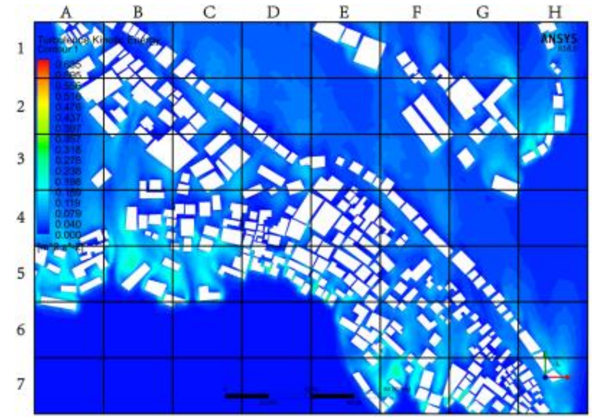
(**a**)The overall village wind environment simulated by SKE.



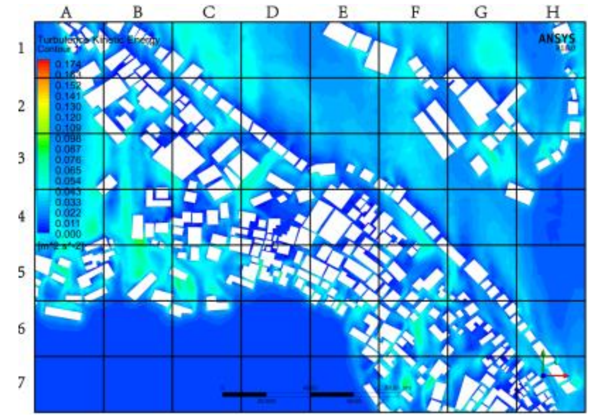
(**b**) The overall village wind environment simulated by RNG.



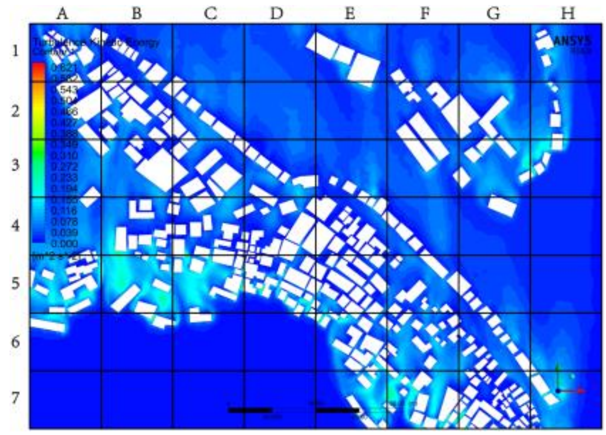
（**c**）The overall village wind environment simulated by RKE.



(**d**) Turbulence intensity of the whole village simulated by SKE.



(**e**) Turbulence intensity of the whole village simulated by RNG.



(**f**) Turbulence intensity of the whole village simulated by RKE.

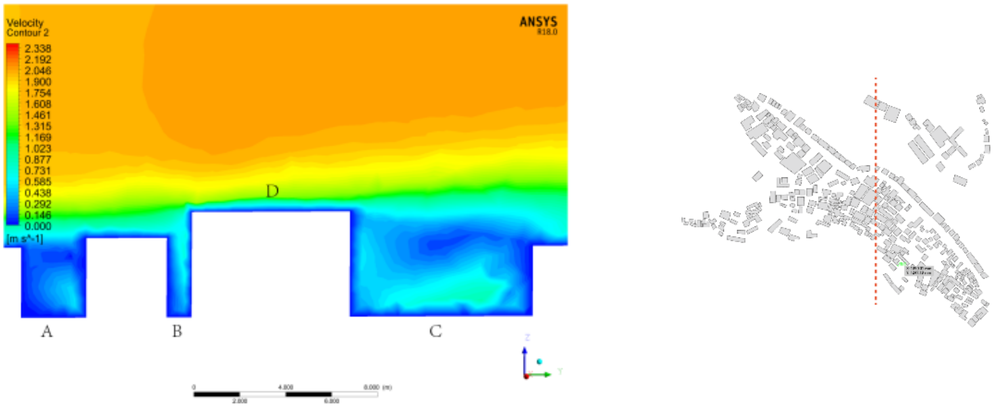
Figure 3-20. Distribution of wind environment and turbulence intensity of the whole village. (a) The overall village wind environment simulated by SKE. (b) The overall village wind environment simulated by RNG. (c) The overall village wind environment simulated by RKE. (d) Turbulence intensity of the whole village simulated by SKE. (e) Turbulence intensity of the whole village simulated by RNG. (f) Turbulence intensity of the whole village simulated by RKE.

Considered as the time required for the outside air to reach a specific location after entering the calculation domain [49]. Therefore, the age of the air in the study area largely depended on the definition of the inlet, and calculations were performed according to this definition. Therefore, for a complex village layout, this may cause more problems because the local average age of the air distribution in the village is more sensitive to the definition of the initial value. However, the time spent in the process of air flowing within the research range was independent of the initial value because it represents the amount of time delay caused by the airflow at each point in the village due to being blocked by buildings.

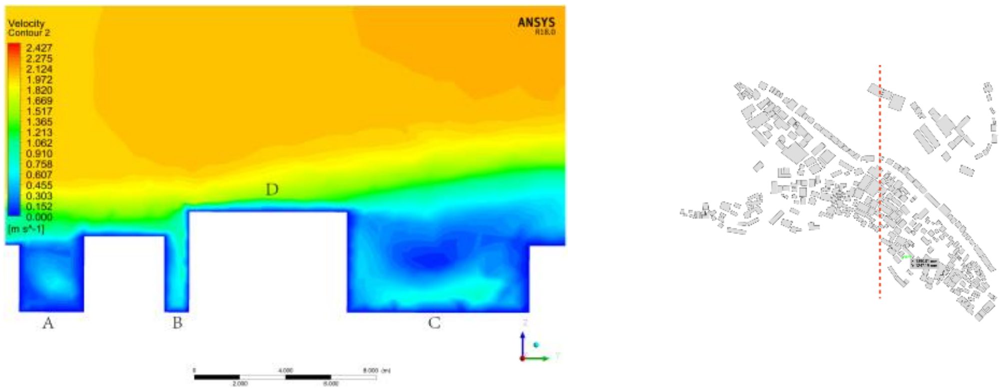
Figure.3-20 shows the distribution of the wind environment at a height of 1.7m (average pedestrian height) produced by SKE, RKE, and RNG. Figure.3-20a–c shows the distribution of wind speed, wind direction, and wind volume in the village obtained by the three methods. To more easily compare and summarize the findings, the picture is divided into 56 squares to more accurately indicate the deviations. The distributions d (SKE) and f (RKE) shown in Figure 13 are similar, but RNG overestimates the turbulent kinetic energy, which can also be explained by RNG overestimating the air age at pedestrian height. In the red area in Figure.3-20a, c, the RNG simulation results obviously deviate from the other two simulations. In this case, the overall average deviation between RNG, and SKE, and RKE is about 42.61%.

3.3.3.2. Vertical contrast

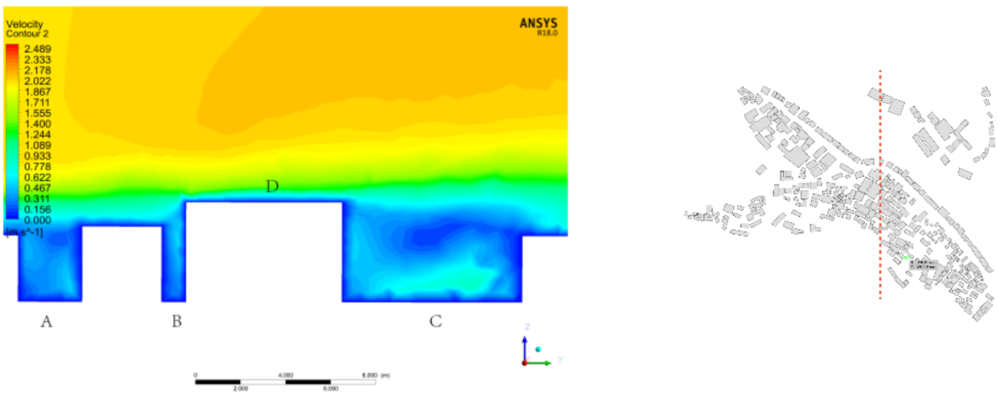
To more clearly reveal the differences between and better understand the performance of SKE, RKE, and RHG, the vertical plane at the same position in the study area was selected, and the vertical wind environment distribution and turbulence intensity distribution were determined. Figure.3-21a–c shows three wind speed cloud diagrams simulated by the different solvers. Figure.3-21d–f shows the simulation results of turbulence intensity. We found that when the wind blows on the face, the wind diverges above and around the building, causing a large amount of fresh air to enter the street along the vertical direction. This causes the average air age in the area to decrease, which could be predicted by SKE, RNG, and RKE. Notably, for SKE, RNG, and RKE, the turbulence levels in the entire roof and street canyons are well-predicted, but the turbulence can be overestimated by RNG. As shown in Figure.3-21d–f, at the stagnation point in front of the eaves of Building D, especially the stagnation point near the front edge, a larger separation area is produced behind Building D. For RNG, the range of the separation area is larger than those of SKE and RKE. This observation is similar to previous studies [50]. As shown in Figure.3-21a–c, the flow field inside Canyon B downstream of the building simulated by RNG is different from those by SKE and RKE. In addition, less turbulence sweeps the front edge of Building D and crosses the roof into the downstream area. After using RNG simulation, the turbulence level inside the canyon marked with “A” and “C” at the top of the street canyon decreased, which deviate from SKE and RKE by 43.92% and 41.54%, respectively. Figure.3-21a–c clearly shows that there are significant differences in the local wind environment distribution obtained by the two methods, especially in the street canyons with the “B” label. The average deviation between the stable RNG and SKE in the street canyons marked “A” and “C” is about 21.41% and 26.86%, respectively. Notably, previous studies showed that the horizontal and vertical average currents and turbulent fluctuations throughout the roof canyons significantly affect the air exchange between the street canyons and the external flows above them to help with air renewal [51].



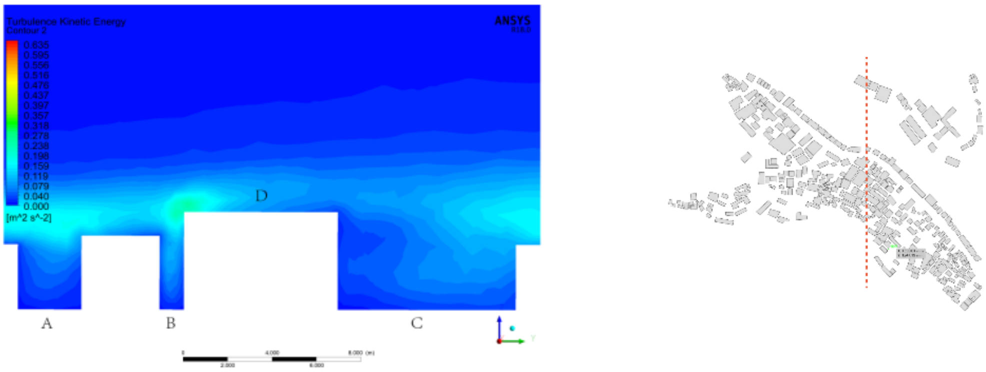
(a)Local wind environment distribution simulated by SKE in the vertical direction.



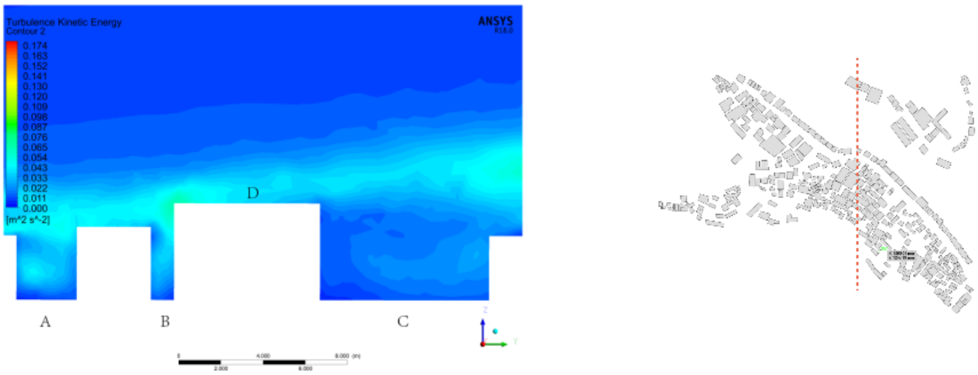
(**b**) Local wind environment distribution simulated by RNG in the vertical direction.



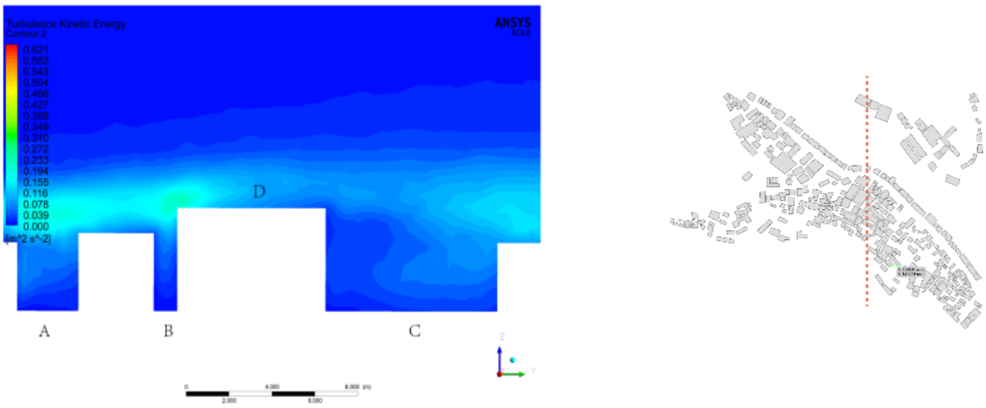
(**c**) Local wind environment distribution simulated by RKE in the vertical direction.



(**d**) Local turbulence intensity distribution simulated by SKE in the vertical direction.



(e) Local turbulence intensity distribution simulated by RNG in the vertical direction.



(**f**) Local turbulence intensity distribution simulated by RKE in the vertical direction.

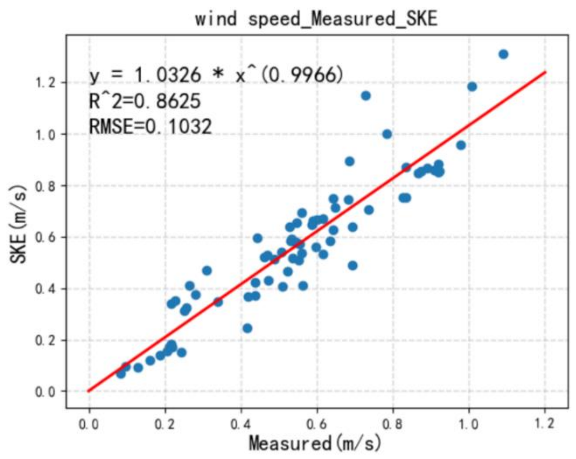
Figure 3-21. Local wind environment and turbulence intensity distribution in the vertical direction. (a) Local wind environment distribution simulated by SKE in the vertical direction. (b) Local wind environment distribution simulated by SKE in the vertical direction. (c) Local wind environment distribution simulated by SKE in the vertical direction. (d) Local wind environment distribution simulated by SKE in the vertical direction. (e) Local wind environment distribution simulated by SKE in the vertical direction. (f) Local wind environment distribution simulated by SKE in the vertical direction.

In several examples of historical towns mainly located in the central and southern regions of China, morphological characteristics similar to those of the study area can be found.

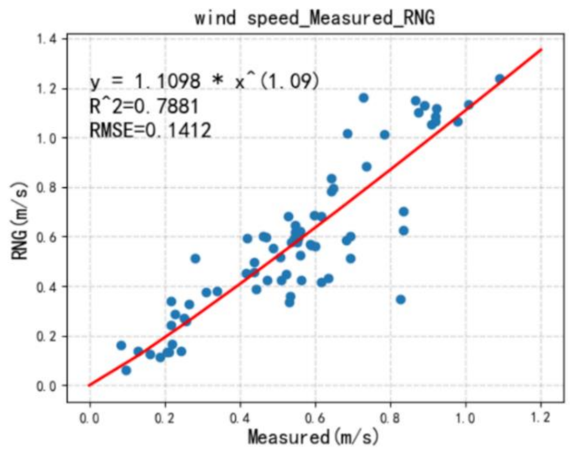
Therefore, the conclusions and any possible suggestions for improving the air permeability of the surveyed areas are considered important and may be useful to urban planners and decision-makers in these areas. Poorly ventilated areas seem to be related to lower building height changes. Therefore, increasing the variability of building heights in villages can improve air permeability in complex urban areas. This is consistent with the results of previous studies on general urban areas [52].

3.3.3.3. Comprehensive reliability analysis of actual measurement and simulation

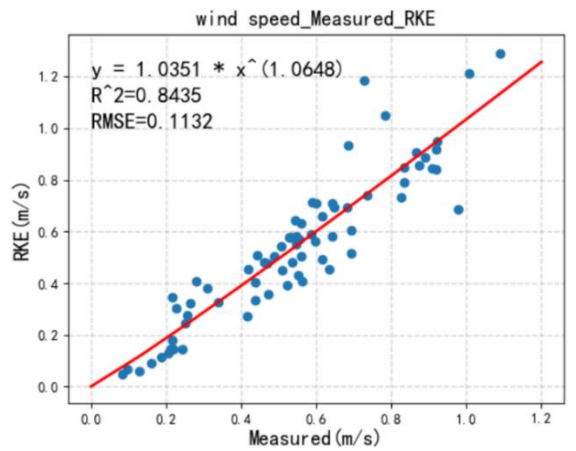
The comprehensive reliability judgment method used in this study is: The index root mean square error (RMSE) [53] and coefficient of determination (R^2) combined with python. Exponential root mean square error (RMSE) and coefficient of determination (R^2) is used to evaluate the difference between simulated and measured values. If the RMSE error is close to zero, the most accurate model will be obtained, and a lower value indicates that the simulated value is within the measured value. Unlike RMSE, R^2 is close to 1, and the two data are similar. The whole process of calculation is done with python.



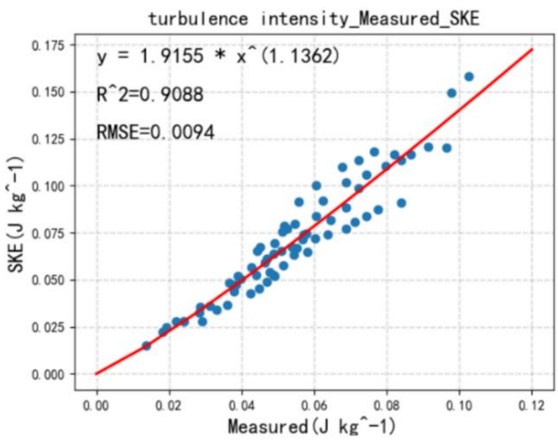
(**a**) Wind speed-SKE.



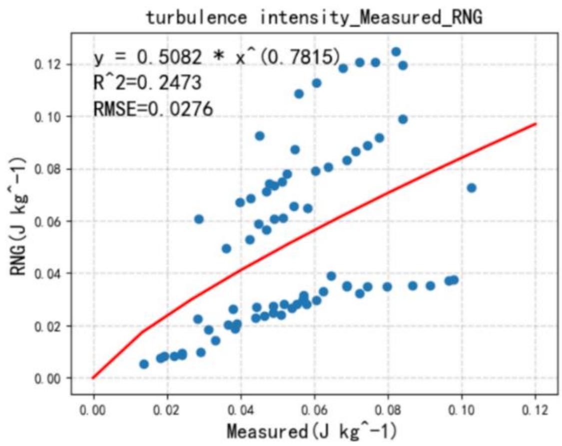
(**b**) Wind speed-RNG.



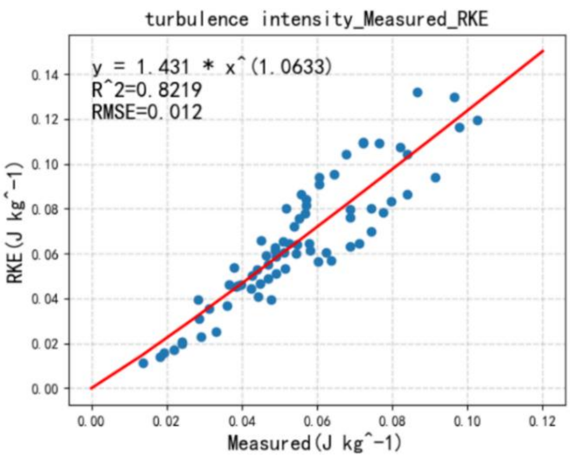
(**c**) Wind speed-RKE.



(**d**) Turbulence intensity-SKE.



(**e**) Turbulence intensity-RNG.



(**f**) Turbulence intensity-RKE

Figure 3-22. Comprehensive reliability analysis of actual measurement and simulation. (a) Wind speed-SKE. (b) Wind speed-RNG. (c) Wind speed-RKE. (d) Turbulence intensity-SKE. (e) Turbulence intensity-RNG. (f) Turbulence intensity-RKE

Figure.3-22 shows the reliability analysis of the three solvers for the simulation of the overall village wind environment. After analyzing all the horizontal and vertical data, it is found that the wind speed and turbulence intensity values simulated by SKE have the highest reliability, and the values of R^2 are 0.8625 and 0.9088, respectively. However, whether it is wind speed or turbulence intensity, the RNG simulation results differ the most from the actual measured values, which is consistent with the previous analysis results. For wind speed, the R^2 value of RNG is 0.7881, and for turbulence intensity, the value of R^2 is only 0.2473. All simulated RMSE values are very close to 0, indicating that the calculation of the data is true and effective.

3.4. Chapter summary

This chapter describes the research methods and related theories used in the research. Research methods include: related theoretical research, investigation and research on research cases, and research on software simulation and comparison methods. Theoretical research mainly includes: the characteristics of wind environment and its influencing factors, the superiority of natural ventilation, the basic way of traditional residential ventilation, the basic principles of CFD simulation and the evaluation index of building comfort. Investigation and research is a macro-survey of the overall layout and planning methods of settlements and a micro-survey of related parameters of settlement buildings. For software simulation, it mainly explains the choice of solver and the verification of simulation accuracy.

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Chapter 4. The Mechanism of the Cold alley in the Traditional Settlement of Southern Shaanxi

4.1. Introduction to traditional cold alley in southern Shaanxi

4.1.1 Definition and technical points of traditional cold alley in southern Shaanxi

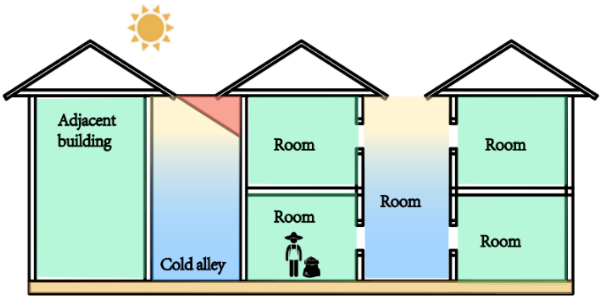
China has a vast territory. From the perspective of architectural climate divisions, China's hot summer and cold winter regions include Chongqing and Shanghai, the entire regions of Hubei, Hunan, Anhui, Zhejiang, and Jiangxi, the eastern half of Sichuan and Guizhou, and the southern half of Jiangsu and Henan. The northern half of Fujian, the southern tip of Shaanxi and Gansu, and the northwestern tip of Guangdong and Guangxi involve 16 provinces, municipalities and autonomous regions. The above area has a population of about 400 million, which is the most densely populated area in China with a rapid economic development. The average temperature of the hottest month in this area is 25-30℃, and the average relative humidity is about 80%. Heat and humidity are the basic climate characteristics in summer [1]. The average temperature of the coldest month in this area is 0-10℃, and the average relative humidity is about 80%. Although the temperature in winter is higher than that in the north, the sunshine rate is much lower than that in the north. The basic climatic characteristics of winter in these areas are cold and humid.

There are many typical residential styles in the hot summer and cold winter areas in China [2]. The southern Shaanxi residential buildings are the most representative ones. The southern Shaanxi residential buildings are basically courtyard-style buildings. The main features of this type of building are as follows:

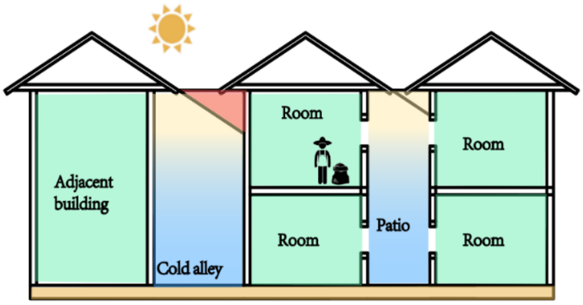
- Organize various functions through the courtyard.
- With clear circulation, overall layout and prominent main buildings.
- There are obvious distinctions and levels between architectural groups.

Along with the courtyard, there will be various corridors as traffic intersections, and also with the separation space between the buildings, which is the laneway. Therefore, narrow lanes and corridors are widely used in traditional residential buildings in areas with hot summers and cold winters, which can be said to be representative features of traditional residential buildings. Narrow lanes usually refer to narrow lanes formed by permuting and combining buildings in traditional settlements. Or it is a small passage set aside on one side of the building for residents to travel. It usually expands along the depth of the building, with a width of 0.8-1.5m, which can only accommodate two people passing side by side. However, corridors usually refer to passages in the inner depth of a building, and their main function is to connect the traffic space of various parts.

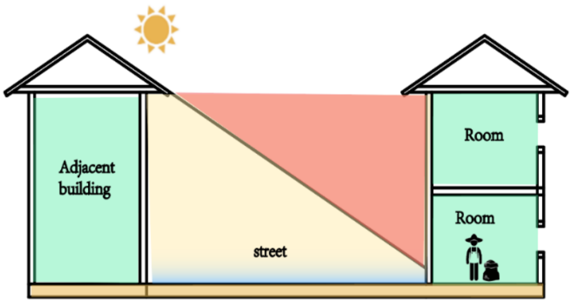
Traditional cold alleys refer to narrow lanes that play the role of shading, ventilation and cooling in traditional settlements. Traditional cold alleys can be divided into outdoor narrow lanes and indoor through corridors according to different locations. Solar radiation is the main source of indoor and outdoor heat in buildings in summer. To improve the indoor and outdoor microclimates of buildings, on the one hand, the hot air needs to be discharged in time to cool down. On the other hand, it is necessary to minimize the direct exposure of the sun, thereby reducing the heat gain from radiation. As shown in Figure.4-1, in summer, outdoor narrow lanes with large aspect ratios and indoor corridors with shading facilities can block a large part of the solar radiation, thereby ensuring that there is no sunlight on the roadway ground and reducing the heat gain from solar radiation [3]. Form a good architectural microclimate. However, for outdoor narrow lanes with a small aspect ratio and indoor corridors with insufficient shading, the sun can directly shine on the ground. The longer the time, the more heat gain, and the more unfavorable the microclimate of the building. Therefore, whether it is north-south or east-west, the roadway should be narrow rather than wide, thus forming a long, narrow and long cold alley, which has a good passive cooling effect and makes the cold alley become the climate buffer layer of the building.



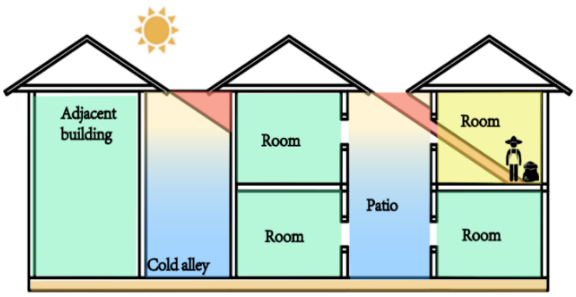
(a) Daylighting in cold lanes and normal-width patios.



(b) Daylighting in cold lanes and narrow-width patios.



(c) Wide street lighting.



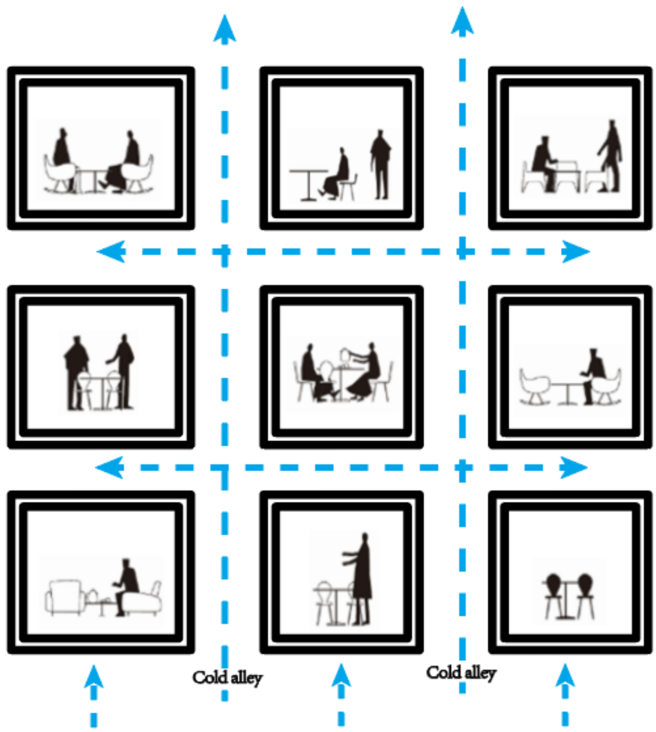
(d) The daylighting of the building by the patio of normal width.

Figure 4-1. Traditional cold alley shading. (a) Daylighting in cold lanes and normal-width patios. (b) Daylighting in cold lanes and narrow-width patios. (c) Wide street lighting. (d) The daylighting of the building by the patio of normal width.

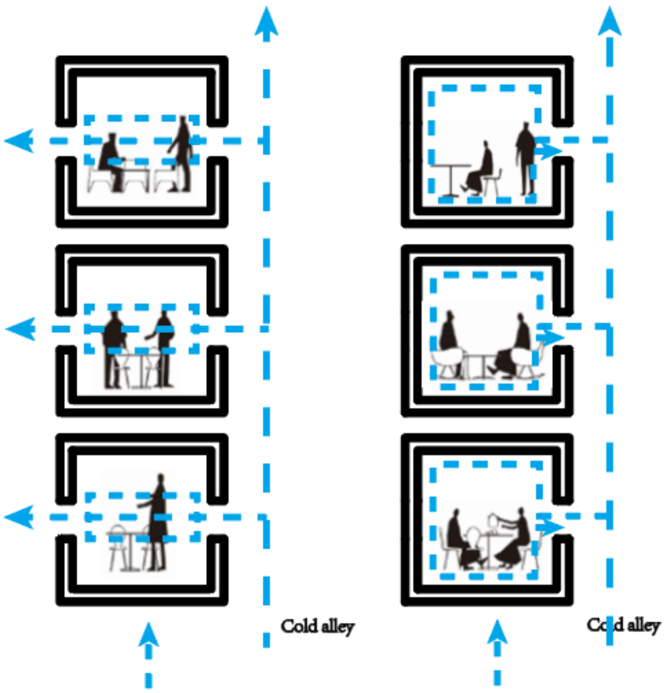
There are three main technical points for cooling in cold alleys: narrow passages for shading and ventilation, cold storage walls and ground, and night ventilation. Traditional cold alleys refer to narrow lanes that play a role in shading and cooling in traditional settlements.

The shaded and ventilated narrow lanes are the prerequisites for cold alleys. Shading mainly refers to the use of self-shading measures or external shading measures to minimize the area of the walls and ground in the lane that is directly irradiated by the sun, thereby reducing the heat gain from solar radiation. In the case of good shading, the walls and ground in the tunnel can still maintain a relatively low temperature during the summer and daytime, thereby forming a good architectural microclimate. The narrow passage in traditional buildings uses its own large aspect ratio as a self-shading facility to reduce the external heat gain of the building. Therefore, corridors, narrow and long atriums or patios, and spaces between buildings can all become cold alleys.

Cold alleys not only need to be shaded, but also need to be ventilated. Natural ventilation improves the indoor thermal environment through heat exchange through the exchange of indoor and outdoor air. Then the reason for the formation of natural ventilation is wind pressure, heat pressure or the combined effect of wind pressure and heat pressure [4]. The first is wind pressure ventilation, its working principle is: The generation of wind pressure is due to the formation of a pressure difference between positive pressure and negative pressure, while wind pressure ventilation is the air flow realized by the air pressure difference between the windward side and the leeward side of the building. This is the most common natural ventilation method. When the wind blows toward the building, a positive pressure zone will be formed on the windward side of the building, and a negative pressure zone will be formed on the leeward side, which will generate a difference in air pressure and form wind pressure ventilation. As shown in Figure 4-2, if there is a passage between the building and the building, the airflow will flow along the passage from the positive pressure area to the negative pressure area, realizing the air convection of the entire building group. Similarly, if the building has openings, then the airflow flows from the opening from the positive pressure area to the negative pressure area. The pressure of the flowing air decreases as the flow rate increases, thereby forming a low-pressure area. The surrounding air supplements the pressure of the low-pressure area, thereby performing air exchange and convection. This is the basic principle of convective ventilation between buildings and inside buildings. According to this principle, it is advisable to keep through air ducts between buildings and inside buildings. This is the meaning of cold alleys.



(a) Cold Alley Ventilation in Closed Buildings.

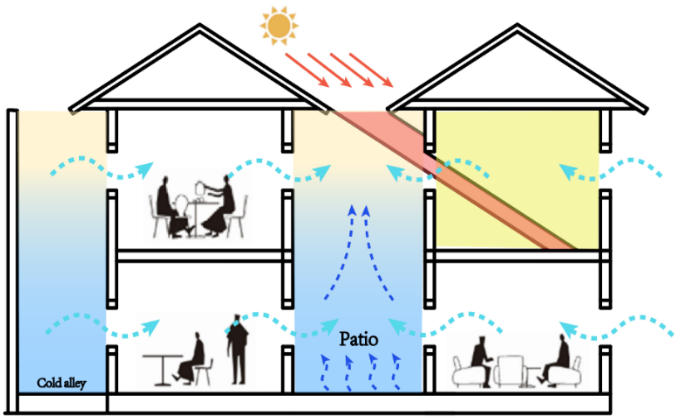


(b) Cold alley ventilation in open buildings.

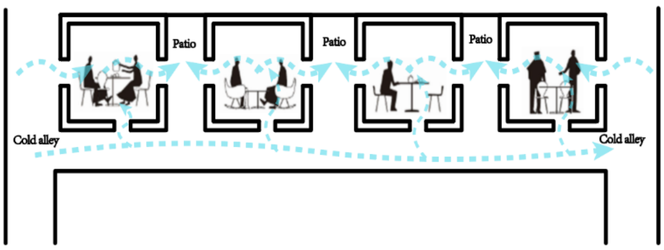
Figure 4-2. Wind pressure ventilation in traditional cold alley. (a) Cold Alley Ventilation in Closed Buildings. (b) Cold alley ventilation in open buildings.

The cold alley space is similar to a longitudinal pipe. When the wind blows through the cold alley due to wind pressure, a negative pressure zone will be formed in the cold alley, thereby driving the entire building complex and the air convection inside the building [5]. In areas with a stable and good external wind environment, wind pressure ventilation is the main means to achieve natural ventilation.

The second is Heat pressure ventilation, the principle of which is: the density of hot air is small, and it rises due to buoyancy [6]. However, the density of cold air is relatively high, and it will sink due to buoyancy, which forms an air flow phenomenon of hot air upwards and cold air downwards, which drives air convection inside the building. Therefore, Heat pressure ventilation uses the thermal pressure difference of the air inside the building to achieve air flow. Using this principle, an air outlet is set at the upper part of the building, and an air inlet is set at the bottom of the building, which can exhaust the turbid hot air in the room, while the fresh cold air outside is sucked into the room through the opening of the building. The effect of Heat pressure ventilation is related to the height difference between the inlet and outlet and the temperature difference between indoor and outdoor. The greater the height difference and temperature difference, the more obvious the effect of Heat pressure ventilation. This is what is usually called the "chimney effect", and the patio is the most typical vertical cavity architectural element. In buildings, the combination of patios and cold alleys can significantly improve the effect of hot-pressure ventilation [7]. As shown in Figure.4-3, the cold alley inside the building is also narrow and covered by high walls and eaves, which keeps the temperature low for a long time and becomes a cold source. The patio has a large space. When the weather is hot, the air in the patio rises due to the solar radiation. With the help of the height difference of the patio, the colder air in the cold alleys and indoors is supplemented. In this way, the indoor ventilation is promoted, and the hot-pressure ventilation in the building is formed. Compared with air pressure ventilation, Heat pressure ventilation is more suitable for areas where the external wind environment is not stable [8].



(a) Heat pressure ventilation of the patio.



(b) Heat pressure ventilation in cold alley.

Figure 4-3. Heat pressure ventilation in traditional cold alley. (a) Heat pressure ventilation of the patio. (b) Heat pressure ventilation in cold alley.

The cold storage body referred to in the building is usually a material with high heat storage coefficient, strong heat storage capacity and good thermal stability. These cold storage materials can exhibit a certain thermal retardation when the ambient temperature changes. There are good cold storage bodies such as ground and thick walls in cold alleys in traditional buildings. The ground plays a vital role in the passive cooling of traditional buildings. The soil is a good cold storage body. The temperature changes throughout the year are very stable. The temperature at a depth of about 1m below the ground is basically equal to the daily average outdoor temperature. Therefore, when the maintenance structure of the building is connected to the ground, the maintenance area can be kept in a relatively stable thermal environment throughout the year. Thick walls also have very good cold storage capacity, which improves the heat storage capacity of the wall. Generally, a heavy wall with a high heat storage coefficient is selected and the thickness is appropriately increased. The greater the thickness of the wall, the greater the coefficient of heat capacity and the greater the thermal stability. Conventional brick walls and concrete walls can meet the requirements. In the Kashgar area of Xinjiang, China, the adobe wall thickness reached 600mm to cope with the dry and hot climate. The wall thickness in the cold areas of northern China should exceed 370mm according to the specification, and the wall thickness in the south has reached 240mm. Therefore, in architectural design, to adjust the microclimate of the building through cold alleys, it is necessary to make full use of the role of cold storage. Firstly, we must re-understand and reuse the value of the ground. In the building, try to increase the area of the cold road corridor in contact with the ground and soil. Secondly, we must try to improve the cold storage capacity of the wall that is connected to the cold. To start with materials, it is necessary to choose materials with high heat storage coefficient for wall construction [9]. Generally, the higher the density of the material, the higher the heat storage coefficient. As shown in Table 4-1. Starting from the capacity, moderately increase the thickness of the wall to increase its heat capacity, thereby increasing the heat storage capacity.

Table 4-1. Thermal coefficient of materials.

Material name	**Reinforced concrete**	**Clay brick masonry**	**Hollow clay brick masonry**	**Rammed clay**	**Construction Steel**	**Gypsum board**	**water**
Thermal storage coefficient w/（m²·k）	17.20	10.63	7.92	12.95	126	5.28	13.5
Thermal Conductivity w/（m·k）	1.74	0.81	0.58	1.16	58.2	0.33	0.60
Specific heat capacity kj/（kg·k）	0.92	1.05	1.05	1.01	0.48	1.05	4.18

Night ventilation is the last link in the key points of cooling technology in cold alleys, and it is also the most important step to achieve the purpose of cooling [10]. The cold storage wall of the cold alley must be combined with the night ventilation of the building in order to sustainably play its role of cold storage. Otherwise, the heat accumulated in the cold storage wall during the day will be difficult to dissipate, which will affect the cooling effect. Night ventilation is the use of the temperature difference between the day and night, and the night ventilation is used at night to let the cold storage structure perform cold storage, thereby cooling the building structure heated during the day. Night heat exchange means that the cold storage body is cooled by outdoor cold air at night. The daytime heat exchange means that the cold storage body cools indoors by absorbing the heat around the cold alley during the day. In summary, it absorbs heat during the day to store heat and cools the room, and ventilates and cools at night to store and cool itself, so as to continue to act as a cold source the next day to absorb heat and cool the room. Therefore, low-temperature ventilation at night is the most important resource for cold alleys.

4.1.2 The spatial form of traditional cold alley in southern Shaanxi

4.1.2.1 Point combination

The point combination method can also be called a centralized layout. Urban settlements are mostly around squares or lake intersections, and residential buildings and roads are restricted by topography and waterways, and thus change and develop according to topography and waterways. This layout is widely found in traditional houses in areas with hot summers and cold winters. As shown in Figure.4-4, the settlements gathered at the confluence of rivers present a form of clustering in the center. The advantage of this layout is that the contact area between the settlement and the water is wide and concentrated, the water transportation is developed, and the landscape is open and beautiful.

Figure 4-4. centralized layout.

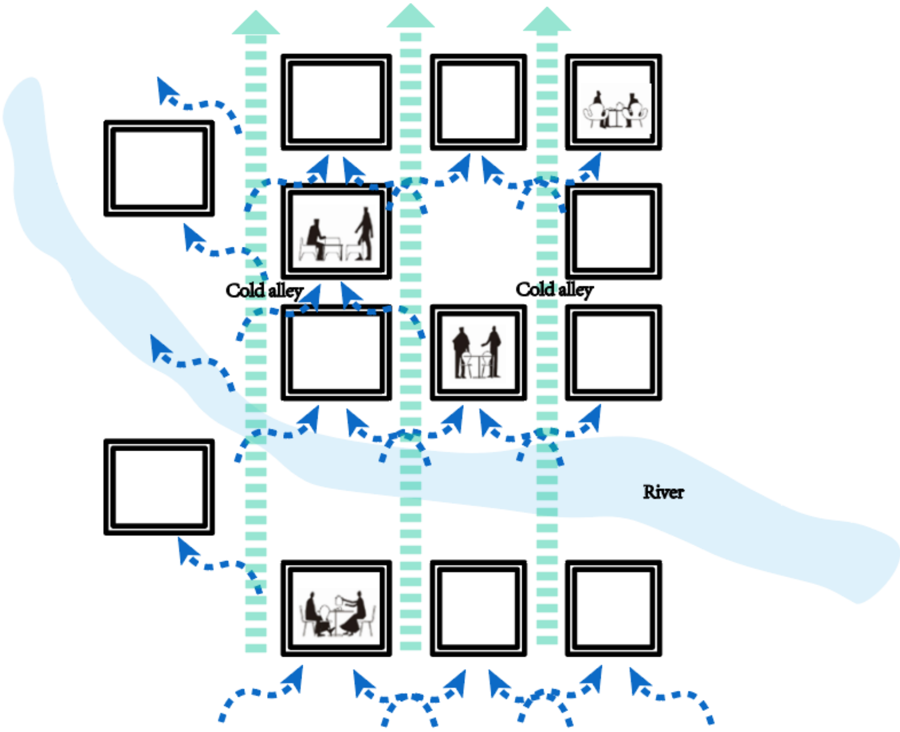
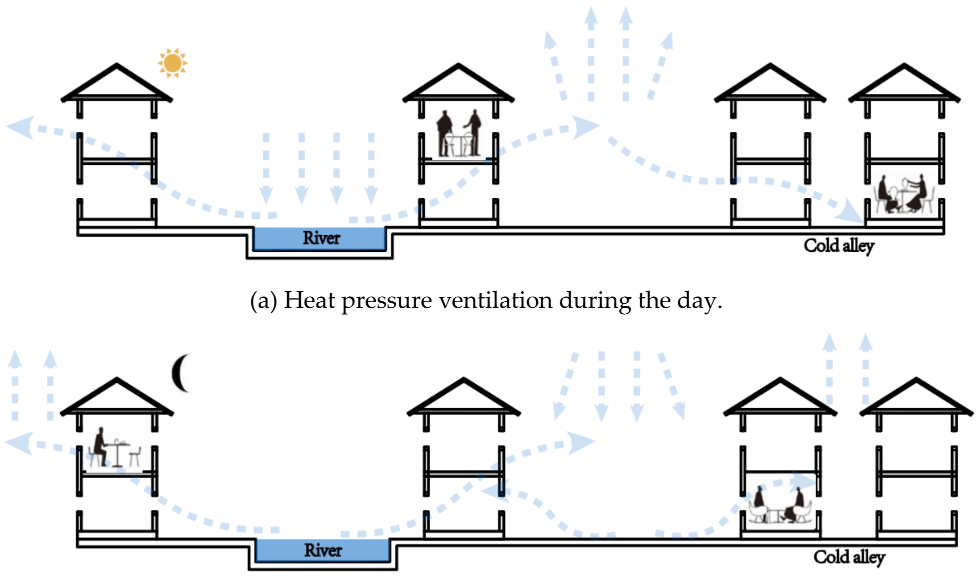


Figure 4-5. Centralized layout of settlement ventilation.

The point-type combination layout is very effective for the ventilation organization of the settlement. Due to its good self-shading effect, the space between the building and the building reduces the area of the inner wall of the tunnel directly irradiated by the sun, thereby reducing the heat gained by the solar radiation [11]. The corridor becomes the climate buffer between the building and the external thermal environment. The walls and ground of the corridor can be kept at a relatively low temperature during the day, thereby reducing the external heat gain of the buildings in the settlement and becoming a cold alley with good cooling effects. When there is a stable and good external wind environment, wind pressure ventilation can be used to achieve ventilation inside the building. The southeast monsoon prevails in southern Shaanxi in summer, and the orientation of buildings and roadways in traditional settlements is mostly east to south. As shown in Figure.4-5, when the settlement is perpendicular to the southeast monsoon or at a small angle, the wind blows from the large space before the settlement to the small space in the settlement, creating a pressure difference, which creates wind pressure ventilation. The cold alley is used as a ventilation cavity between the building and the external wind environment, which reduces the attenuation of wind in the settlement, and can make good use of the monsoon for ventilation and cooling. If the building opens to the cold alley, it can be ventilated and dissipated through the cold alley, thereby improving the internal microclimate.

Similarly, when the external wind environment is not stable, cold alleys can use the thermal pressure difference to ventilate the inside and outside of the building. When the point-type combination is concentrated around the square, due to the large area of the square and no shading facilities, during the day, the ground of the square is directly exposed to the sun for a long time, and the radiation heat is very large, and the air temperature rises rapidly. The air floats up due to the decrease in density, which creates a thermal pressure difference on the ground, which attracts cooler surrounding air to supplement it. Because the cold alley corridor is blocked by walls on both sides, the heat gain is less and the air temperature rises slowly. The interlaced river network in the building has a good specific heat capacity and good thermal inertia, and the temperature rises after heat gain is minimal. In summary, the temperature of each part of the settlement is arranged from low to high as: water network <cold alley <square [12], as shown in Figure.4-6a. Therefore, during the daytime settlements, there is generated hot air ventilation blowing from the water network to the cold alleys and squares, and from the cold alleys to the squares. At night, the open-air square quickly radiates heat to the sky, and the temperature drops the most. Due to the good insulation effect of the water body, the water surface temperature is slightly higher than that of the square surface. In cold alleys, heat dissipation is slow due to the good heat storage capacity of the ground and walls. In summary, the temperature in each part of the settlement is arranged from high to low as: cold alley> river network> square [13], as shown in Figure.4-6b. Therefore, in the settlements at night, there is a hot air ventilation blowing from the square to the river network and cold alleys, and from the river network to the cold alleys.



(a) Heat pressure ventilation during the day.

(b) Heat pressure ventilation at night.

Figure 4-6. Heat pressure ventilation for centralized layout settlements. (a) Heat pressure ventilation during the day. (b) Heat pressure ventilation at night.

4.1.2.2 Line combination

The linear combination means that the buildings in the settlement are distributed in strips along the two ends of the river, as shown in Figure.4-7. The characteristic of this settlement combination method is that the buildings are arranged on one or both sides along the river. The edge of the river is generally a wide road, and the houses and shops are lined up along the river, showing the form of "front street and back river". To facilitate the transportation of goods or the nearby rural shoppers. Generally, there are access gaps around 3-4 buildings, which are connected to the rest of the settlement in the form of narrow lanes. It is a fairly common type in traditional settlements in areas with hot summers and cold winters. The linear combination method can also be called the horizontal street and vertical lane layout. The horizontal street refers to the wide road lined up along the river, and the vertical lane refers to the fact that the buildings in the settlement are mostly southeastward, and there are large and small longitudinal cold alleys between the buildings. Longitudinal cold alleys can form self-shading due to the large aspect ratio, thereby keeping low temperature during the day and becoming a climate buffer layer outside the building. When a stable and good external wind environment is available, wind pressure ventilation can also be used to achieve ventilation inside the building. As shown in Figure.4-8, the longitudinal cold alleys conform to the wind direction of the summer wind. Under the action of wind pressure, the wind can be coldly poured into the settlements along the longitudinal direction to form street breeze.

Figure 4-7. Strip-shaped distributed settlements.

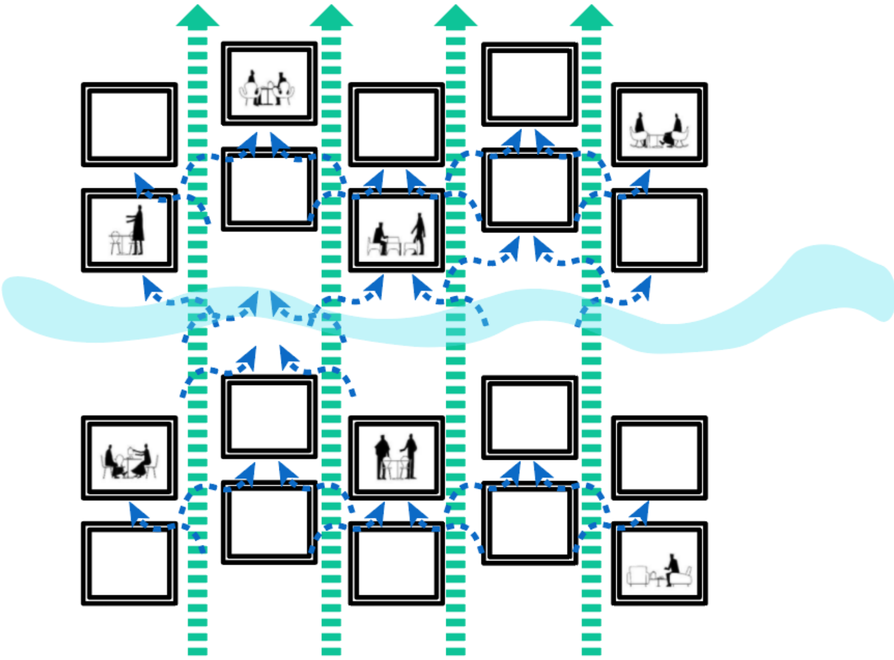
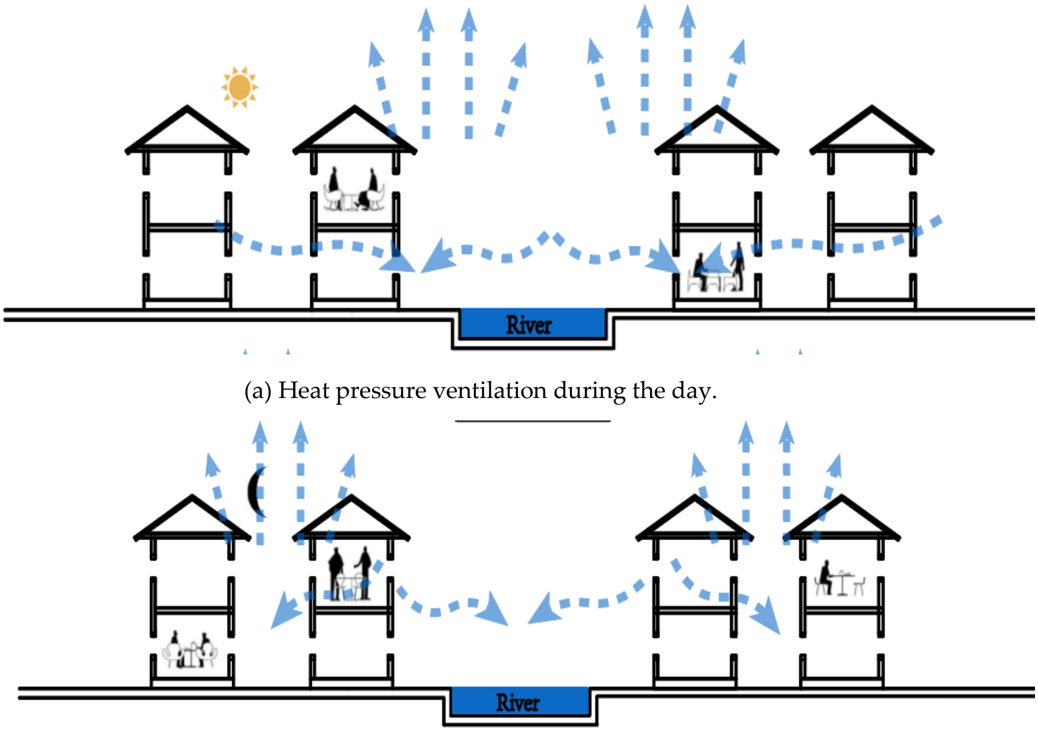


Figure 4-8. Ventilation of strip-shaped distributed settlements.

When the external wind environment is not stable, because the horizontal street is generally east-west, and the size is much wider than the longitudinal cold alley. In the daytime, the side street is exposed to the sun for a long time, so the temperature during the day is very high, while the cold alley has a slower temperature rise because its high walls block most of the solar radiation. Therefore, the temperature is kept low for a long time during the day. The river water has a good specific heat capacity and good thermal inertia, and the temperature rises after the heat gains are minimal. In summary, the temperature of each part of the settlement is arranged from low to high as: river water <longitudinal cold alley <horizontal street, as shown in Figure.4-9a. Therefore, in the daytime settlements, there is generated heat

and pressure ventilation that blows from the river water and the longitudinal cold alleys to the horizontal streets. While the settlement buildings are ventilating and dissipating heat, the supplement of cold air on the side street also makes the side street form a better microclimate. At night, the side street cools down quickly due to the faster heat dissipation, and the cold alley is slower due to the thermal inertia of the heat storage of the wall. Due to the good thermal insulation effect of the water body, the surface temperature of the river water is slightly higher than that of the horizontal street surface. In summary, the temperature of each part of the settlement is arranged from high to low as: longitudinal cold alley>river>horizontal street, as shown in Figure.4-9b. Therefore, in the settlement at night, there is a heat pressure ventilation blowing from the horizontal street to the river and the longitudinal cold alley.



(a) Heat pressure ventilation during the day.

(b) Heat pressure ventilation at night.

Figure 4-9. Hot-pressure ventilation of strip-shaped distributed settlements. (a) Heat pressure ventilation during the day. (b) Heat pressure ventilation at night.

4.1.2.3 Surface combination

The surface combination method is also called the horizontal and vertical staggered layout, as shown in Figure.4-10. The layout of the building group is regular and square, arranged in rows along the depth direction, and there is a laneway between the two rows of buildings as the main traffic passage. If the depth of the building is too long, cross lanes will generally be set up to connect east and west to assist traffic. The streets are basically cross-shaped. Most of the residential houses open their doors to the streets and lanes, and there is no obvious difference in size between the streets and lanes, and they arbitrarily exist in the settlements where the land is concentrated. Because the settlement is far away from the river, manual digging of the river channel is often used. The river water is introduced into suitable places, so the river channel often follows the roadway of the settlement, so that residents can not only get domestic water easily, but also can be used as a fire-fighting reservoir to reduce the occurrence of fires.

Figure 4-10. Staggered settlement.

The horizontal and vertical lanes also have the characteristics of cold alleys, which can become the climate buffer layer outside the building, effectively insulating. In the external normal wind state, as shown in Figure.4-11, the cold alley is used as a ventilation duct, and the air pressure ventilation is used to take away the hot air in the settlement and maintain the ventilation of the overall environment. In addition, the cold alley and the patio in the residential building form another layer of ventilation system, as shown in Figure.4-12. Under the sunlight during the day, if the temperature of the upper part of the patio is higher than the temperature of the upper part of the cold alley, the thermal pressure difference at the lower part of the patio will be large, resulting in the heat pressure ventilation that flows from the cold alley into the building through the building openings and flows to the patio. If the temperature in the upper part of the patio is lower than the temperature in the upper part of the cold alley, the thermal pressure difference at the lower part of the cold alley will be large, which will cause the passing from the patio to the inside of the building. Heat pressure ventilation that flows through the building opening to the cold alley. The wind speed and air volume of Heat pressure ventilation are affected by the height-to-width ratio and location of outdoor cold alleys and patios.

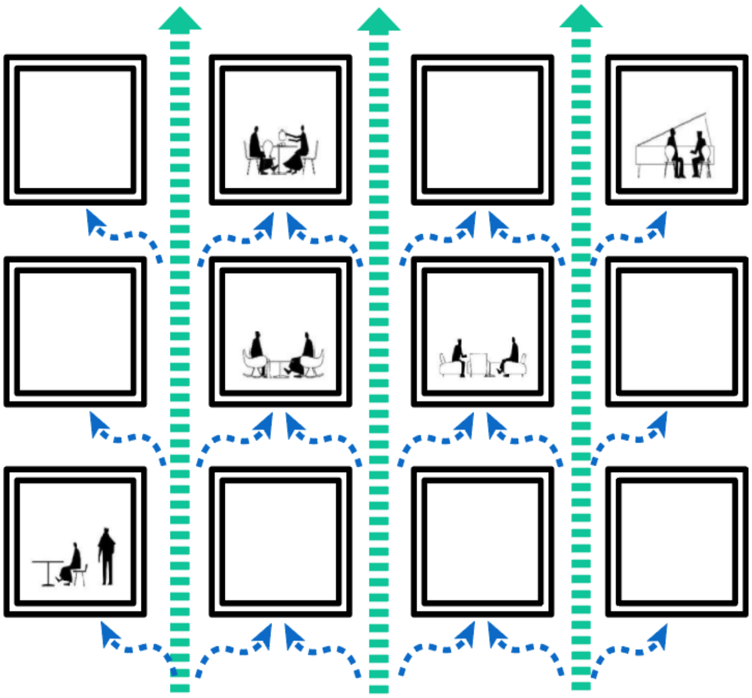
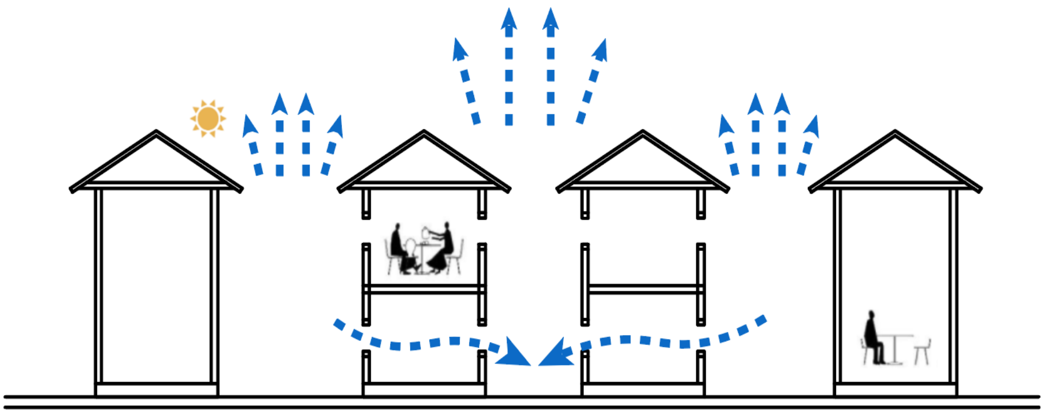
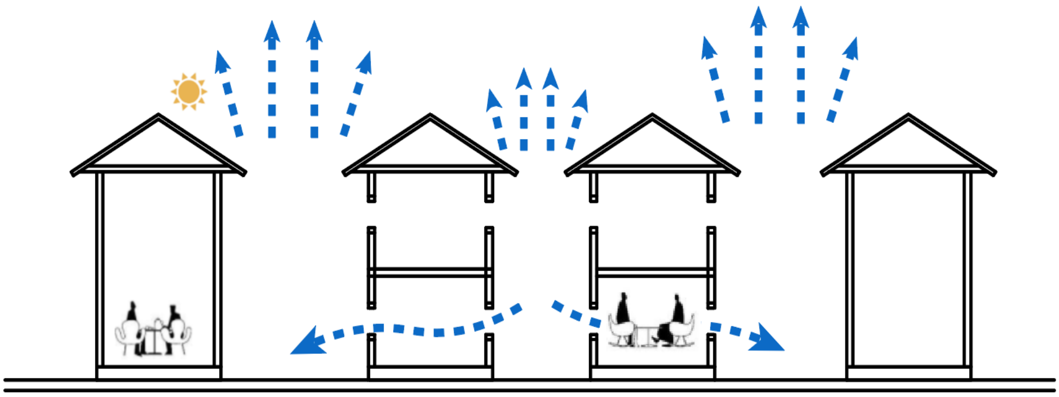


Figure 4-11. Staggered layout of settlement ventilation.



(a) Heat pressure ventilation during the day.



(b) Heat pressure ventilation at night.

Figure 4-12. Staggered layout of settlements with Heat pressure ventilation. (a) Heat pressure ventilation during the day. (b) Heat pressure ventilation at night.

4.1.3 The characteristics of cold alley space types in traditional dwellings in southern Shaanxi

The hot summer and cold winter area in China is a densely populated and economically developed area. This area is the essence of the country and its development status is extremely important. The vast land has created a variety of residential types, mainly including southern Shaanxi residential buildings, Jiangnan water village residential buildings, dry-line residential buildings distributed in mountainous areas, and so on. Its common feature is strong regionality, and traditional residential buildings in areas with hot summers and cold winters respond significantly to the climate. In the construction process, the local climate, environment, humanities and other factors are fully considered, and the characteristics of the construction technology basically meet the ecological building standards. Without modern heating, refrigeration and air conditioning technology and almost no energy consumption, a relatively comfortable indoor and outdoor physical environment is created. Cold alley is one of the most common passive energy-saving building elements. Abundant residential building forms, there are various types of cold alley spaces, and different types have different characteristics and functions.

4.1.3.1 Side-by-side type

As shown in Figure.4-13, the side-by-side type means that the cold alley space expands along a certain linear space, and the building units are arranged side by side along the cold alley. At this time, the cold alley space is often a transitional space from one space to another. The most common type in architecture is the laneway below the arcade in the arcade-style building. This narrow lane divides the outdoor space and the interior space of the building into two, becoming an excess of indoor and outdoor spaces.

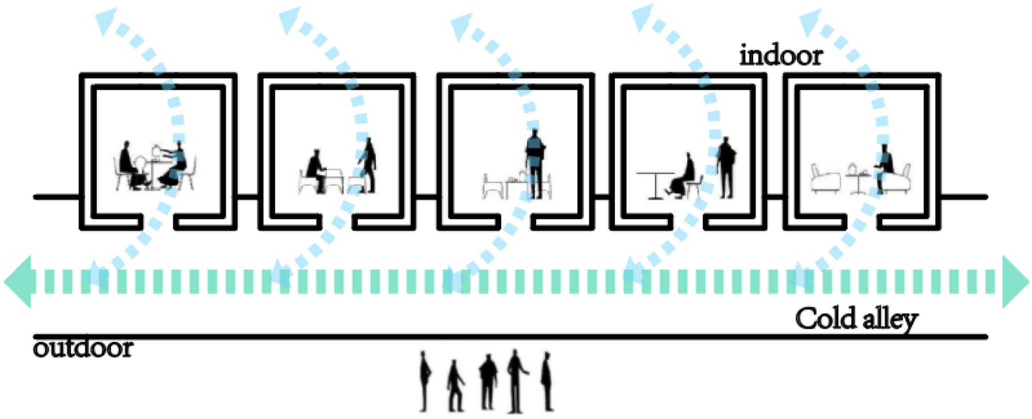


Figure 4-13. Side-by-side layout of cold alley ventilation.

Arcade-style buildings are widely used in residential buildings in hot summer and cold winter areas. Most of them are commercial buildings, usually two or three floors. The storefront on the ground floor facing the street is open. There are often canopies and corridors in front or the buildings are made into arcades to facilitate shade and rain. At the same time, the canopy corridors or arcades can be used as safe walking paths with less traffic interference. It also makes it a typical outdoor cold alley. The pattern of "front store and back house" and "down store and upper residence" is formed as a whole [14], as shown in Figure.4-14. As shown in Figure.4-15, at noon in summer, the strong sunlight is blocked by the corridors under the arcade street, and when the sun is low, the sunlight is blocked by the arcade buildings on the opposite side of the road [15]. Therefore, the ground of the sidewalk in the corridor is less exposed to solar radiation, and the bottom temperature remains low for a long time. The sidewalk shops are traditional houses with mechanical ventilation, so the temperature in the corridor is lower than the external road and slightly higher than the temperature in the shop. Even when there is no wind and sultry heat, this relative temperature difference provides the basic conditions for the three types of spaces to also form local thermal and pressure ventilation.

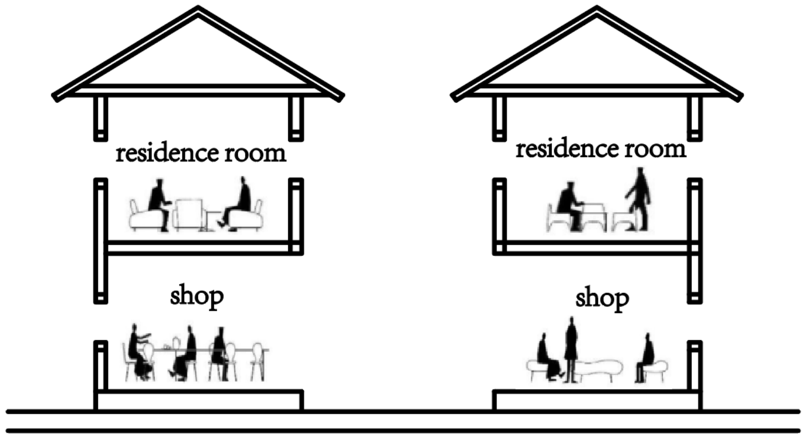


Figure 4-14. Arcade building.

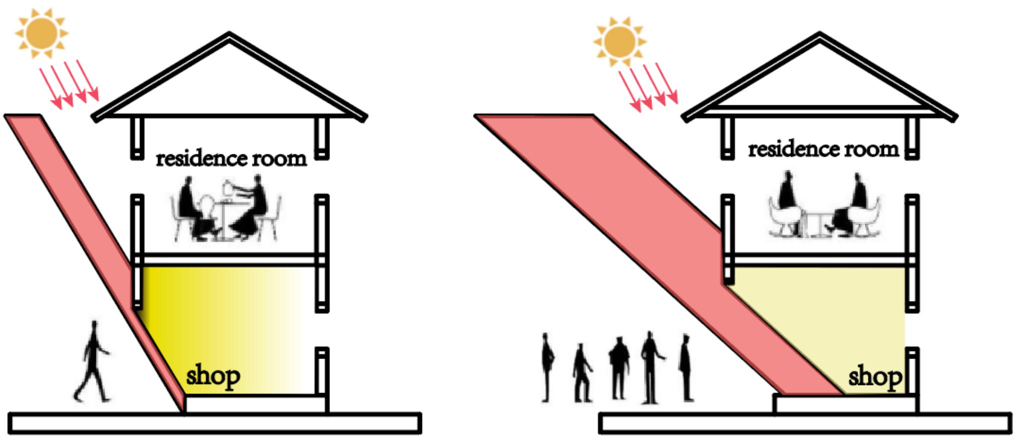


Figure 4-15. Two lighting methods in arcade building.

As shown in Figure.4-16, during the daytime, due to the long-term exposure of open-air streets to the direct sunlight, the air temperature rises, forming a thermal pressure difference. Part of it passes directly through the arcade corridor to the external road, and the heat rises and some heat is taken away. The other part is heated when entering the corridor and rises to the top of the arcade corridor, then after cooling down, it descends and finally flows to the road. In this way, two micro air currents are formed to blow towards the arcade corridor and the external road, making customers feel cool. In the evening, the external open-air streets quickly dissipate heat and cool down, and the corridors are slightly hotter due to the good thermal inertia of the walls and the ground, thereby forming a slight airflow from the external roads to the arcade corridors, making customers feel a little cool breeze. At this time, the overhead space of the arcade becomes a kind of outdoor cold alley, forming a building's climate buffer layer. The arcade cold alley saves commercial mechanical ventilation while providing long-term shading, ventilation, and rain protection, which has the effect of cooling and energy saving. The heat and pressure ventilation generated by the temperature difference forms a cool and comfortable micro-environment. In summer, the cold alley of the arcade becomes a good natural ventilation channel on the sidewalk under the blowing of the southeast or south wind, which plays a good role in windward, driving and hiding wind. The north-south arcade corridor is faster than the east-west wind speed, and the average temperature of the north-south arcade corridor is lower than that of the east-west direction. In the rainy season, the arcade becomes a shelter from wind and rain, and pedestrians can still go shopping freely. At the same time, the cold alley of the arcade is a semi-outdoor gray space, forming a buffer layer between public and private, inside and outside, with strong permeability. The arcade carries various functions of public leisure and life, and at the same time it effectively promotes the development of commerce, so it also has the dual functions of public space and commercial activity space.

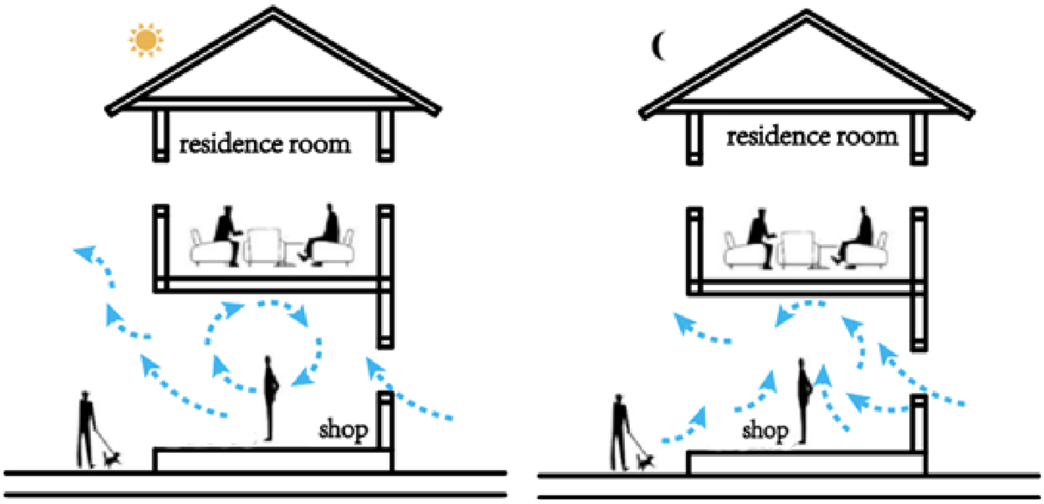


Figure 4-16. Ventilation of arcade building.

4.1.3.2 Embedded type

The embedded type refers to the cold alley space directly interspersed with the functional units of the building, as shown in Figure.4-17 The main task of cold alley space is to form an effective traffic space. Due to the influence of various physical spaces in the building, it can diverge from a certain central space to the surroundings. It can also stretch freely along the building plan, with strong traffic, functional organization and connection, and internal communication. Embedded cold alleys are widely found in traditional residential buildings in hot summer and cold winter areas. The cold alleys connect the front, middle, and rear parts of the building, and some are separated by patios. The long and deep layout of traditional dwellings, as well as the characteristics of the patio and atrium as the center, have created congenital conditions for the ventilation of the building.

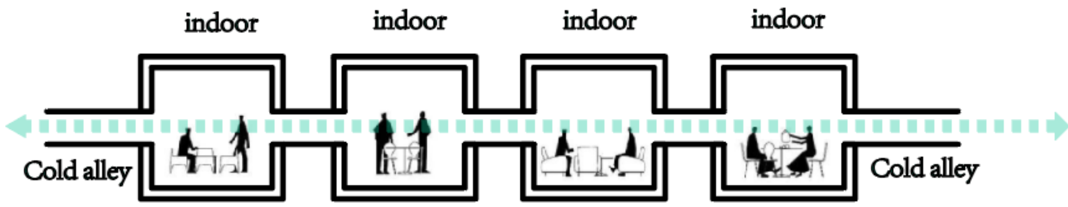


Figure 4-17. Ventilation of embedded cold alley.

When the outdoor street wind or the dominant summer wind acts on the building, the windward and leeward sides of the building form a positive and negative pressure difference, thereby forming wind pressure ventilation. The two winds on the left and right of the main body enter the building through the openings of the building. The internal passages are connected with the various indoor spaces in series, which are not only traffic space, but also because the plane is relatively straight. There is no shelter inside, and it becomes the main ventilation duct in the house, thus becoming a ventilated cold alley. Bring indoor hot air out of the outdoors to form a ventilation streamline of streets-patios-wing rooms-outdoor. The wind in the middle of the main body connects the main hall and the patio space in series. Due to the setting of the patio, the building sometimes has different building roofs at the front and rear, resulting in air pressure differences at different levels. The two work together to form wind pressure ventilation, forming a ventilation streamline of streets-patio-main hall-patio-main hall-outdoor, which is better than the ventilation effect of the building on the left and right side of the building. The wind enters the indoor main hall from the street or the front patio, bringing the internal hot air out through the cold alley. A small part of it flows forward through the hall and out of the room, and most of it passes through the cold alley and is discharged through the patio to the sky above the building, thus forming a "passing wind".

Traditional dwellings are centered on high and deep patios. Patios can be set up in the front, middle and back of the house. The patios, indoor cold alleys and the main hall of the house together form a ventilation system that penetrates the building. As shown in Figure.4-18, under the direct sunlight during the day, the air at the patio mouth is heated and sucked by heat and pressure, forming a clear updraft. The indoor cold alley drives the air flow in the cold alley due to the pull-out effect of the patio to supplement the patio. The hot air in the functional rooms connected with the indoor cold alley is also taken out, thereby forming Heat pressure ventilation to achieve the ventilation effect.

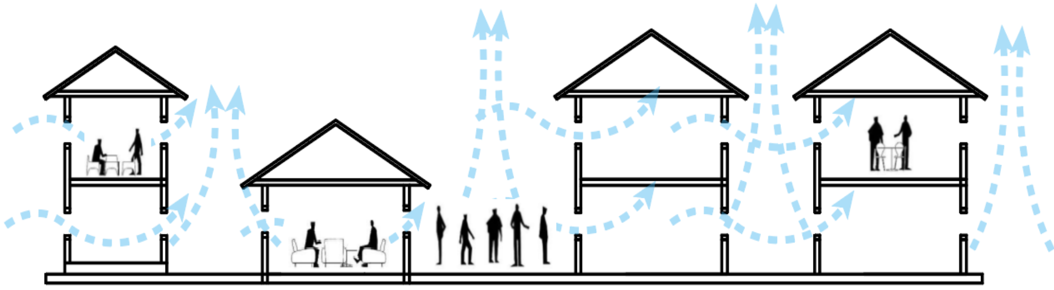


Figure 4-18. Use patios for natural ventilation.

4.1.3.3 Contained type

Contained cold alleys are similar to embedded cold alleys and side-by-side cold alleys. The difference is that embedded cold alleys are interspersed with building functional units. The contained cold alleys are juxtaposed with the building units, and the contained cold alleys often serve as the transitional space or traffic space between the building and the building or the building and the outdoor. This is similar to the side-by-side cold alley, the difference is that the side-by-side cold alley exists alone, while the inclusion type is a cold alley that needs to be included with the patio. The contained cold alleys mainly exist on both sides of the building plan. The exterior space and flow lines of the building are formed in the form of laneways and patios. The functional spaces in the building are connected by cold alley lanes and patios along the depth. Contained cold alleys are often juxtaposed with embedded cold alleys to form the internal ventilation system of the building.

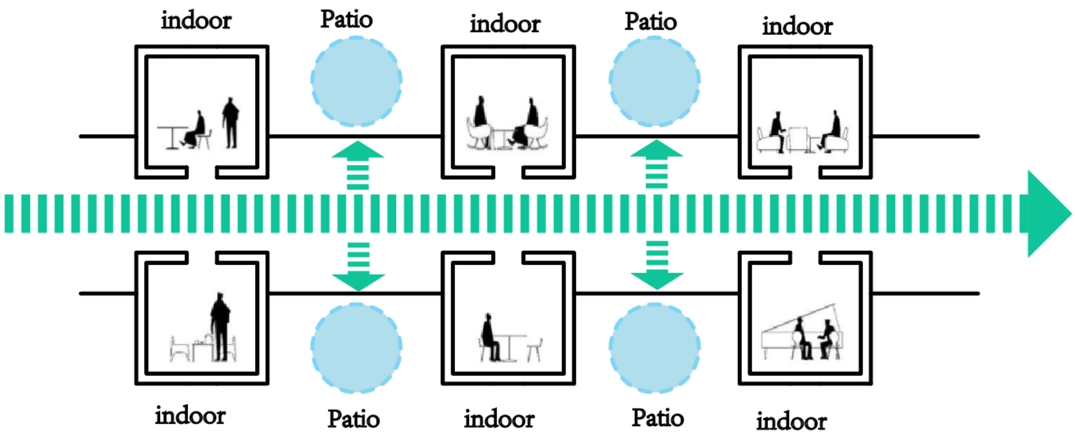


Figure 4-19. Natural ventilation of contained cold alleys.

Like other forms, street wind and summer wind have a greater impact on the ventilation of contained cold alleys. When the wind blows towards the building, a positive and negative pressure difference is formed before and after the building, and the air pressure difference brought by the roof of the building with varying heights forms wind pressure ventilation. The wind enters the room from the front opening, and is accelerated by the cold alley, and then discharged from the rear opening, forming a "passing wind", which drives the air flow in other rooms in the room. At this time, the cold alleys in the inclusion type run through the building front and back, and are connected to the heavy patios to become ventilation ducts. The patios in traditional dwellings usually differ in size. The temperature difference in the patio during the day caused the circulation ventilation with the small patio as the air inlet and the large patio as the air outlet, which clearly formed the ventilation mode of small patio-indoor cold alley-large patio.

In the daytime, the small patio space is relatively closed. Due to the shelter of the walls around the patio, the patio is less heated by sunlight. Therefore, the bottom surface of the small patio maintains a relatively low temperature, and the air near the ground cannot be heated, but the temperature at the mouth of the small patio is higher than that near the ground. However, the large patio is relatively open, and the bottom is more heated by sunlight, and the air near the ground is heated to a greater extent and rises. The air in the large patio rises due to heat, and the cold alley runs through between the large and small patios, and the cold air inside it moves along with the trend to supplement the air pressure at the large patio. At the same time, the cold alley effectively drives the airflow in the building, and brings the air from the small patio into the cold alley, thus continuously forming ventilation. And through the repeated use and clever arrangement of this pattern, the heat and pressure ventilation in the multi-yard dwellings is formed.

4.1.4 Materials of traditional cold alleys in southern Shaanxi

4.1.4.1 Soil wall

It has good heat preservation and heat insulation performance, which is the thermal performance requirement of the traditional residential envelope structure in the hot summer and cold winter area [16]. In hot summer and cold winter areas, the daily average temperature is relatively high, and thick heavy walls are used, which can effectively play the role of heat preservation and heat insulation. At the same time, the thermal delay can be increased, so that the time of the highest indoor temperature and the highest outdoor temperature are staggered, and the indoor thermal environment is more stable. The effect is specifically manifested in the summer heat storage during the day to keep the wall surface low, and at night it is cooled by outdoor cold air to store cold. In winter, with the good thermal insulation performance and high thermal resistance of the wall, it can maintain a stable indoor thermal environment.

4.1.4.2 Rammed earth wall

Rammed earth is a material often used as walls in ancient buildings, and it is widely used in traditional Chinese houses. It is a denser "rammed soil" formed by tamping and strengthening the original ecological "raw soil" [17]. China's rammed earth technology has a long history and has been very mature as early as the Qin and Han Dynasties. The ancient working people used rammed earth to build the foundation or filling platform of the building, which shows that the structure is relatively stable. Due to the characteristics of soil, rammed earth walls have better heat storage and hygroscopicity, which can not only adjust indoor humidity, but also make the living space warm in winter and cool in summer. The construction method of rammed earth is to make a trough box with wooden boards and rope, mix and stir the clay, sand, lime and other materials, pour it into the trough box for compression. When the trough box is filled and the soil is compacted, the plank can be removed and the model can be continued along the wall. Its method is similar to the modern concrete pouring process. The thickness of the wall varies from 300mm to 500mm according to the difference in the nature of the soil and the mixed materials in the area.

Figure 4-20. Rammed earth wall.

4.1.4.3 Adobe wall

The traditional adobe wall method of residential houses is to add water to the raw soil for thorough mixing, and add the reinforcement during the mixing process [18]. After the raw soil and the reinforcement are evenly mixed, they are placed in a mold of a specific size to form the soil. The broken bricks are then built with mud to form a wall. Compared with rammed earth walls, adobe walls are low in cost, economical and practical, and more flexible in use. It can be built into various forms of walls according to needs. Simple construction techniques and randomly variable construction time enable adobe walls to be widely used in traditional residential buildings.

Figure 4-21. Adobe wall.

4.1.4.4 Brick wall

Traditional blue bricks are sintered with clay. After the clay bricks are heated to become red bricks, the heating is stopped, and then quickly turned into blue bricks with water. Both the blue brick and the red brick have good waterproof and moisture-proof performance, can resist wind and rain, and their performance and strength are far superior to that of earth walls [19]. In the traditional dwellings of southern Shaanxi, the exterior of the exquisitely crafted building is masonry with water-polished blue bricks and silk seams. The blue brick walls of traditional dwellings in southern Shaanxi include solid single-layer walls and empty bucket double-layer walls. The single-layer wall masonry method is simple and the construction is convenient, layer by layer is stacked with cracks, and the wall and wood components are attached and fixed. The empty bucket double-layer wall adopts the method of filling the empty bucket with blue bricks and filling it with yellow mud. The blue bricks are erected to form a cavity and then filled with yellow mud to strengthen the integrity and firmness of the wall. The size of the general blue brick is 320mmX160mmX30mm, so the wall thickness is roughly 350mm.

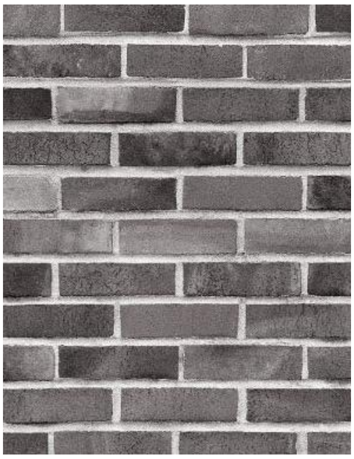


Figure 4-22. Brick wall.

4.1.4.5 Stone wall

As a natural resource, stone has been a commonly used wall material in traditional houses since ancient times. The hot summer and cold winter areas are vast and rich in resources, and there are abundant mineral resources, so stone is also quite suitable for the construction of residential buildings [20]. The stone used for masonry walls can be divided into three types: rubble, material stone and pebbles. The difference between rubble and material stone is that rubble is unprocessed stone that is mined in the natural state, while material stone is a stone that has undergone a series of processing and has a certain specification. Both are often used in the toe part of the building wall. Pebbles are naturally formed non-angular rock particles, which are mainly used for the masonry of courtyard walls.

Figure 4-23. Stone wall.

4.1.4.6 Wooden wall

Southern Shaanxi is a typical hilly area. Mountains and hills account for more than 90% of the total area. The soil is fertile, which is conducive to the growth of trees, and the wood output is more prominent. It is precisely because of the unique geological conditions in southern Shaanxi that there is a large amount of high-quality wood as a foundation, which has laid a solid foundation for the construction of southern Shaanxi dwellings. Wooden walls are mostly used as partition walls in residential rooms, and they are all infill walls inlaid between wooden pillars [21]. The method is to place the slabs on the bottom, and the upright planks are used as partitions, and the ends of the planks are connected with the wooden pillars in a tenon and tenon way to make them fixed. In order to enhance its stability, there is also a method of filling mortar in the gap between the bottom stone and the lower end of the board, but it is extremely rare.

Figure 4-24. Wooden wall.

4.1.5 The definition and development of modern cold alleys

4.1.5.1 Definition of modern cold alley

With the progress of the country and society, the change of lifestyle, the progress of science and technology, and the change of ideas, the traditional cold alley space has not been able to fully adapt to the needs of modern life. We must follow the trend of the times and develop and evolve. Therefore, when we inherit the traditional cold alley space, we cannot completely copy the size and material of the original space, and more importantly, continue its space essence and spirit. We need to fully consider the existing environment and conditions while ensuring that the essence of the space remains unchanged. Through the new interpretation method, it is appropriately developed in many aspects to form a lively and diverse space to adapt to various needs, so that it can be better used in contemporary architecture.

In today's world, there are various building types, and a lot of new ideas and creativity have emerged. The spatial form of contemporary cold alleys no longer stays in the traditional cold alleys. So how to limit the spatial form of contemporary cold alleys? The visual form, light characteristics, measurement, and scale of the space completely depend on the boundaries defined by the formal elements. For contemporary cold alleys, it can generally be defined by a combination of four parts: bottom, side, end, and top. The spatial form of contemporary cold alley is produced by the combination of these four parts.

The bottom surface of the contemporary cold alley is the basic interface of the cold alley space, directly carrying the basic functions of the space such as transportation, communication, and organization space. The choice of the bottom material and the change of the topography can produce a rich and varied spatial form, bringing people different visual feelings and spatial experiences. The bottom surface directly affects the microclimate regulation of the cold alley. When it is connected to the earth, the soil is a good cold storage body, which can provide a cold source for the space for a long time. It can provide a cold source for the space for a long time, so that the maintenance area is in a relatively stable thermal environment all year round.

The top surface of contemporary cold alleys can be divided into three types: virtual, real, and half-virtual and half-real interfaces. When Contemporary Cold alley is located outdoors, the sky is the virtual top surface. When a half-open sun-shading structure or a roof that extends from the two sides of the interface forms a half-shielded top surface, a half-virtual and half-solid top surface is formed. The solid top surface is usually the roof of the building or the floor of the upper space of the building. The three types of roofs have different effects on the self-shading of contemporary cold alleys, and directly affect the microclimate regulation of cold alleys.

The two sides of the contemporary cold alley directly affect the shape and intuitive experience of the cold alley, and its trend changes determine the spatial change of the contemporary cold alley. The choice and thickness of the side material also directly affects the microclimate adjustment effect of contemporary cold alleys. If we choose a wall material with a high heat storage coefficient, it can show a certain thermal retardation when the ambient temperature changes, and the greater the thickness of the wall, the greater the heat capacity coefficient and the higher the thermal stability.

There are two situations at both ends of contemporary cold alleys. When the width of the end face is much smaller than the width of the side face, because the distance between the end faces is too large, the limiting effect on the space is much smaller than that of the side face, so it can be ignored, and the end face is often kept open. But it contradicts the closed requirements of some contemporary buildings. Therefore, openable windows or semi-enclosed walls can be set at both ends to make the cold alley space relatively independent, while maintaining ventilation with the outside world. When the width of the end face is close to the width of the side, the end face becomes a side, and its influence on contemporary cold alleys is the same as that of the side. As shown in Figure 4-25, according to the permutation and combination, the spatial forms of contemporary cold alleys can be divided into: There are four types when the end surface is much smaller than the side surface, bottom surface + two side surfaces, bottom surface + top surface, bottom surface + one side surface + top surface. When the end face is close to the side, there are a total of eight kinds, except for the four just now, there are four more. Bottom + three sides, bottom + four sides, bottom + three sides + top, bottom + four sides + top. Therefore, there are many types of architectural spaces in contemporary cold alleys, and there are many types of spaces that meet this definition: Promenades, ventilated atriums, courtyards, patios, double-walled spaces, empty floors, etc.

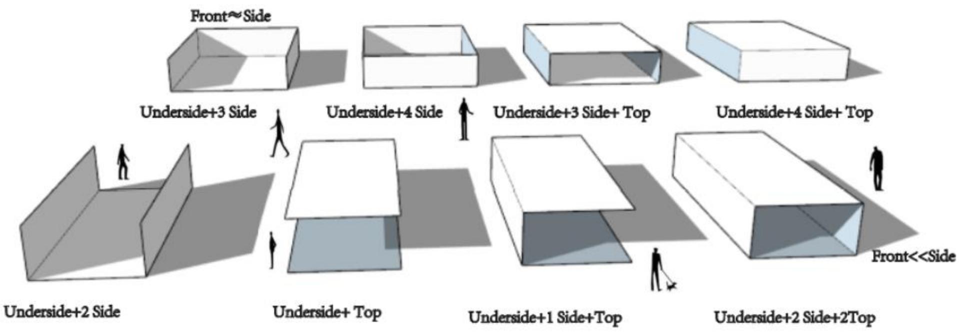


Figure 4-25. The combination of cold alleys.

Compared with the traditional cold alley, the contemporary cold alley has some changes in form, but its adjustment effect on the micro-climate of the building is consistent, otherwise it cannot be called a cold alley. Therefore, contemporary cold alleys can be defined as tubular architectural spaces with shading, ventilation and cooling functions in contemporary buildings and cities. Its technical points are also three: shading and ventilating building space, using cold storage materials at the enclosed interface, and ventilating at night.

4.1.5.2 The development of modern cold alleys

The form evolution of contemporary cold alleys can be summarized as a shift from linear to nonlinear, and traditional cold alleys are typical linear spaces. Linearity is the most fundamental form characteristic of traditional cold alleys. The linearity referred to in this article includes two concepts:

A. Linearity of cold alley form:

This is discussed from the formal characteristics of cold alley. The so-called linearity of the cold alley means that the length and width of the cold alley are relatively large, so that the overall space has a trend characteristic of extending along the linear expansion. Therefore, the larger the value of the aspect ratio, the more obvious the trend of linear expansion of the space.

However, with the continuous progress of society and the continuous development of architecture, more and more architectural forms have appeared, and contemporary cold alleys are no longer limited to the so-called linear characteristics. The size of a modern patio is not fixed, it can be narrow and long, or wide and short, but as long as it has the characteristics of contemporary cold alleys and can play a role in regulating the climate, it belongs to contemporary cold alleys. Traditional cold alleys have linear characteristics, because traditional cold alleys are restricted by the architectural form at that time, and their spatial form can only be narrow lanes with shading and ventilation. The form of contemporary cold alleys has undergone great changes, it can be non-linear.

B. Linearity of the activity pattern inside the cold alley:

This is discussed from the behavioral pattern of cold alley. The so-called linearity of the activity pattern in the cold alley means that the activity pattern of the users in the cold alley is affected by the linearity of the space form, and thus has obvious directivity characteristics, and its directivity is consistent with the spatial linearity.

Contemporary architectural forms are constantly enriched, and people's requirements for the use of various parts of the building are also constantly improving. In the space of traditional cold alleys, such as walkways and laneways, the mode of activity that occurs is traffic connections with clear directions. However, modern cold alleys that are enriched and improved on the basis of traditional cold alleys, such as "galleries" and "exhibition galleries", have various activities in them, but the most fundamental mode of activity is still linear transportation. It's just that other activity modes are expanded on this basis. These modes mainly occur at the edge of the cold alley space and do not affect its traffic connections.

The functional evolution of contemporary cold alleys can be summarized as a shift from single to comprehensive. The cold alley space in traditional settlements is often in the form of narrow lanes due to its large aspect ratio. In addition to regulating the microclimate of the building, its function is basically to satisfy a single traffic function. However, with the continuous development of the times, while continuing the traditional cold alley functions, contemporary cold alleys have gradually evolved from linear to nonlinear, and their functions have also evolved from a single transportation function to a comprehensive multi-function. It can accommodate the functions of many activities and show an open situation. The functional models of contemporary cold alley are summarized as follows: traffic function, communication function, spiritual function, and ecological function. Each functional mode corresponds to an evolutionary mode of contemporary cold alley.

Traffic function. The traffic function of the contemporary cold alley maintains the traditional connection and organization, guidance and evacuation. With the increasing expansion of the scale of buildings, many buildings are facing the problem of renovation and expansion. The cold alley space has the ability to grow, and the functional mode of building renovation and expansion is derived. The reconstruction and expansion of the building can be extended along the direction of the corridor, or perpendicular to the direction of the corridor. The reconstruction and expansion mode of the corridor not only solves the complicated internal traffic flow, but also makes the overall building flexible and adaptable.

Communication function. The contemporary cold alley space has the same intermediary nature as the traditional cold alley space. It is often a transitional space between the interior and the exterior, and is shared by both. The cold alley space plays the dual function of maintaining internal privacy and connecting with external publicity, and publicity can promote various public behaviors of users and become an important place for users to rest, entertain, and communicate. As contemporary cold alley breaks through the limitation of traditional size, and contemporary society is people-oriented and pays attention to the communication between people, the communication function of cold alley space is increasingly emphasized and valued by designers.

The intermediary and transitional nature of contemporary cold alley space can stimulate the interaction between people more than public space and private space. Compared with public space and private space, the intermediary and transitional nature of contemporary cold alley space can stimulate the interaction between people. The cold alley space of contemporary architecture often has a humanized space, a relaxed atmosphere and a pleasant scale, making it one of the popular places for users to stay. At this time, the transportation function of the cold alley space is combined with the communication function, and various contact opportunities are generated during walking, and the generation of contact opportunities increases various communication opportunities. The architectural space is infused with spirit and increased vitality.

Mental function. With the continuous enrichment of people's spiritual realm, their requirements for architecture are no longer just to satisfy the use function and beautiful form. The status of museums and exhibition halls in cities is becoming more and more important. They are responsible for meeting people's daily spiritual needs. Architecture is a symbolic form, it has symbolic meaning. The contemporary cold alley space has obvious and unique form characteristics, but it is not restricted by volume, size, and materials. Architects can suggest abstract concepts of contemporary cold alley space according to their own needs. Nowadays, the symbolic meaning of contemporary cold alley is no less than its practicality.

4.1.5.3 The spatial evolution of modern cold alleys

The spatial evolution of contemporary cold alley can be summarized into two points: one is the change from dynamic to static; the other is the change from concrete to fuzzy.

A. Transition from dynamic to static:

The dynamics of the cold alley space is a dynamic feature displayed through vision, specifically referring to the tendency of a kind of power displayed by the spatial form in the visual range. The dynamics of cold alley space is determined by its linear characteristics. In other words, the dynamics of cold alley spaces are related to the proportions and scales of their linear shapes. The larger the aspect ratio, the more obvious the linear characteristics and the stronger the dynamics. On the contrary, the dynamics weakens. When the width of the cold alley space is large enough to accommodate a certain range of activities for users, the cold alley space becomes static. The form characteristics of contemporary cold alleys gradually change from linear to non-linear. This is reflected in the cold alley space, which can be summarized as the contemporary cold alley space changing from dynamic to static. But it must be emphasized that the static nature of contemporary cold alley space will not affect the original dynamics. The static activity range of the user is often at the edges of both sides of the space. Therefore, the types of human activities corresponding to the two attributes of the cold alley space can be divided into two types: horizontal dynamic activities and vertical static activities. The location of the activity type is consistent with the location of the cold alley space.

B. Transition from concrete to fuzzy:

The space types of traditional cold alleys are very concrete. According to the internal and external characteristics of the space, they can be divided into indoor cold alleys, semi-outdoor cold alleys and outdoor cold alleys. The division of space types is based on the enclosure degree of the space, and the enclosure degree is mainly determined by the top surface, side surface and end surface of the space. Firstly, divide the indoor and outdoor according to the enclosure of the top surface. Those with a top surface are indoors, and those without a top surface are outdoor. Secondly, for indoor, it is divided into indoor and semi-outdoor. When the end face width is much smaller than the side width, the end face can be ignored. Two sides are indoor, no sides or one side is semi-outdoor. When the width of the end face is much smaller than the width of the side face, the end face can be ignored. Two sides are indoor, no side or one side is semi-outdoor. When the width of the end surface is close to the width of the side surface, the end surface is equivalent to the side surface, and there are four sides indoors, and the lack of any one side is semi-outdoor.

Nowadays, the completely enclosed interior space gives people a depressive feeling, so contemporary architecture needs a bright space atmosphere. With the progress of the times and the development of architecture, more and more materials are used to construct buildings, and glass material is a typical representative of them. When the top or side of the indoor cold alley space is enclosed by transparent glass villages, it brings a bright space and weakens the indoor attributes of the cold alley space. It makes the indoor cold alley space present a tendency to be externalized. But as long as it meets the requirements of space enclosure, it still belongs to the indoor cold alley space. This tendency of indoor and outdoor makes the contemporary cold alley space gradually change from concrete to fuzzy. The more glass material used on the top and side surfaces, the stronger the degree of externalization. However, the stronger the sense of enclosure formed by the components on the top and side surfaces, the stronger the degree of internalization, and the conflict between the two increases the level of the cold alley space.

4.1.6 Classification of modern cold alleys

With the rapid development of contemporary architecture, the cold alley space, as an indispensable and important architectural element in contemporary architecture, has become more and more diverse in its forms of expression, and the resulting spatial characteristics are also very different. According to different classification standards, contemporary cold alleys can be divided into different types. Different from the classification of traditional cold alleys, due to the development of technology, contemporary cold alleys have become more and more massive and rich in architectural shapes. Contemporary cold alleys are no longer constrained by the number of layers, forms, functions, and spaces. In contemporary architecture, those that meet the definition and technical points of contemporary cold alleys can be called contemporary cold alleys. It can be said that contemporary cold alleys are almost everywhere in contemporary architecture. Contemporary cold alleys can be divided into three types according to its different classification methods: divided according to spatial location, divided according to spatial expression form, and divided according to spatial combination. The following will explain the prototype combination of contemporary cold alleys according to different classification methods, and master the application rules of contemporary cold alleys.

4.1.6.1 Divided by spatial location

Contemporary cold alleys are developed from traditional cold alleys. In the long-term development process, the attributes, forms, functions, and spaces of cold alleys have undergone major changes. However, contemporary cold alleys can be divided into three categories: outdoor cold alleys, semi-outdoor cold alleys, and indoor cold alleys.

A. outdoor cold alley

Outdoor cold alleys refer to the narrow open spaces formed between adjacent buildings, building exterior walls, or between buildings and other enclosure structures in contemporary cold alleys, including narrow passages, narrow patios, and so on. From the perspective of space limitation, the outdoor cold alley refers to the cold alley space that is enclosed by at least two end surfaces or two side surfaces and the bottom surface without a top surface. When the height and width of the cold alley are relatively large and the space is relatively narrow, the area exposed to solar radiation during the day is small, thereby keeping the temperature low and giving people a sense of coolness. And the enclosure structures on both sides are mostly closed tall solid walls with good cold storage performance. During the day, it absorbs heat to store heat to keep the wall surface low, and at night it is cooled by outdoor cold air to store cold. Therefore, the temperature fluctuation in the outdoor cold alley is usually smaller than that in the outdoor open space. It should be noted that contemporary outdoor cold alleys are mostly used in group building spaces, but whether it is residential buildings or public buildings, it needs to meet the requirements of building codes when using outdoor cold alleys. Therefore, when designing outdoor cold alleys, it is necessary to design under the premise of meeting specifications.

B. Semi-outdoor cold alley

Semi-outdoor cold alley refers to the transitional space in the contemporary cold alley, which is located in the indoor diplomatic area, and the interface is appropriately open. The semi-outdoor cold alley is defined by the space between the top surface and the bottom surface, and at least one side cold alley space is missing. Due to the openness of the enclosed interface of modern semi-outdoor cold alleys, its architectural forms are also diverse. As a gray space attached to the building, actual measurement studies have proved that the semi-outdoor cold alley forms a climate buffer layer on the periphery of the building, which has a good thermal buffer effect. The outer colonnades, eaves corridors and arcades in contemporary buildings are common semi-outdoor cold alleys. Semi-outdoor cold alleys are shaded by the roof, so the corridors are less exposed to solar radiation and maintain a low temperature for a long time. In addition, due to the cold storage effect of the enclosure structure, the temperature of the cold alley is relatively stable, thus becoming a good thermal buffer layer from indoor to outdoor.

The semi-outdoor cold alley space is between the indoor space and the outdoor space, adding a spatial level as a transition, so that the building and the external space are ingeniously combined. While strengthening the continuity and connectivity between the spaces, the semi-outdoor cold alley creates a sense of visual hierarchy of the space and breaks the monotony of the space.

C. Indoor cold alley

Indoor cold alleys refer to unobstructed spaces with a certain aspect ratio inside the building that can be naturally ventilated, including corridors, indoor ventilated atriums, and so on. From the perspective of space limitation, the indoor cold alley refers to the cold alley space enclosed by the top surface, two sides and the ground. When the size of the end face is much smaller than the side, the end face is optional. But when the end face size is close to the side face, it must exist. Because it is not exposed to solar radiation for a long time or receives less solar radiation heat, the air circulation is smooth, and there is less residual heat from activities, which forms an indoor cold alley. The good cold storage of the enclosure structure can pre-cool the external ventilation to achieve the effect of adjusting the indoor climate. It exists in many building types, often in the form of a traffic space or a shared communication space within the building. Because of its good penetration, it becomes an excellent ventilation duct inside the building, which solves the ventilation problem inside the building.

4.1.6.2 Divided by spatial expression

The definition of contemporary cold alleys is different from traditional cold alleys. With the continuous development of architecture, modern cold alleys have gradually emerged from the constraints of traditional forms, functions, and spaces. Contemporary architecture pays attention to the creation of space. Many spaces with the characteristics of contemporary cold alleys can be found in contemporary architecture. These spaces belong to the category of contemporary cold alleys. It can be mainly summarized into three spatial manifestations: corridors or narrow lanes, courtyards or patios, and staircases. In practical applications, there may be different cold alley spaces in the same building at the same time, each of which performs their duties but can be matched with each other.

A. cold alley as a corridor or narrow alley

a. Concept of corridor and lane

There have been a lot of researches on corridors, which usually refers to passages that are covered with sunshade and rain protection. They can exist inside or outside the building, or they can exist independently. The corridor space is linear and intermediary. The linearity of the gallery space means that its length is greater than its width and thus has a tendency to extend linearly. However, intermediary means that the corridor space is often the middle level of the two spatial levels. Corridor space is public with respect to the indoor private space, and private with respect to the outdoor activity space, so the corridor space has an intermediary nature. For roadways, it can be that when the buildings are closely arranged, the distance between adjacent buildings is very small to form a narrow lane space similar to a traditional cold alley. The tunnel space can also be formed by adding an enclosure structure at a certain distance outside the building. The most essential difference between it and the corridor is that the corridor is enclosed by the top surface and the bottom surface (the sides are optional), while the roadway has no top surface, but is enclosed by the bottom surface and two side surfaces. So lanes are outdoor spaces and corridors are indoor or semi-outdoor spaces. But both are traffic spaces, and the combination of the two can cover all the linear passage spaces contained in the cold alley. With the continuous development of the building, the corridors and lanes are no longer bound by the number of floors, and can even exist in layers.

b. Cold alley space between corridors and lanes

The cold alley space as a corridor or narrow lane is essentially a linear space due to its traffic function. It also has an intermediary nature and can exist depending on the building or exist independently. But this kind of cold alley space performance is mainly reflected in its vertical aspect ratio. The difference in aspect ratio directly affects the spatial form of cold alleys in corridors or narrow lanes. The greater the height-to-width ratio of the corridor or narrow lane, the stronger the vertical characteristics, and the more obvious its cold alley space performance. Conversely, the smaller the aspect ratio, the weaker the performance of the cold alley space, and it cannot even become the cold alley space. Corridors or narrow lanes as cold alley spaces can also have vertical dynamic activities and horizontal static activities at the same time. The behavior pattern of cold alleys is mainly reflected in its horizontal aspect ratio. The greater the aspect ratio, the more obvious the linearity of the cold alley and the stronger the dynamics, which mainly reflects the horizontal dynamic activity. The smaller the aspect ratio, the linear weakening of the cold alley and the strengthening of staticity, showing horizontal dynamic activity combined with vertical static activity. In addition, the degree of spatial enclosure of corridors or narrow lanes should also meet the technical points of cold alley space. Corridors or narrow lanes as cold alleys are not as open as possible. In addition to meeting self-shading to reduce heat gain, the interface also needs to be properly closed and the use of good cold storage performance enclosure materials, which has a better heat insulation effect. Then combined with the opening of the channel for ventilation, the role of the cold alley becomes more obvious.

B. As a cold alley in the atrium or patio

a. Concept of atrium and patio

Patio has been widely used in traditional dwellings in areas with hot summers and cold winters since ancient times. It is especially common in dwellings in southern Shaanxi, and has even become the main representative spatial feature of local dwellings. Patio mainly refers to the open-air space enclosed between houses and houses (or walls) in traditional dwellings. This design ecologically can make the house full of light and air circulation. In contemporary buildings, due to the continuous increase of the building volume and the continuous expansion of the standard floor plan, the internal lighting and ventilation are becoming more and more difficult to meet. Therefore, a patio is still reserved in the middle of the building to solve the lighting and ventilation problems. Not only that, the patio has also become the main expression of architectural space and one of the main places for people to rest and communicate. The most essential difference between the atrium and the patio is that the atrium enclosure is formed by enclosing the top surface, bottom surface, side surface, and at least one end surface. The patio has no top surface, so the atrium is an indoor or semi-outdoor space while the patio is an outdoor space. The atrium usually refers to the courtyard space inside the building, and its biggest feature is that it forms an "outdoor space" inside the building. It is a form of internal space created in architectural design that is isolated and integrated with the internal private space, or it can be said to be a way to share the external environment inside the building. The atrium is very popular in contemporary architecture because it can give a sense of space and bring a sense of brightness. At the same time, it is a relatively private external space that is rarely disturbed by the external environment.

b. Cold alley space in the atrium and patio

The atrium and patio can be regarded as large cold alley spaces. Due to its large aspect ratio, it can form a self-shading to avoid direct sun exposure, thereby reducing radiant heat gain. The “chimney effect” can be used to pull out the wind, and the tops of the atrium and patio are appropriately heated by solar radiation. An air outlet is provided at the top, and the hot air rises and is discharged into the outside air, thereby forming a thermal pressure difference, driving the air flow in the internal space, and forming thermal pressure ventilation. At this time, if the atrium or patio is combined with a corridor and cold alley, the two can form a ventilation system and the effect will be more obvious. However, the atrium is superior to the patio not only in reducing the interference of the external environment. In winter, the air outlet at the top of the atrium can be closed to ensure normal ventilation. Then the air at the top of the atrium will not be discharged after being heated, thus forming the "greenhouse effect". A good thermal environment is formed inside the building to resist the severe external cold. In addition, because the cold alley space as an atrium and patio can stimulate people's leisure, communication and other activities, vegetation, water features and other natural environmental factors are often introduced here, and these landscapes can also adjust the microclimate of the building.

C. As the cold alley of the stairwell

a. The concept of a stairwell

In traditional buildings, limited by the number of floors, the main function of the ladder room is to connect the traffic space of the upper and lower floors. In modern times, with the increasing number of floors and stricter evacuation regulations, the status of staircases in buildings has become more and more important. With the discovery of more and more materials, more and more functional requirements, higher and higher space requirements, and more and more abundant forms of stairs. According to the location, the stairs can be divided into: indoor stairs, outdoor stairs. According to the nature of use: traffic stairs, auxiliary stairs, evacuation stairs. According to the function of anti-smoke and fire, it can be divided into: open staircase, enclosed staircase, anti-smoke staircase, outdoor fire-proof staircase. According to the structural form, it is divided into: beam staircase, slab staircase, cantilever staircase, suspended staircase, wall support staircase. According to the combination method, it can be divided into: single-run stairs, double-run stairs, triple-run stairs, double-fold stairs, curved-foot bent-angle stairs, double-part stairs, double-fold stairs, scissors ladders, cross double-run stairs, circular stairs, spirals Shaped stairs, curved stairs. Different types of stairs correspond to different types of stairwell spaces, which correspond to various types of cold alley spaces.

b. Cold alley space in the stairwell

In contemporary buildings, in order to leave the sunny side more for the main functions, middle and low-rise buildings often move the stairwell to the north of the building, and high-rise buildings move the stairwell to the central core tube. Therefore, the stairwell is often not directly exposed to the sun, so it gets less heat. Due to the high safety requirements of the stairs, the construction of the stairs is often made of heavy materials with good cold storage properties. It can absorb heat and cool down during the day, and then release heat and store cold at night.

As the number of building floors gets higher and higher, the height-to-width ratio between the stairways is getting bigger and bigger. Due to the connectivity of the upper and lower spaces, it can produce a "chimney effect" like an atrium and a patio to pull out the wind, thereby forming a Heat pressure ventilation. It can also produce a "greenhouse effect" in winter like the atrium to form a good thermal environment. Therefore, the stairwell is also an important cold alley space in contemporary architecture.

As an important transportation connection in contemporary architecture, the stairwell is often connected with the corridor. When the "chimney effect" is generated in the stairwell and the thermal pressure difference is formed, the cold alley space of the corridor connected to it will supply cold air to the stairwell in time, thereby driving the ventilation of the rooms connected to the corridor. When the stairwell produces a "greenhouse effect" to generate hot air, the hot space can be transmitted to each room through the cold alley space of the corridor connected to it, thereby forming an overall greenhouse.

4.1.6.3 Divided by spatial combination

There are many types of contemporary buildings, various external forms, and ever-changing internal spaces. The various spaces of the building are integrated with each other, but they are connected to each other. Architectural space can be divided into single space and composite space according to space combination. Cold alley can also be divided into single cold alley and compound cold alley. In addition, in actual buildings, it is not the independent application of a certain type of cold alley space, but the coexistence and compound application of the same type or different types of cold alleys.

A. Single cold alley

Single cold alley means that there is only a single type of cold alley unit in the building, or it can be understood that there are more than one type of cold alley units, but they are not connected to each other. One of the most common is a simple linear space with a relatively large height and width. If the height and width are small, it is an independent corridor or laneway. When the height and width are relatively large, it is a patio or courtyard. Single cold alleys often appear in small-volume building groups or individual buildings, but can be reused in large-scale buildings, which can not only divide the building shape into suitable scales, but also increase the sense of rhythm.

B. Compound cold alley

Compound cold alley refers to a cold alley space with a complex system of internal cold alley units combined in a certain combination. Compound cold alleys are divided according to the combination of their space functions, which can be summarized into plane compound cold alleys and three-dimensional compound cold alleys. Plane composite cold alley refers to the formation of composite cold alleys on the same plane through the combination and connection of the plane cold alleys. Such as a composite cold alley is formed between indoor corridors and outdoor roadways, and a composite cold alley is formed between semi-outdoor eaves and indoor corridors, etc. Three-dimensional composite cold alley refers to the combination of three-dimensional multi-level cold alley space by adding three-dimensional cold alley space, such as vertical stairs, ramps, atrium space, etc. On the basis of these, it is also possible to form a rich and diverse space by changing its cross-section and other interface forms to enhance the space effect. Composite cold alleys are usually used in large-scale buildings or group buildings on a larger scale to increase internal connections and improve space utilization.

4.2. Design inspiration and strategy of traditional cold alley in modern architecture

4.2.1 Subtraction to generate cold alleys

The cold alley is generated by subtraction. As the name implies, the cold alley space is obtained by subtraction in the building block. At this time, the cold alley space exists inside the building, it is a space that cannot be separated from the main body of the building and exists independently. The cold alley is a kind of space cavity. If you want to design the cold alley inside the building, it is bound to be obtained by volume subtraction. The combination of contemporary building blocks is rich in changes. Compared with traditional cold alleys, contemporary cold alleys are also free from the constraints of form, function and space. Therefore, through the same subtraction method in the building, completely different contemporary cold alley spaces can be obtained. Mastering these techniques can better deal with the relationship between the internal physical functions of the building and the cold alley space in the design.

4.2.1.1 Through type cold alley

Through-type cold alleys generally refer to the use of subtraction in the design, and hollow up the building block along the vertical direction to form a narrow patio, thereby forming a vertical through cold alley space. The hollowed out patio space is diverse in specific architectural design, and the resulting spatial form is also colorful, often becoming the main feature of the internal space of the building. This through-type cold alley space combines climate and space treatment, strengthens the ventilation and lighting inside the building, and solves the problem of shading at the same time. It is a common space treatment method to solve the problem of lighting and ventilation inside large buildings with large depths. The hollowed-out space becomes a large climate buffer space inside the building. When the sun shines on the building, the narrow and high-shaped space forms a good self-shading, forming a larger shadow inside, and the air at the top of the building is heated to form a thermal pressure difference, which drives the air in the cold alley to rise and circulate. At this time, if an air inlet is set at the bottom of the building, fresh air can be continuously added to form a good ventilation path. The incoming fresh air is pre-cooled at the bottom of the cold aisle so that the temperature drops. During the rising process, it will continue to exchange heat and ventilation with the indoors of each floor, and finally form a good overall ventilation system.

The specific form of the through-type cold alley is determined according to the specific actual situation and design conditions. According to its overall space, it can be divided into two types: segmented type and integral type:

As shown in Figure.4-26, the sectioned through cold alley space is the sectioned treatment of the cold alley space, with multiple regular ventilation units, each of which is independent but connected to each other. If a high-rise building is set up with a ventilation patio dominated by natural ventilation, the combined effect of heat pressure and wind pressure may cause excessive internal wind speed and turbulence. Therefore, it can be segmented by combining several layers into a unit. The segmented treatment is more open than the integral cold alley, and the ventilation effect is better. Using this method can make the exterior of the building form a sense of rhythm, and make the interior of the building form a unique architectural space.

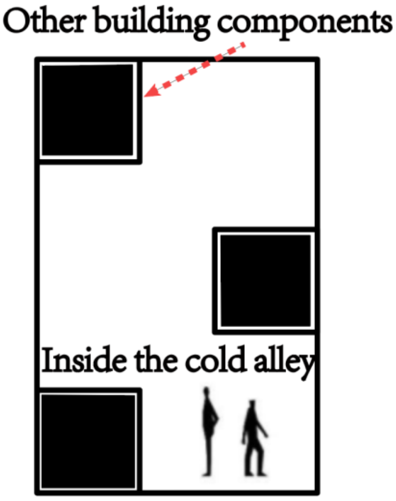


Figure 4-26. Through-type cold alleys.

Integral type: Compared with the segmented type, the integrated cold alley structure is clearer and clearer, and it is often through up and down to the end without segmented processing, as shown in Figure.4-27. However, the above analysis also shows that the integral type is not suitable for super high-rise buildings, because there is no segmentation treatment, the wind speed is often too fast and turbulence is generated.

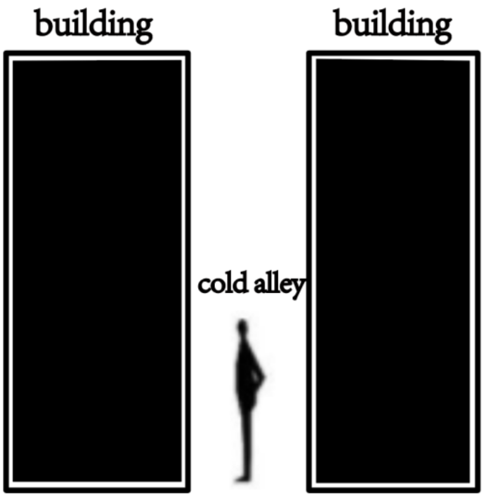


Figure 4-27. Integral cold alley.

4.2.1.2 Indented type cold alley

Indented type cold alley generally refers to the use of subtraction in the design, partial or overall small distance retreat or indentation in the building block, thereby forming the cold alley space. Indented type cold alleys usually have fewer open areas, and the space receives less external interference, and is relatively quiet and private. The shading and heat insulation of the indented space are good, which is conducive to generating good natural ventilation, thereby improving the local climate adaptability of the building. There are many ways of indentation, such as single layer partial indentation, single layer all indentation, layered partial indentation, cross-layer partial indentation and so on. Different ways of indentation result in different cold alley spaces, which can be divided into three types: overhead type, layered type, and overhead type.

Overhead type: Overhead cold alley refers to the cold alley formed by cutting inwardly along the vertical crosswise on the bottom or middle layer of the building. This kind of cold alley is a covered, transparent and continuous space, a semi-outdoor space that is open to the outside, and it plays the role of traffic space and transitional space in the building. Greening and rest facilities are usually introduced into the overhead space to become people's public activity space. The overhead space is conducive to the formation of an open interface in a tight site, and is especially suitable for high-density urban spaces. The overhead part can be located at the bottom of the building, or in the middle of the building. The cold alley space formed by the overhead usually needs to be appropriately limited with columns or other enclosing elements to form a certain degree of sealing to ensure continuous and good ventilation, and heat insulation and cold storage. As shown in Figure.4-28, it can be divided into a single-layer inner concave to form an arcade cold alley, or it can be divided into a jump layer to form a side courtyard, and the entire layer can be concave to form a layered space.

Figure 4-28. Indented cold alley.

The first type of arcade retracted cold alley and the second type of side courtyard retracted cold alley are one type, but the size is different. This type of cold alley can also be seen everywhere in traditional buildings. The cold alley forms a low-temperature zone through its own shading, thus becoming a climate buffer layer between the interior of the building and the outdoors. At the same time, the thermal pressure difference with the outdoor open field is used for thermal pressure ventilation, thereby driving indoor ventilation.

The overhead cold alley can not only become the climate layer inside and outside the building, but also can form the rich light and shadow of the building facade through its own form of rich value modeling, and also play a role in shading. In commercial buildings, businesses along the street often use this type of cold alley as a traffic space. On the one hand, it can be used as a shelter for people and the climate layer of buildings; on the other hand, it has become an important place for people to gather and communicate in the morning and evening, and become a communication space.

The third type of pick-up and retracted cold alleys often appear in high-rise buildings, and the entire floor is often raised to form cold alley spaces. Overhead floors are not the latest in China. The tall buildings in southern Shaanxi are built on the water, the bamboo buildings of the Dai family, the hanging buildings of the Miao family, and the water pavilions in Suzhou gardens. This type is common at the bottom of the overhead. The advantages of this are:

- To avoid interference, the function use layer is moved up to avoid interference from other factors on the ground.

- People and vehicles are separated. Ground vehicles run on the overhead floor and people move above the second floor. This solves the parking problem and protects personal safety.
- Ventilation and cooling, the overhead layer can reduce the shelter of the monsoon, so that the natural wind can better enter the interior of the building, thereby ventilating and cooling.

There is also a shared layer that is used as a user in the middle floor, which usually appears in high-rise residential or high-rise office buildings with tight land use. Even if you are on a high level, you can enjoy the landscape of the ecological garden. In addition, if used properly, such as introducing natural wind into the building through design, it becomes a cold alley. The sky garden is formed by overhead, and then the overhead cold alley is combined with the through cold alley to achieve the purpose of ventilation and cooling.

Layered type: Layered cold alleys exist in each floor of the building, with the number of floors as the basic unit. As shown in Figure.4-29, the internal corridors and external side corridors of the building are the most common layered cold alleys, which mainly serve as traffic functions in the building. This kind of cold alley has good self-shading effect and strong enclosure. The linear feature of the corridor makes it a good ventilation cavity in the building. The good cold storage of the enclosed wall keeps its temperature in a low and stable range all the time. Because all buildings need corridors to organize the connection between functions and safe evacuation, it is the most commonly used climate buffer layer in general conventional buildings.

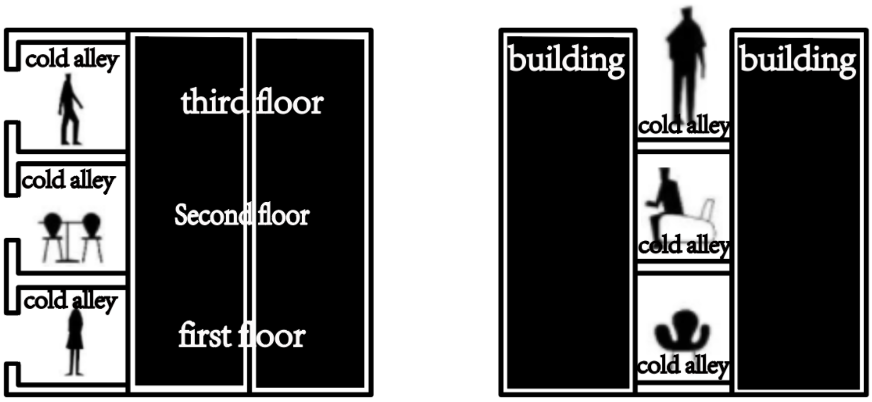


Figure 4-29. Layered cold alley.

Overhead cold alley: The empty cold alley is similar to the through cold alley, the difference is that it is an indoor space that exists inside the building, so it is classified as a concave cold alley. As shown in Figure.4-30, the most common form of this kind of cold alley is the internal atrium of the building. Because there is no top opening, other air inlets and outlets are set separately. Hollow cold alleys are often created to obtain the internal space effect of the building.

Figure 4-30. Aerial cold alley.

4.2.1.3 Open type cold alley

The open cold alley belongs to the category of outdoor space, and its enclosure has no top, so it often exists on the top of the building, as shown in Figure.4-31. Through the subtractive treatment of the volume, it can also form a self-shading. If the enclosed interface uses materials with good cold storage properties and can maintain ventilation, it also belongs to the category of contemporary cold alleys.

The form of the open cold alley is somewhat similar to the laneway between the buildings in the traditional settlement. Its form determines that it can only contribute to the wind environment of its surrounding buildings, and it is difficult to optimize the overall ventilation of the building. Therefore, it is not widely used in contemporary architecture.

Figure 4-31. Open cold alley.

4.2.2 Addition to generate cold alleys

Compared with the above-mentioned subtraction to generate cold alleys, the method of adding cold alleys to generate cold alleys is to maintain the original shape of the building by adding components to the building block, or the building block is surrounded by other blocks. The design techniques of cold alleys can be generated by combining, or by adjusting the site, etc. The contemporary cold alleys generated by addition often exist outside the building. Although it cannot be separated from the main building, it is indeed an independent architectural element outside the main building. The cold alley generated by addition is often used to enrich the facade of the building or enrich the external site space of the building. By understanding this technique, we can combine architectural design, site design and passive energy-saving design in future designs.

2.2.1 Additional type cold alley

Additional cold alleys refer to contemporary cold alleys generated by adding components to the building or enclosing the building with other blocks. The additional cold alley is the external enclosed space of the building, which has no influence on the internal function and space of the building. The additional cold alley forms a self-shading through the framework or other blocks, and becomes a good thermal buffer layer outside the building. The additional cold alleys can basically be divided into three types: wall type, side-by-side type, and under-eave type.

Piece-wall type: piece-wall cold alley refers to a contemporary cold alley formed by adding a wall outside the building volume to form a good climate buffer layer on the side of the building, as shown in Figure.4-32. In hot summer and cold winter areas, the climate is hot in summer and the sun is strong, especially the western sun in the afternoon is very serious. If you leave a suitable interval outside the west of the building and add walls, the double-layer walls will maintain a large aspect ratio as a whole, so that when the sun goes to the west, the additional walls can provide good shading. The air between the inner and outer walls flows due to heat pressure and wind pressure to produce better heat insulation. The external wall should maintain proper openings to facilitate ventilation, and use materials with better heat storage performance to enhance the microclimate regulation and reduce cooling energy consumption. This method is especially suitable in areas with strong sunshine and large temperature changes. The wall has various changes in the architectural shape, and it can often form a sharp contrast between the real and the whole building and receive a striking and peculiar artistic effect. In addition, the function of the cold alley space of the piece wall is not only to play the role of ventilation, lighting, and heat insulation, but also the characteristic space and facade form in contemporary architecture. It has a certain cultural significance and can appropriately improve the quality of residential buildings. Appropriate changes are made to the piece-wall cold alleys. While combining the architectural functions, the cold alley space can become an artistic and cultural landscape.

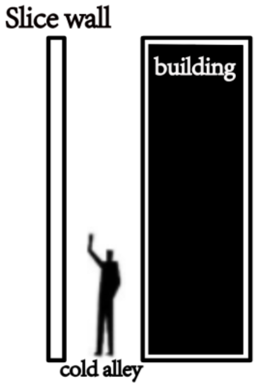


Figure 4-32. Piece wall cold alley.

Side-by-side cold alleys: Side-by-side cold alleys refer to contemporary cold alleys formed by two or more building blocks side by side and enclosing each other, as shown in Figure.4-33. The roadway space is formed between the various volumes, and the aspect ratio meets the requirements of contemporary cold alleys. The openings should be oriented as good as possible, similar to the prevailing wind direction in summer, which is conducive to ventilation. In this way, a conventional contemporary cold alley space is generated between adjacent blocks, the size of which depends on the size of the block. Usually when this technique is used, multiple cold alleys are formed side by side. The top of this contemporary cold alley is transparent and open, with less covering to maintain good ventilation.

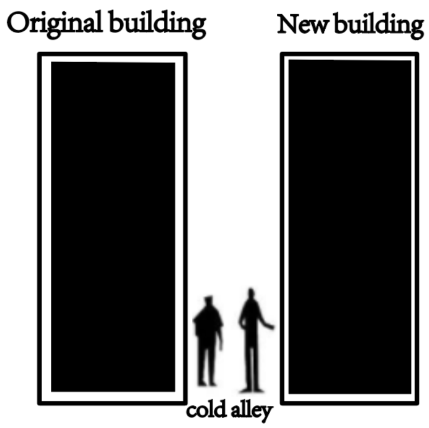


Figure 4-33. Side-by-side cold alley.

Under the eaves: cold alley under the eaves refers to the cold alley space under the eaves formed by adding eaves components or forming eaves in its own shape, as shown in Figure.4-34. This type of cold alley can provide users with a space under the eaves for shading and sheltering from the rain, and secondly, by virtue of its own cold alley nature, it forms a climate buffer layer outside the building. Cold alleys under the eaves formed by adding eaves components often appear in buildings along the streets of commercial streets, which are very similar to the cold alleys of arcades with hollow hollows. The difference between the two is that the under-eaves type is the cold alley space obtained by addition, while the concave type is obtained by subtraction.

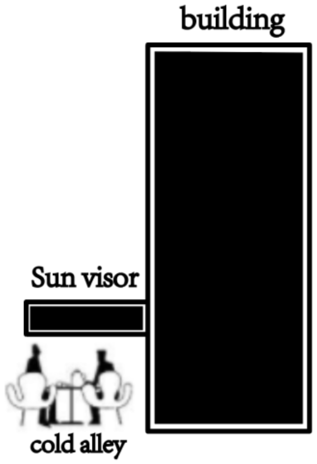


Figure 4-34. Canopy cold alley.

2.2.2 Sunken cold alley

The formation of cold alleys through addition can not only add elements to the exterior of the building, but also divide the building and the site to form an underground narrow patio space, as shown in.4-35. The narrow patio sinks, and the side is connected to the ground for a long time, serving as a cold source for a long time. Due to the large aspect ratio of the narrow patio and the particularity of the layout, it can be self-shading, thereby forming the "frost hole effect" of the sloped building. Therefore, as long as the appropriate aspect ratio is adopted, the narrow patio can maintain low temperature for a long time and become a kind of semi-underground cavity space for cooling and storing. Combining the terrain can make good use of this method, especially suitable for office, education and other types of architectural spaces. The sunken cold alley is placed on one side of the building, which can perform functions such as cooling, lighting, and ventilation. At the same time, low-temperature air enters the room for adjustment, which induces natural ventilation of the building. Tall plants can be planted in the sunken cold alley, which plays a role in shading and cooling. The inner wall of the patio can be planted with vertical greening or drop wall, and the ground can also be equipped with platforms and water features. In this way, it not only creates a good landscape space and microclimate environment, but also becomes an outdoor leisure activity space for people, which serves multiple purposes.

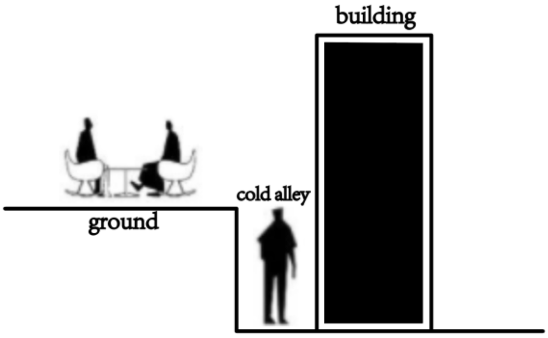


Figure 4-35. Sunken cold alley.

4.2.3 Design strategy for cold alleys as corridors or lanes

The above chapter mainly discusses the design principles and design methods of contemporary cold alleys, which are the basis for designing contemporary cold alleys. However, if you want to effectively apply contemporary cold alleys to contemporary buildings, you need to cooperate with the corresponding cold alley design strategies. For different contemporary cold alley types, each will have its own cold alley design strategy. Fully combining the design principles, design methods and design strategies of cold alleys can help designers prescribe the right medicine, so as to design efficient contemporary cold alleys for different situations. As the design strategy of contemporary cold alleys, it needs to be distinguished from the cooling strategy of contemporary cold alleys. The design strategy is a process from scratch, and its main task is to design the shading method and natural ventilation of the cold alley through certain design methods when designing contemporary cold alleys. The cooling strategy is to improve on the existing basis, and its main task is to improve the cooling effect of the existing contemporary cold alley space through certain modification methods. Therefore, the design strategy of contemporary cold alleys is mainly aimed at the shelter of the cold alleys from external sunlight and the use of external natural wind. This section mainly focuses on the types of contemporary cold alleys divided by spatial expressions. They are contemporary cold alleys as corridors or alleys, contemporary cold alleys as atriums or patios, and contemporary cold alleys as stairwells.

Contemporary cold alleys, as corridors or laneways, serve the function of connecting traffic, and they are widely used in various building types. Corridors or laneways are often directly connected to the main body of the building, thus becoming a transitional space between the interior and the exterior of the building. This type of cold alley directly affects the microclimate environment of the building interior, so it is necessary to study the design strategy of contemporary cold alley as a corridor or lane.

4.2.3.1 Shading design strategy

As a corridor or laneway, contemporary cold alleys are divided according to the spatial location, and are mainly divided into outdoor passages, semi-outdoor arcades, and indoor corridors. The indoor corridors do not need to consider shading design. Contemporary cold alley shading design strategies are divided into self-shading and artificial shading.

Self-shading: The design strategy of self-shading is mainly to use its own architectural shape for the corridor or lane to self-shade. This requires designers to fully consider the relationship between the shape design of the corridor or alley and the height angle of the sun when designing the cold alley. As shown in Figure.4-36, the contemporary cold alley as a corridor or alley can be self-shading by changing the height difference of the building shape enclosed on both sides of the corridor or alley. It can also be self-shading by designing the corridor or lane. It is also possible to overhang the building above the corridor or alley as much as possible for self-shading.

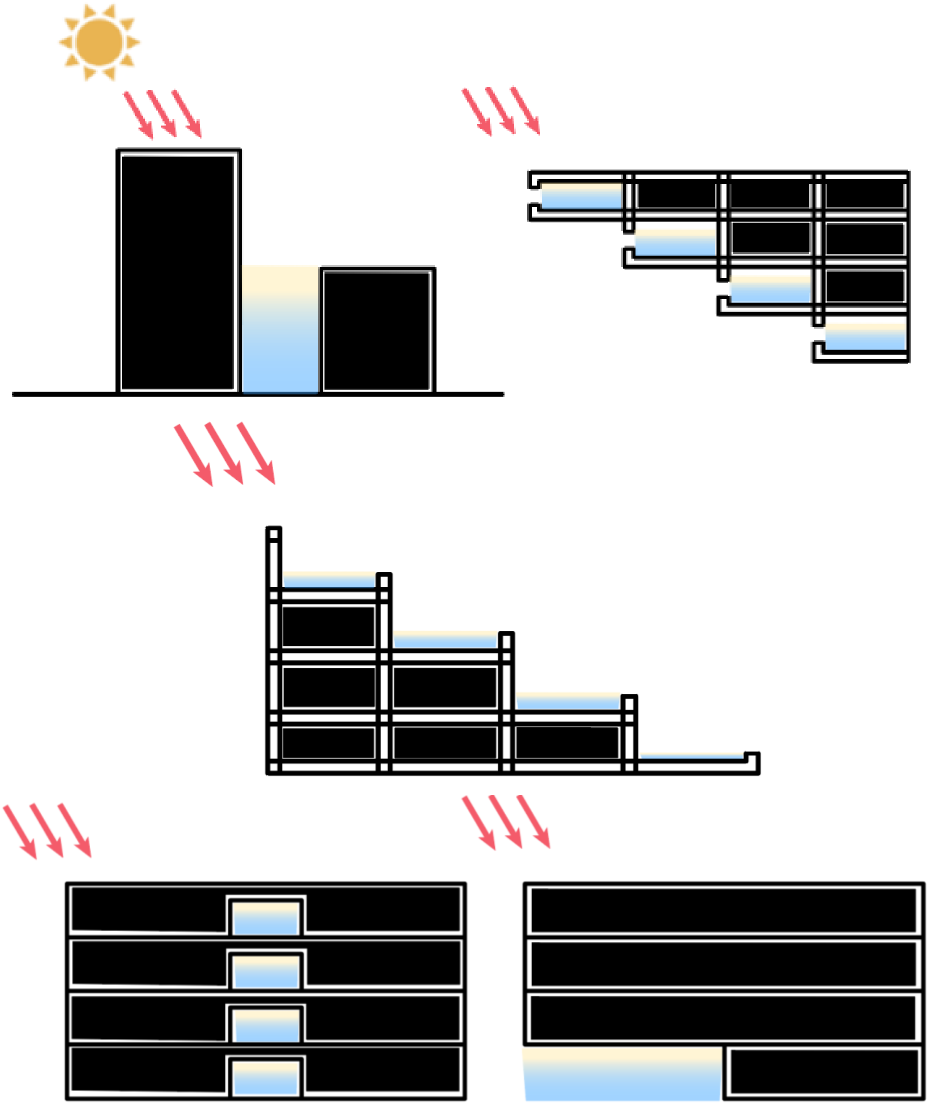


Figure 4-36. Self-shading in the alley.

Artificial shading: The artificial shading design strategy is mainly to rely on external equipment for shading on the roof of the gallery or alley through artificial design. This kind of shading design strategy can increase the controllability and effectiveness of cold alley shading, thereby making up for some of the disadvantages of self-shading. However, designers should not rely solely on artificial shading strategies when designing, but should combine self-shading strategies with artificial shading strategies to complement each other. As shown in Figure.4-37, the contemporary cold alley as a corridor or lane can adjust the sunshine by adding movable grilles on the facade or top surface of the corridor or lane. It can be adjusted according to needs, divided into three modes: sunshade and daylighting, full sunshade, and illumination. It is also possible to add shading components to the enclosed interface of the corridor or alley for shading, such as a wall or a canopy.

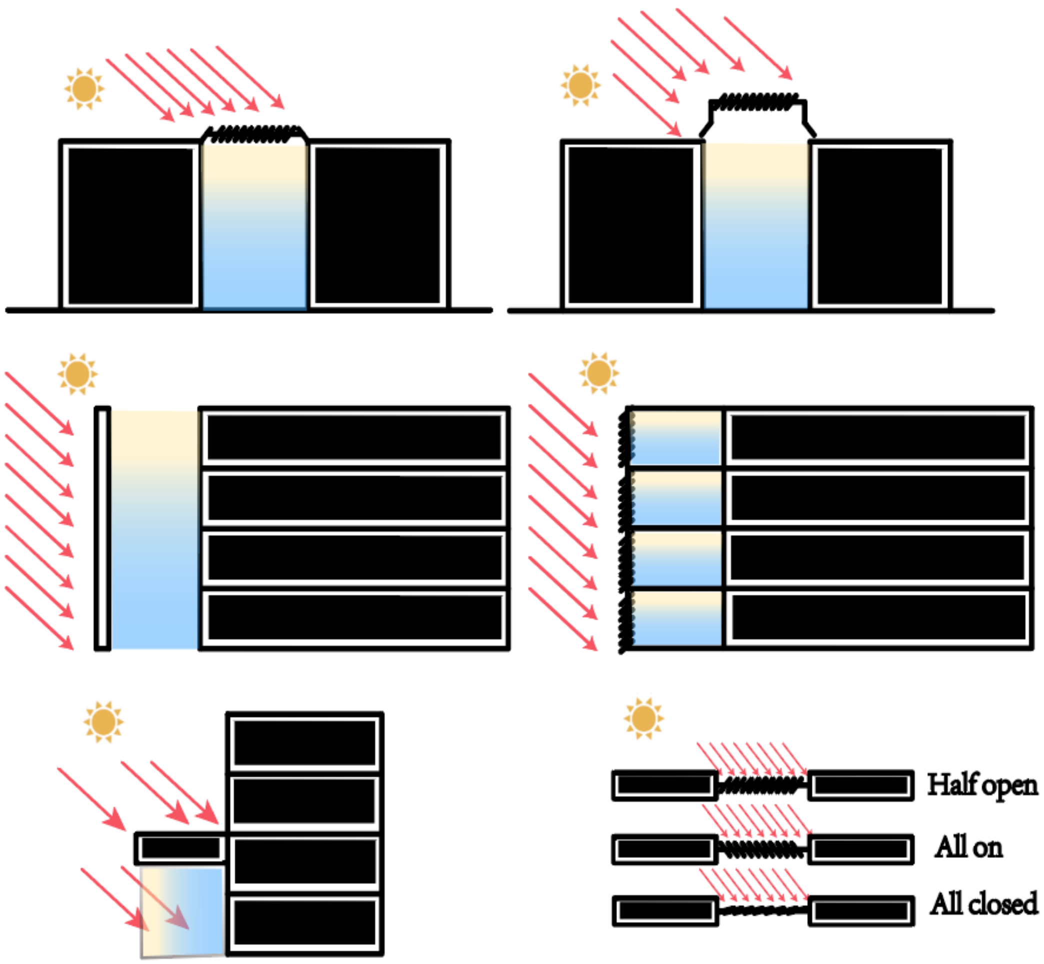


Figure 4-37. Artificial shading of the alley.

4.2.3.2 Ventilation design strategy

As a corridor or laneway in contemporary cold alleys, no matter which type, ventilation design needs to be considered. Like shading, natural ventilation is also the key to cold alleys. Contemporary cold alley ventilation design strategies are divided into air pressure ventilation and Heat pressure ventilation.

Application of pressure ventilation: The design strategy of pressure ventilation needs to fully consider the prevailing wind direction in summer and winter in the area where the design is located. It is necessary to make contemporary cold alleys as corridors or lanes face the prevailing winds in summer and avoid the prevailing winds in winter, so as to make full use of natural ventilation for cooling in summer and adopt thermal insulation strategies as much as possible in winter. As shown in Figure.4-38, the design of cold alleys requires comprehensive consideration of the lighting direction of the building and the prevailing wind direction in summer. When the two can be unified, the lighting direction of the building is adjusted to cater to the prevailing summer wind, and the building itself is used to block the prevailing wind in winter. When the two cannot be unified, the building shape can be adjusted to cater to the prevailing summer wind. When necessary, manual equipment can be installed to shield the prevailing wind in winter.

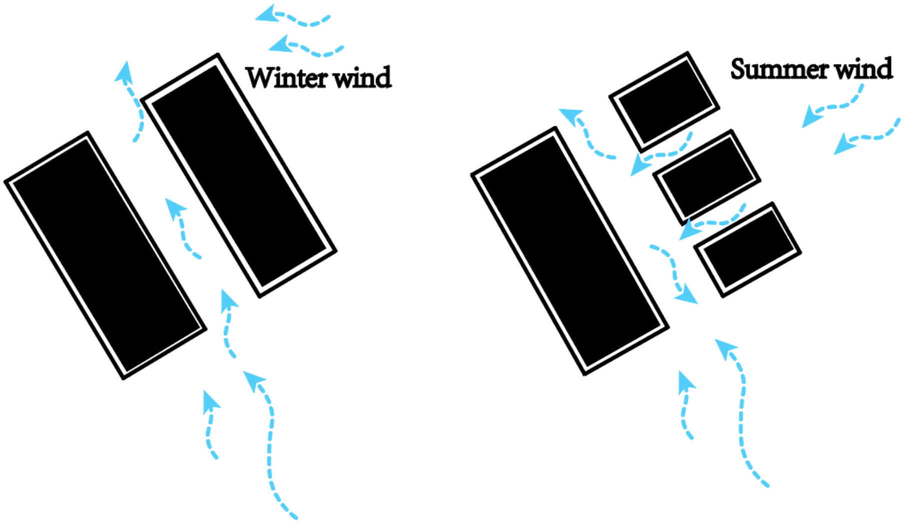


Figure 4-38. Wind pressure ventilation in the alley.

Application of Heat pressure ventilation: The design strategy of Heat pressure ventilation needs to fully consider the thermal pressure difference generated under sunlight, and apply it through cold tunnel design. Try to take away the hot air inside the building and bring in cold air. Heat pressure ventilation is also divided into summer and winter. In summer, hot air should be removed as much as possible, and hot air should be kept as much as possible in winter.

As shown in Figure.4-39, the first type is aimed at outdoor cold alleys, with movable sunshade grilles and switchable air outlets set on the top surface of outdoor passages. When ventilation is required in summer, set the sunshade grille to sunshade daylighting mode or full sunshade mode, and open the air outlet. When the air at the top of the outdoor passage is heated up, it will drive the air flow inside the passage, and finally drive the ventilation inside the enclosed building on both sides. When ventilation is not required in winter, on the basis of maintaining healthy ventilation, set the sunshade grille to the lighting room irradiation mode and close the air outlet. Under the direct sunlight, the air temperature of the passage rises, forming a greenhouse effect, thereby improving the microclimate of the enclosed buildings on both sides.

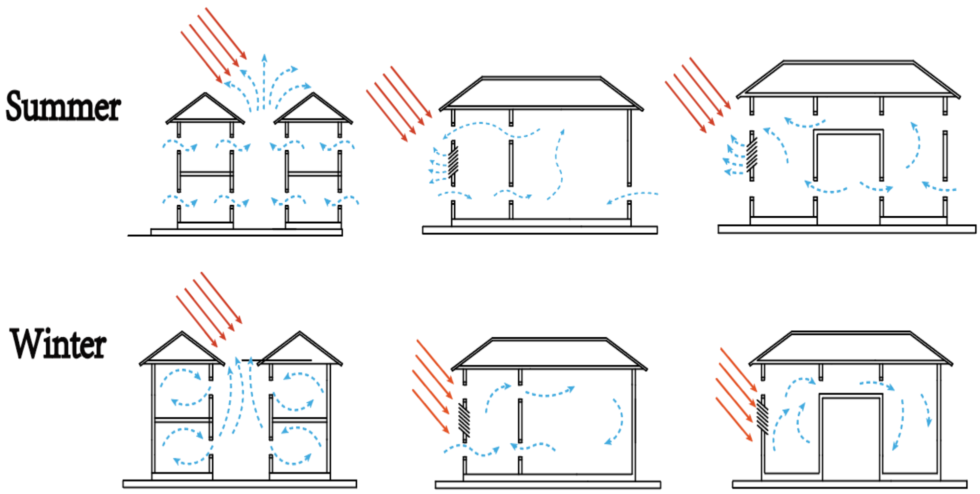


Figure 4-39. Heat pressure ventilation in the alley.

The second is for semi-outdoor cold alleys, such as arcade passages or side corridors. A movable sunshade grille is arranged on the outer side of the channel, and switchable air vents are left up and down, and the switchable air vents are also set up and down on the inner side of the channel. When ventilation is required in summer, set the outer sunshade grille to sunshade daylighting mode or full sunshade mode. Open the upper air vent, close the lower air vent, and then open both the upper and lower air vents on the inner side. When the air near the outer side is heated, the hot air in the channel and the upper part of the room will be brought out of the outdoor together. However, the cold air will enter the room from the lower opening on the inner side and the window on the rear side of the room, and finally form ventilation and cooling. When ventilation is not required in winter, on the basis of maintaining healthy ventilation, set the sunshade grille on the outer side to the irradiation mode. Open the lower air vent, close the upper air vent, and then open both the upper and lower air vents on the inner side. When the air in the channel rises under direct sunlight, it enters the room through the opening on the inner side, while the cold indoor air enters the channel through the lower opening on the inner side to heat up, forming a greenhouse effect.

The third type is aimed at internal cold alleys. A movable sunshade grille is installed on the indoor south-facing facade, and a switchable air outlet is provided above the south facade, and a switchable air outlet is provided below the north facade. On the two sides of the indoor corridor, switchable air openings are arranged up and down, and the upper air openings are closed and connected. When ventilation is required in summer, set the sunshade grille on the south-facing facade to sunshade daylighting mode or full sunshade mode. Open the air outlets on the facade, open the air outlets on both sides of the corridor, and open the air outlets on the north facade. When the air near the exterior of the south facade rises due to heat, the hot air from the upper part of the interior of the south facade is brought out of the outdoors under the action of heat pressure. The hot air from the upper part of the north interior enters the interior of the south through the upper openings on the two sides of the corridor, and is also taken out of the outdoor together. However, the cold air is pre-cooled through the corridor and enters the north and south rooms through the lower openings on the two sides of the corridor. The cold air from the north of the building also enters the room through the lower opening of the north façade to form ventilation. When ventilation is not needed in winter, on the basis of maintaining healthy ventilation, set the sunshade grille on the south facade to the illumination mode. Close the openings of the north and south facades, open the upper air vents of the corridor, and close the lower air vents, so that the southern interior becomes a greenhouse. When the indoor air in the south is heated and rises under direct sunlight, it enters the room in the north through the upper openings on both sides of the corridor, thereby improving the overall microclimate of the room.

4.2.4 Design strategy for cold alleys as atriums or patios

Contemporary cold alleys, as atriums or patios, often exist in larger buildings. Because large-scale multi-storey buildings generally occupies a large area and have a large depth, it is difficult to take into account the interior of the building with ordinary through-flow ventilation and single-sided ventilation. The maximum depth of single-sided ventilation should not exceed 2.5 times the height of the floor. The maximum depth of tubular ventilation should not exceed 5 times the floor height, and the depth of large-scale buildings can easily exceed these values [1]. Therefore, it is very necessary to set up an atrium or patio inside a large-scale building. The patio is relatively open, which can provide good shading and timely ventilation and heat removal in summer, but in winter, it will lose heat quickly and make the temperature lower. The atrium is relatively closed, which can effectively reduce heat loss in winter and form a greenhouse effect under sunlight. However, summer is not conducive to the timely removal of heat and makes the temperature higher. So we need to combine the two when designing.

The top surface of the atrium is set to a mode that can be turned on and off through artificial control, so that the atrium has both passive cooling and heat gain working modes. The chimney effect can be used in summer, and the greenhouse effect can be used in winter.

4.2.4.1 Shading design strategy

Self-shading: The self-shading design strategy is mainly to use its own building shape for self-shading in the atrium or patio. This requires the designer to fully consider the relationship between the shape design of the atrium or patio and the height angle of the sun when designing the cold alley [22]. As shown in Figure.4-40, the atrium or patio can be set back to make it into an inverted "V" shape to reduce the top surface opening area of the atrium or patio, thereby achieving self-shading.

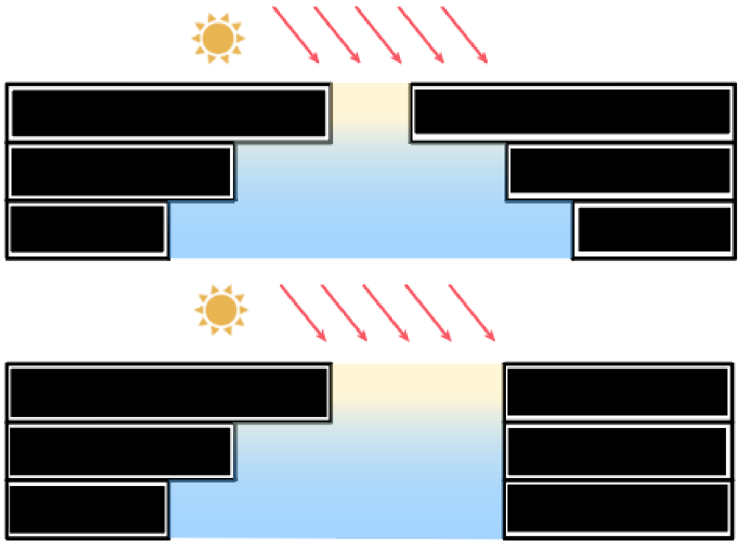


Figure 4-40. Self-shading of the patio.

Artificial shading: The artificial shading strategy is mainly to rely on external equipment for shading on the top surface of the atrium or patio through artificial design [23]. This shading design strategy can increase the controllability and effectiveness of cold alley shading. As shown in Figure.4-41, the contemporary cold alley as an atrium or patio can adjust the sunlight by adding a movable grille on the top surface. It is also possible to raise the top surface and add a wind tower to transfer the area directly exposed to the sun for shading.

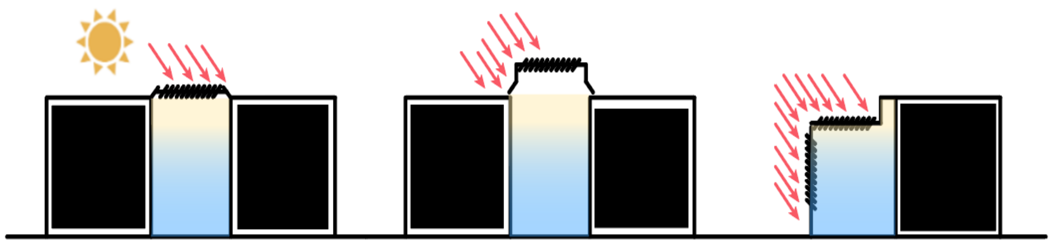


Figure 4-41. Artificial shading for patios.

4.2.4.2 Ventilation design strategy

Application of pressure ventilation: The design strategy of pressure ventilation needs to fully consider the prevailing wind direction in summer and winter in the area where the design is located. It is necessary to make the contemporary cold alley as an atrium or patio as far as possible to face the prevailing wind direction in summer and avoid the prevailing wind direction in winter. So as to make full use of natural ventilation to cool down in summer and adopt thermal insulation strategy in winter as much as possible. But not only need to consider the wind direction, but also need to design together with the volume of the building. As shown in Figure.4-42, if the building is arranged in a circular shape around the atrium or patio, there are three situations:

- In the case of small depth, comprehensive use of wind pressure for cross-flow ventilation and single-sided ventilation.
- In the case of a large depth, make an opening on the windward side of the building to the summer breeze through reasonable design. So that the summer breeze can smoothly enter the interior of the building through the atrium or patio.
- When the depth of the building is large, but the integrity of the facade must be ensured, wind is induced by digging a semi-underground space and setting the air inlet at the summer wind direction.

If the building is arranged in a retracted form around the atrium or patio, that is, one side of the atrium or patio is open, try to make the opening face the summer wind direction as much as possible [24]. When necessary, manual equipment can be installed to block the prevailing wind or sunshine in winter.

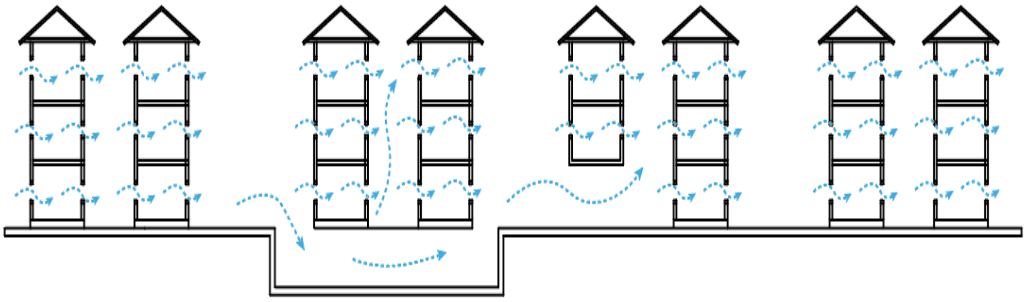


Figure 4-42. Application of air pressure ventilation in patio.

Application of Heat pressure ventilation: The design strategy of Heat pressure ventilation needs to fully consider the thermal pressure difference generated under sunlight. It is applied through cold alley design, so as to take away the hot air inside the building and bring in cold air as much as possible. The atrium or patio as the cold alley space itself is set due to the fact that the cross-flow ventilation and single-side ventilation cannot meet the natural ventilation and hot-pressure ventilation inside the building. Its main working principle is Heat pressure ventilation, but it also has summer and winter distinctions. In summer, hot air should be removed as much as possible, so we must pay attention to shading and enhance air circulation. However, in winter, the hot air is kept as much as possible, so we must pay attention to sunshine and reduce heat loss. As the atrium or patio, the cold alley space must rely on artificial shading for Heat pressure ventilation. Thereby strengthening the controllability of ventilation and improving efficiency.

As shown in Figure.4-43, the first type is to set a movable sunshade grille and a switchable air outlet on the top surface of the atrium or patio. When ventilation is needed in summer, set the sunshade grille to sunshade daylighting mode or full sunshade mode, and open the air outlet. When the top air is heated up, it drives the air flow in the atrium or patio, and finally drives the ventilation inside the enclosed building on both sides. When ventilation is not required in winter, on the basis of maintaining healthy ventilation, set the sunshade grille to the irradiation mode and close the air outlet. Under direct sunlight, the air temperature in the atrium or patio rises, forming a greenhouse effect, thereby improving the microclimate inside the surrounding buildings.

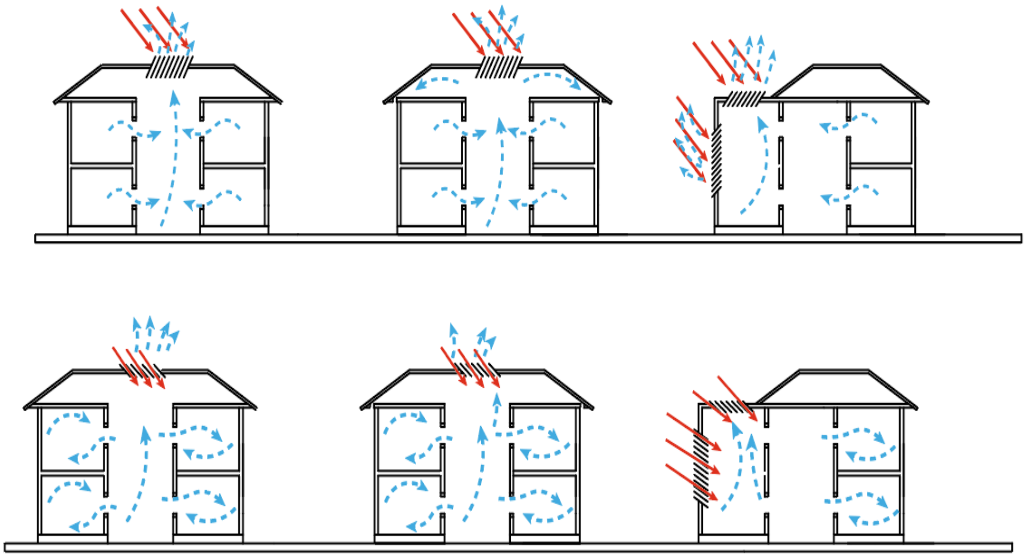


Figure 4-43. Application of Heat pressure ventilation in patio.

The second type is to set up a wind tower on the top surface of the atrium or patio, and the side of the wind tower is equipped with open and close air outlets [25]. When ventilation is required in summer, open the side vents of the wind tower. When the air in the wind tower rises due to heat, it will drive the air flow in the atrium or patio, and finally drive the ventilation inside the building on both sides. When ventilation is not required in winter, on the basis of maintaining healthy ventilation, close the side vents of the wind tower, and the air temperature in the atrium or patio will rise under direct sunlight, forming a greenhouse effect, thereby improving the micro-structure of the surrounding buildings.

The combined effect of air pressure ventilation and Heat pressure ventilation: In the previous section, we can learn that the building can be used for Heat pressure ventilation through the cold alley as the atrium or patio. The hot air rises and discharges will require cold air to sink in. If the summer breeze is introduced into the atrium or patio through the design at this time, as shown in Figure.4-44, a better ventilation effect will be achieved.

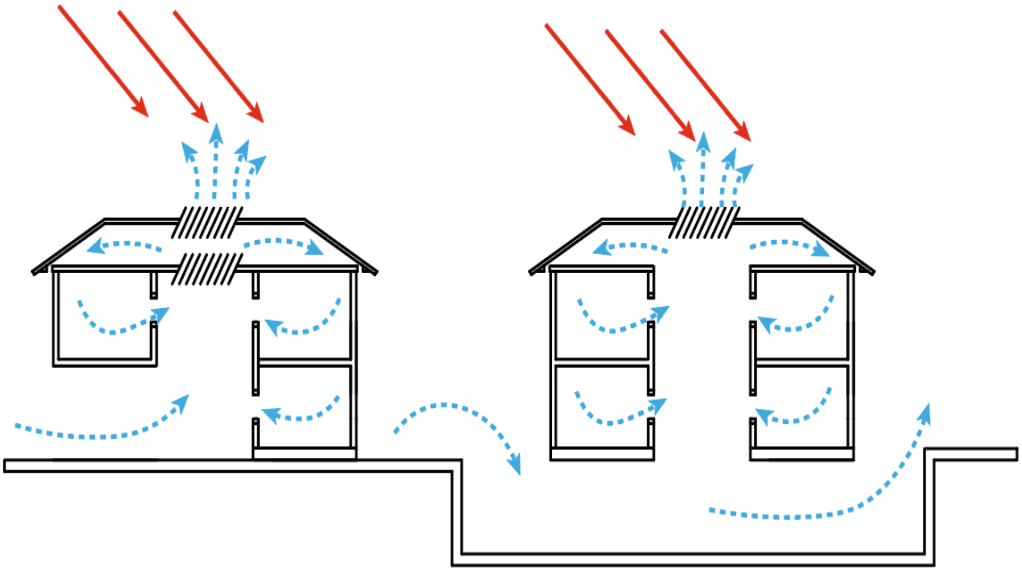


Figure 4-44. Co-application of air pressure and Heat pressure ventilation in the patio.

4.2.5 Design strategy for cold alleys as stairwells

The design strategy of the contemporary cold alley as a stairwell is similar to the previous two. It not only assumes the traffic attributes and is closely connected with the interior, but also presents the characteristics of high-altitude, and the effect of ventilation is very good [26].

4.2.5.1 Shading design strategy

Self-shading: As the contemporary cold alley self-shading of the stairwell, the self-shading is based on the shape of the building. As shown in Figure.4-45, when there are building blocks around the stairwell, self-shading can be done through the height difference of the shape.

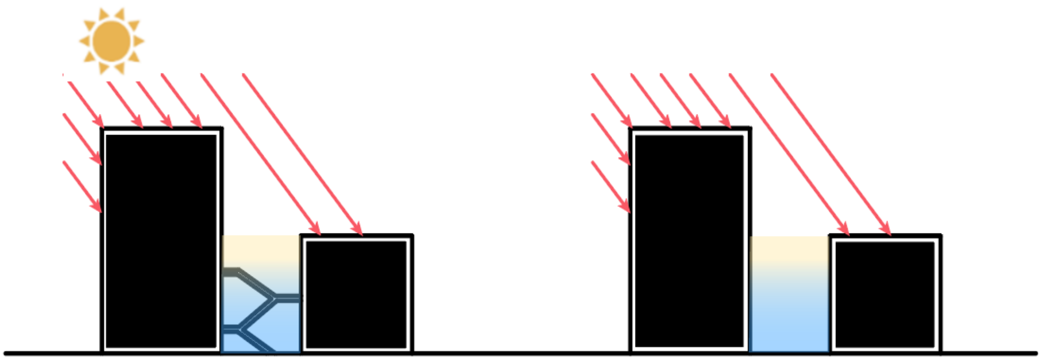


Figure 4-45. Self-shading in the stairwell.

Artificial shading: As shown in Figure.4-46, when the stairwell is located on one side of the building, movable grilles need to be set on the side and top of the stairwell for artificial shading. When the stairwell is located inside the building but the height difference cannot be used for self-shading, it is necessary to set a movable grille on the top surface of the stairwell for artificial shading.

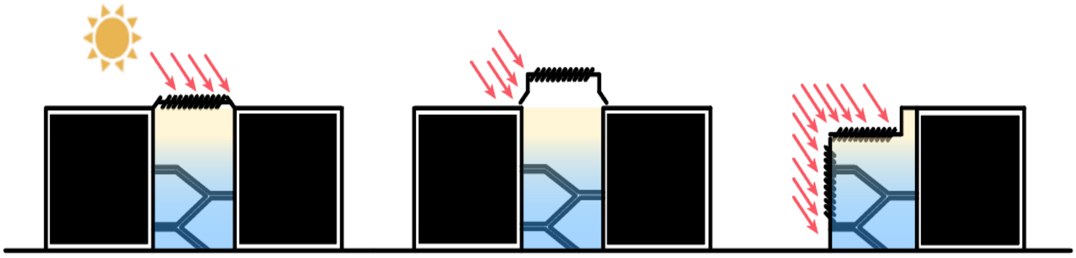


Figure 4-46. Artificial shading in stairwells.

4.2.5.2 Ventilation design strategy

Application of wind pressure ventilation: As shown in Figure.4-47, when the stairwell is outdoors, its ventilation strategy is the same as that of the cold alley as a corridor or lane, and it is to face the summer wind as much as possible and avoid the winter wind. When the two cannot be unified, the building shape can be adjusted to cater to the prevailing summer wind [27]. When necessary, manual equipment can be installed to shield the prevailing wind in winter. When the stairwell is indoors, it is also necessary to open windows or holes to guide the wind.

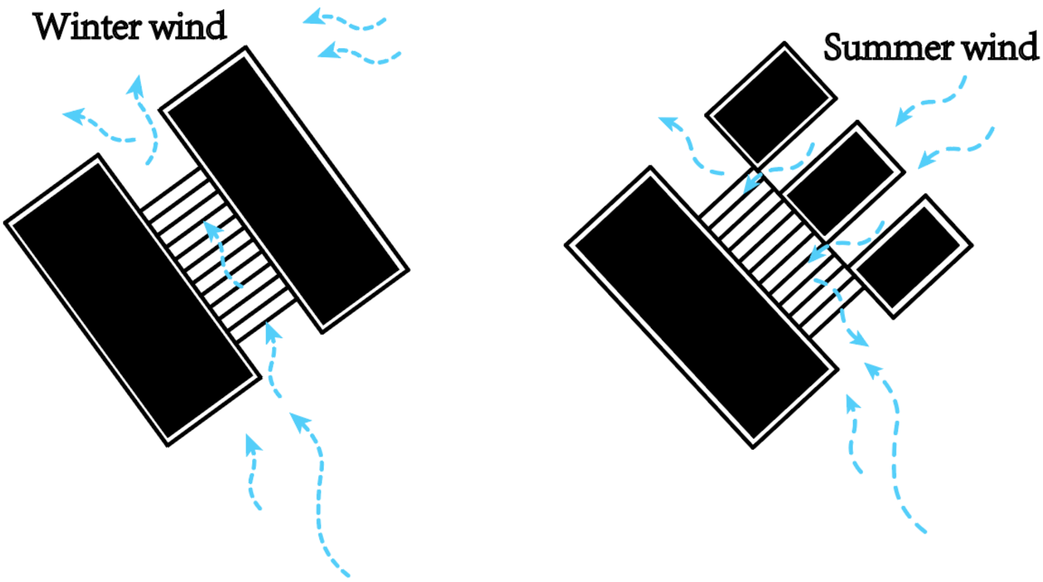


Figure 4-47. Wind pressure ventilation in the stairwell.

Application of Heat pressure ventilation: As shown in Figure.4-48, the Heat pressure ventilation of the stairwell requires the help of artificial shading. The side and top surface of the stairwell are equipped with movable sunshade grilles, and the upper and lower air outlets can be switched. When ventilation is needed in summer, set the sunshade grille to sunshade daylighting mode or full sunshade mode, open the upper air vent and close the lower air vent. When the top air is heated up, it will drive the air flow inside the stairwell, and finally drive the ventilation inside the building. When ventilation is not required in winter, on the basis of maintaining healthy ventilation, set the sunshade grille to the irradiation mode, close the upper air vent and open the lower air vent. The air temperature in the stairwell rises under direct sunlight, forming a greenhouse effect. Hot air enters the interior of the building, while cold air continues to enter the stairwell from the downwind to be heated, thereby improving the microclimate of the surrounding buildings.

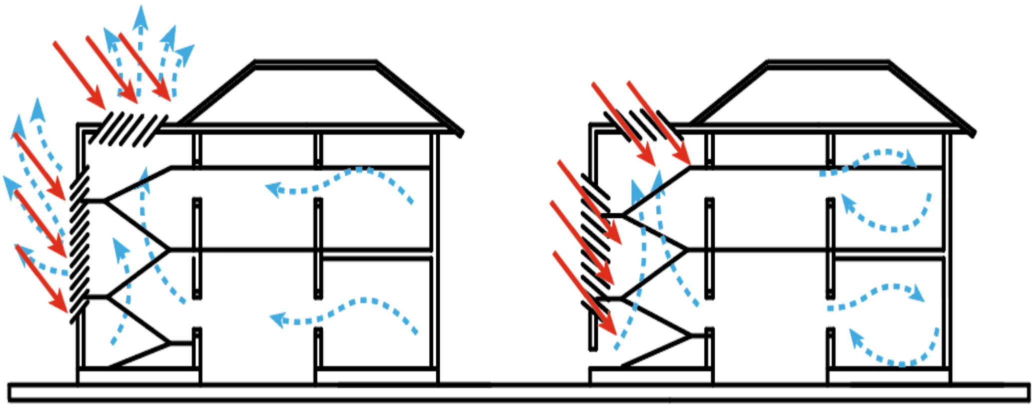


Figure 4-48. Heat pressure ventilation in the stairwell.

4.3. Chapter summary

This chapter mainly explains the mechanism of the role of cold alleys in traditional settlements in southern Shaanxi, China. The first is a detailed introduction to the cold alleys of traditional settlements in southern Shaanxi. The content of the introduction includes the definition and technical points of cold alleys, the spatial form of cold alleys, the types of cold alley spaces, the materials used in cold alleys, the definition and development prospects of modern cold alleys, and the classification of modern cold alleys. Secondly, through the research of traditional cold alleys and modern cold alleys, the design method of cold alleys and the design strategies of its reasonable application in modern buildings are summarized.

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Chapter 5. Natural ventilation and cooling in traditional settlements in southern Shaanxi

5.1. The definition of natural energy-saving methods in traditional residential buildings

There are two main energy-saving methods, one is the energy-saving of building equipment, through intervention to reduce the energy consumption of equipment, that is, "active energy-saving". Such as air conditioning and ventilation systems, lighting systems, heating systems and other building equipment systems. The other is energy saving through non-mechanical means, that is, "passive energy saving"[1,2,3,4,5]. Realize building energy saving and consumption reduction through energy-saving insulation materials and construction methods. Specifically, it refers to the reduction of energy consumption such as ventilation [6], air conditioning [7,8,9,10], and heating required by the building through the thermal insulation technology of the envelope structure, the reasonable setting of shading, and the roof design of ventilation and insulation. For example, in northern China, in order to resist the cold, people thickened the walls when building houses and invented the "fire bed" as a heating device [11,12]. In southern China, people raise the roof to a certain height to prevent heatstroke, which is conducive to ventilation and heat dissipation. At the same time, the rainy climate in the south can help drain water. These are typical passive energy-saving methods. In the past, there was no concept of energy saving in buildings. Most of the traditional houses were built to protect themselves, and the background was also in a natural environment with low technical level and relatively abundant resources. Therefore, most of the construction of folk houses is a set of methods summarized by our ancestors through observation of nature and rich life experiences. This set of methods can generally be summarized as design by combining the local natural climate characteristics, adapting to the local topography, and using local native materials. It can be seen that the design principle contained in traditional houses is the passive energy-saving design mentioned above. That is, a design that optimizes energy saving through natural factors. The natural energy-saving methods in traditional houses belong to "passive energy-saving" in a certain sense. Mainly refers to a design that optimizes energy conservation according to natural factors such as the orientation of the building, natural lighting, and shading [13].

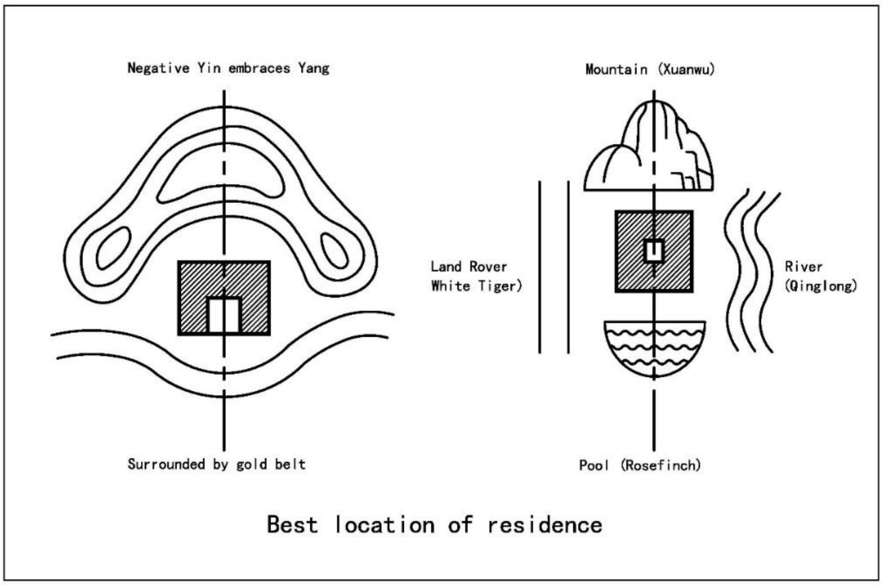

Figure5-1. Best location of residence.

5.2. Site selection and layout design of traditional houses

In the overall construction work process, the location of the building is the first step in all work. The site selection directly affects the construction site of the house. Choosing a good site and designing it according to the local topography can save a lot of unnecessary energy consumption [14].

5.2.1 Site selection design

There are many traditional Chinese cultural spirits in the traditional houses. The location and orientation of the houses emphasize the idea of harmony between man and nature. The harmony between man and nature is the most important basic concept in Chinese traditional culture. The term "heaven and man" here not only refers to man and nature, but also includes human's understanding and utilization of the surrounding environment and harmonious development with nature. "Feng Shui", which is often mentioned in Chinese traditional architecture, is the science of living environment, which is based on the laws of nature, following the laws of nature, using the knowledge and life experience accumulated over the years to make reasonable guesses about things.

Take the architectural courtyard in northern my country as an example. It is a symbol of traditional Chinese culture and fully follows the principles of Feng Shui in its layout. From the site selection to the size of the entire building, they are all designed in accordance with Feng Shui theory. The reason why it is called "siheyuan", "si" refers to the four sides surrounded by east, west, south and north, forming a mouth-shaped courtyard in the middle [15]. The Fengshui studies included in the Siheyuan should start with the site selection. The ground of the courtyard house is generally higher than the ground of the alleys and streets outside, and the position of the back house is generally higher than the position of the front house. At the same time, facing the slow stream, surrounded by mountains and rivers, so that the qi will not be lost. The enclosed courtyard is spacious and bright. This layout not only achieves the Tibetan wind, but also enables gathering but not scattered, benefiting from the environment. The enclosed courtyard is spacious and bright. This layout can not only store the wind, but also make the "qi" gather but not disperse, and benefit from the environment with better quality "qi".

5.2.2 Choice of orientation

When choosing the orientation of the building, various factors need to be considered, especially the factors that value solar radiation and wind direction. In China, the geographical location belongs to the northern hemisphere, at low latitudes, the sun shines from the south all year round [16]. The daily life of human beings is based on the prerequisite of direct sunlight, so Feng Shui emphasizes "living south". South-facing houses have the best daylight. In summer, the sun shines directly in the northern hemisphere. The strong afternoon sunlight deflects to the north. The south-facing houses can avoid direct sunlight and avoid high temperatures. However, in winter, when the sun shines directly in the southern hemisphere, the sun will be biased to the south, and the house can maintain a warm and moderate temperature in the cold season. It fully complies with the laws of the sun, uses the sun's light to keep the house warm in winter and cool in summer, saves the use of air conditioning systems, and saves energy. In addition, on the one hand, sunlight can ensure the lighting in the house and make the house brighter. On the other hand, ultraviolet rays have the effect of sterilization and disinfection on the human skin. Frequent sunlight in the room can reduce the spread of diseases.

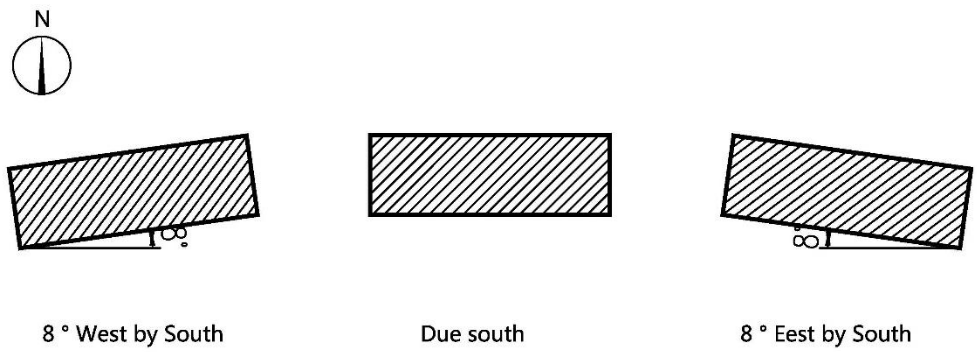

Figure 5-2. Best orientation of residence.

The other aspect that pays attention to sitting north and facing south is closely related to the main direction of the monsoon wind. China is a country with a monsoon climate. It is located in the southeast of Eurasia, the largest continent in the world, and faces the Pacific Ocean, the largest ocean in the world to the east. When summer comes, strong sunlight shines on the sea. As the temperature rises slowly on the ocean, the temperature in the Pacific Ocean is lower and high atmospheric pressure is formed. However, because of the rapid temperature rise above the land, the surface temperature is high, and the air is expanded and rises, forming a low pressure on the ground. The wind direction is generally from high air pressure to low air pressure, so the summer monsoon in my country comes from the warm and humid wind blowing from the ocean, that is, the southeast wind. On the contrary, it is colder on land in winter, and the pressure is higher. The temperature of the Pacific Ocean is higher, and the pressure is lower. The air current flows from high pressure to low pressure to the right, so a northerly wind is formed, which belongs to the northwest monsoon. The south-facing house can blow into the house through the door or window in the summer, which makes people feel cool in the summer, has good ventilation effect, and can avoid the cold wind in the winter. In fact, it’s not easy to find a position facing north and south. When planning the residential area, it is impossible for the site to meet the designer's requirements everywhere. Therefore, when the building cannot face the south, it is best to follow the principle of the true south. A slight deviation of 5-8° to the east or west can also be considered [17].

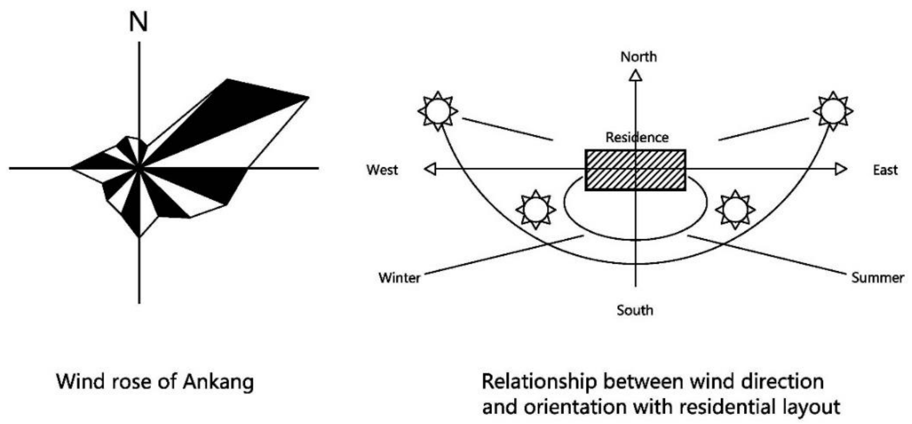

Figure 5-3. Relationship between wind direction and orientation with residential layout.

The location and orientation of traditional houses should generally avoid the building on the wind outlet with strong wind. A better choice is that the location of the building conforms to the prevailing direction of the summer monsoon and is not affected by the cold monsoon in winter. This choice of orientation not only guarantees sufficient lighting and the demand for the residence to be warm in winter and cool in summer, but also to save the use of refrigeration or heating systems. At the same time, the residence also has a good ventilation effect, which fully conforms to the laws of nature. The goal of energy saving is achieved through passive energy-saving design.

5.3. Natural ventilation design of traditional houses

With the process of urbanization, people's requirements for thermal comfort are gradually increasing. Most of today's buildings use mechanical ventilation, which has caused a large number of residential natural ventilation problems and excessive energy consumption by air-conditioning equipment [18]. Natural ventilation is an absolutely environmentally friendly passive energy-saving measure. It can lower the indoor temperature without consuming resources, reduce the energy consumption caused by air conditioning equipment, and bring a little fresh air to the room.

Natural ventilation refers to the use of heat pressure or wind caused by the temperature difference between indoor and outdoor air to promote the exchange of indoor and outdoor air [19]. It is mainly produced by the combined effect of heat pressure and wind pressure. Hot air ventilation is an air flow phenomenon in which the air density difference is caused by the temperature difference between indoor and outdoor. If the density is different, the hot air tends to rise, and the cold air tends to fall. Wind pressure ventilation means that when the airflow meets an obstacle, the air pressure on the windward side increases, while the air pressure on the side and leeward side decreases. The resulting pressure difference forms the phenomenon of air flow from the windward side to the leeward side. The importance of natural ventilation is mainly reflected in two aspects:

- Natural ventilation does not require power, which means that it does not need to consume energy, which can save system equipment investment and operating costs. It can not only form an effective passive refrigeration, but also a scientific and economical ventilation method. It meets the requirements of lowering the indoor temperature without using air-conditioning and other equipment, taking away heat, and improving the comfort of the occupants.
- The air provided indoors through natural ventilation is fresh and clean, thus satisfying people's desire to be close to nature. Natural ventilation also avoids the "air-conditioning disease" caused by the decline of resistance caused by modern people's common air-conditioning and other refrigeration equipment. Therefore, it is of great help to the body's physical and mental health.

Traditional Chinese houses have always attached importance to natural ventilation. In buildings, good natural ventilation is a basic requirement for a house, especially in southern Shaanxi, which is hot in summer. The key to solving natural ventilation is to solve the design of the orientation, layout and environment of the building. The architectural orientation has been explained above, and secondly, it can also be dealt with through the indoor and outdoor spaces of the residential buildings. Such as: the application of small patios, the organization of draughts, and the design of Heat pressure ventilation in cold alleys.

5.3.1 Application of patio

Small patios are very common in traditional dwellings, and there are patio-style buildings in southern Shaanxi. Due to the hot weather in southern Shaanxi, the climate is humid and the wind is quiet, the ventilation problem in the house can be solved very well through the pull-out effect of the small patio. The patio introduces fresh air into the house, thereby promoting the hot air in the house to be discharged from the patio. There is a certain amount of air flow in the house, which speeds up the air velocity and achieves a good ventilation effect [20].

Patio-style buildings are the main form of courtyard-style dwellings in southern Shaanxi. The houses on all sides are enclosed by the patio. An open free space is left from above the courtyard, which is named "patio" because it resembles a well. The patio is actually mutated from the courtyard building. But the patio buildings in southern Shaanxi are different from the courtyard-style buildings in the north. The weather in the north is cold and dry. Warmth and lighting are the first considerations for northern architecture. Courtyard-style buildings increase the absorption of sunlight by expanding the courtyard, so that the space is no longer so cold. While the weather in southern Shaanxi is wet and rainy, ventilation and drainage are the primary problems that need to be solved. Patio-style buildings create a cooler and more comfortable space by reducing the size of the patio, thereby regulating the dampness and coldness of the climate.

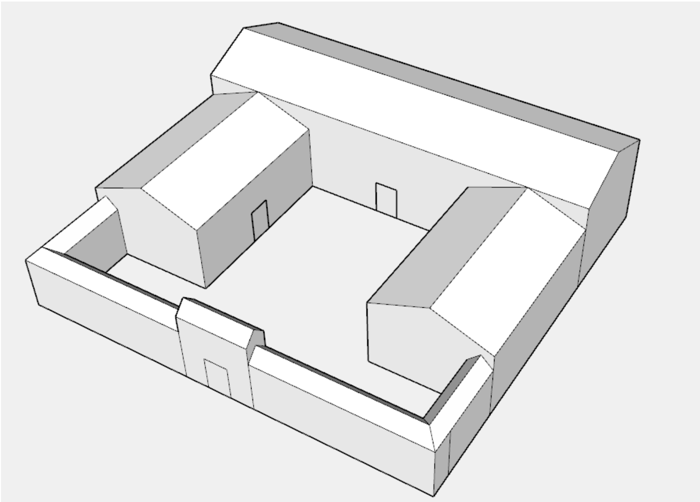

Figure 5-4. Quadrangle model.

The small patio is generally located in front of the main hall, with a cylindrical shape, narrow longitudinally and long horizontally. During the day, the surrounding walls blocked the direct sunlight, blocked the heat waves outside the wall, and created a cool environment inside the house. In addition, in some places, the patios will be placed with vegetation, which increases the evaporation of vegetation and further reduces the temperature of the courtyard. At the same time, the free convection in the patio is active, and the hot air rises, resulting in a low temperature below the patio and a high temperature above it. However, we know that the flow of air flows from places with high density to places with low density. The temperature below the patio is low, so the density is high, and the temperature above it is high and the density is low. The air naturally flows from bottom to top along the cylindrical shape. In addition, the small patio is enclosed by four surrounding walls. The walls are tall and narrow. They are not deliberately chimney-shaped, but have a wind-up effect similar to that of a chimney. The pull-out effect refers to the phenomenon that indoor air rises or falls along a vertically extending space, forming air convection. The hall is a wide and open internal space. The patio is an external space. From the wing to the hall to the patio, the narrow patio plays the role of pulling out the wind, forming a natural suction from the inside out, speeding up the flow of air [21].

5.3.2 Draught organization

"Drought wind" refers to the wind that circulates indoors. Doors and windows are opened on both sides of the room at the same time, and outdoor air flows into the room from one side, and then flows out from the other side, forming convective wind. The draught wind belongs to the natural "air conditioning system" and is one of the best ways of natural ventilation. However, in traditional houses, it can be seen that there is a certain degree of avoidance from the wind. This mainly refers to strong winds, high winds, not completely without wind, but the need to store wind. Traditionally, draughts are considered unlucky. Old and weak women and children have weak resistances, and can easily catch colds or aggravate their illnesses after experiencing this wind. But we need to look at the problem in two, wind is indispensable in some places. Especially in the hot and humid areas such as southern Shaanxi and Lingnan, the effect of cooling through wind energy can improve the microclimate environment and save energy without consuming power. In traditional houses, the design of courtyards and interior spaces with scattered heights is used to organize draughts, and its handling methods and patio ventilation methods are the same principle.

Through the high and low layout, the buildings outside the courtyard are connected with the wall corridors in the courtyard to block direct sunlight and reduce the temperature in the courtyard [22]. The air in the courtyard is heated unevenly, the heated air rises, and the cold air sinks, forming longitudinal convection, which promotes the flow of air and wind energy and forms a draught. However, since the draught is difficult to control and the ventilation effect is unstable, the following points should be paid attention to when designing it:

- Requirements for the depth of the building. The principle of draught wind is to ventilate convectively from the vents on both sides of the building, blow into the room from the air inlet on the windward side, and then flow out from the air outlet. The greater the wind pressure difference between the air inlet and the air outlet, the smaller the resistance of the convective air, and the smoother the draught. On the contrary, the ventilation is not smooth.
- The orientation of the building should be arranged as far as possible in an orientation with an incidence angle of less than 45 degrees to the prevailing wind direction in summer, and the main rooms are in the same direction as the prevailing wind direction in summer. The leeward side is set as an auxiliary room.
- Requirements for building openings. The area ratio of building doors and windows directly affects the ventilation effect of the draught. The area of the air outlet is generally larger than that of the air inlet, preferably greater than 10%, for the best ventilation effect. The opening positions on both sides also play a great role in the airflow path during ventilation. Generally, the positions of the openings on both sides can be staggered, so that the airflow changes direction during ventilation, and the ventilation effect is more uniform.

5.3.3 The principle of cold tunnel hot pressing

In traditional Chinese dwellings, we can often see some narrow alleys scattered high and low, which are very common in traditional dwellings in the south. This kind of narrow lane is called cold alley, also called "Qingyun lane", as the climate transition layer of the building has a good passive cooling effect. There are two types of cold alleys [23], indoor cold alleys and outdoor cold alleys. The indoor cold alley is a channel connecting various rooms in the room. Its main function is transportation and ventilation, with little residual heat in life and long-term exposure to sunlight. Outdoor cold alleys refer to narrow lanes between adjacent buildings. Such lanes are the most common in residential buildings in southern Shaanxi. Walking into these lanes, you can feel the coolness coming on your face, very comfortable. The air pressure difference formed by the high and low staggered cold alleys results in a good ventilation effect. Secondly, because the roadway is narrow, the wind speed will increase when there is wind passing by, which has a good cooling effect [24]. When the wind is calm, the area of solar radiation received is small and the time is short due to the high walls and narrow lanes [25]. According to the principle of wind formation, the air temperature in the lane is low and dense, and the low density of the hot air outside the lane forms convective air. The hot air in the house connected to the cold alley is exhausted to achieve the ventilation effect. Traditional houses pay attention to the integrity in the design of natural ventilation, which is a design that integrates with the environment, climate and architecture [26]. On the one hand, it has the influence of the traditional "feng shui view", and at the same time, it is adapted to local conditions under the premise of fully respecting nature.

5.4. Daylighting and shading treatment of traditional houses

From ancient times to the present, designers have attached great importance to the treatment of natural lighting and shading in buildings. It can be said that natural lighting and building shading are two related but contradictory aspects [27]. Too much shading means insufficient lighting, and the room is dark and cold, while too little shading means too much incident sunlight, resulting in excessive indoor temperature and glare [28,29]. Due to the difference in climate between the north and the south, there are different requirements for the lighting and shading of the building, so the design has a strong regionality.

5.4.1 Space form

For areas with higher temperatures in the south, people’s demand for shading is relatively high. Residential buildings will be designed according to the building’s own design or take some shading measures to reduce unnecessary sunlight [30]. For the northern regions of our country where the climate is relatively cold, daylighting is especially important for them. The use of solar energy can reduce the energy consumption of many heating equipment for them. In order to receive the maximum amount of sunlight, the layout of the house is very elegant [31].

Courtyard-style building, that is, a courtyard is built with houses on all sides, quadrangular houses, and the center is the courtyard. The courtyard buildings in the north and south of China show various forms. For example, the winter in the north is longer and the sun's high angle is small, so the courtyard is more closed as a whole. Increase the distance between the main room and the wing room as much as possible, and expand the area of the middle courtyard. Therefore, the courtyards of northern dwellings are generally very wide and narrow in order to get more sunlight. Gradually formed the northern residential form of "small house with big courtyard". The "big yard" is to allow the courtyard to fully enjoy the sun, and the "small house" is for the insulation of the house. On the other hand, the net height of the northern houses is not very high, and the height is generally lower than the roof ridge. The lower houses can not only shield each other, and the lower bungalows are good for keeping warm.

The courtyard buildings in southern China are the opposite. Taking into account the hot and humid climate in the south and the strong sunshine, the courtyard gets smaller and smaller as it goes south, gradually shrinking the courtyard into a narrow patio. On the one hand, it can reduce strong direct sunlight, and on the other hand, it is good for ventilation and coolness. In terms of architectural style, due to the large height angle of the sun in the south, houses are generally two-story or even three-story buildings. By increasing the density of houses, the arrangement, height, and spacing between the buildings are set. In this way, the buildings are shielded from each other due to the staggered heights, which can also achieve the purpose of shading.

5.4.2 Door and window settings

The northerly wind prevails in the north, and the prevailing wind direction is directly related to the heat loss in the house in winter. Taking into account the wind direction of the local dominant wind, the long axis direction of the main building is generally perpendicular to the dominant wind direction in winter as far as possible in the orientation of the building to strengthen the blocking effect between buildings. Avoid the cold air from the north in winter from adversely affecting the thermal environment of the building. Therefore, the northern buildings strive to sit north and face south, and at the same time, for building insulation, there are almost no north windows. However, the windows on the south wall are wide open to get enough sunlight to increase the temperature and brightness of the room [32].

In southern China, the temperature in summer is high, so the houses are taller, helping to dissipate heat. The windows are mostly shutters, small in size, which can improve the intensity of direct sunlight. For door and window shading, some door and window shading components, such as porches, retractable doors and windows, are also adopted. A porch is a facility built for aesthetic purposes, or a passage with a roof and a corridor that protrudes in front of the building's door. The architectural form of "courtyard + porch" has a significant effect on shading. Retractable doors and windows are used to deal with the door and window sinking into the wall, and the thickness of the wall is used to create shadows from the sun to achieve the effect of shading [33].

5.4.3 Roof form

Most residential buildings in northern China use sloped roofs, which were developed from the sloped roofs in the south to adapt to the northern climate. The characteristic is that the roof is flush with the narrow wall at the end of the narrow wall, or slightly higher than the roof [34]. The use of this type of roof in Northeast China is conducive to storing an appropriate amount of snow on the roof, so that snow can be used as a thermal insulation material to enhance the thermal insulation effect of the house in winter.

In the design of residential buildings in the south, in order to reduce unnecessary sunlight exposure, eaves extension methods are generally adopted, such as overhanging eaves, waist eaves, double eaves, etc., which can create a hint of coolness under the shadow of the eaves. It takes advantage of the changing characteristics of the high noon sun altitude angle in summer and low in winter. A certain width is selected through the eaves to block strong sunlight in summer. Southern dwellings are generally high-rise buildings [35]. In three or four-story buildings, no matter how wide the eaves are, they cannot provide shade. So there appeared waist eaves and double eaves for shading. Waist eaves is to add another layer of roof in the middle of the building, and double eaves refer to the roof of buildings with more than two floors. They solve the problem of shading on each floor. In addition, the rainy and humid climate in the south determines that most of the roof forms used in residential buildings are roofs with steep slopes. The roofs of the front and rear buildings form a shape similar to a funnel. On the one hand, making the roof a bit steeper is helpful for drainage, and on the other hand, it is helpful for ventilation and reduces the influence of radiation on the roof [36]. It can be seen from the traditional buildings that the differences in the local climate between the north and south houses are reflected in the different architectural appearances reflecting their suitability to the local climate. From the overall layout of the building to the spatial form, it serves to meet the climatic conditions, and it is also a way of energy saving.

5.5. Material selection of traditional houses

There are many examples of local materials in traditional houses. In the past, due to the strong awareness of environmental protection, the inconvenience of transportation, and the restriction of economic conditions, it was a very common energy-saving measure to directly use local native materials when choosing building materials.

5.5.1 Soil

Soil has a long history as a building material. From the earliest primitive society's digging of caves to the building of houses on the ground today, humans have never left soil, the most primitive material [37,38,39,40]. The main reason for using soil as a building material is its convenience and low cost. As a building material, soil has fine texture and high adhesion, can mix well with clay sand, and has good stability and integrity. Ramming, that is, using the action of ramming to make loose soil firm. The small gaps in the soil can be removed by the way of rammed earth, which has the characteristics of moisture-proof and heat-insulation. Many buildings in traditional houses use rammed earth to build walls. Rammed earth walls have a certain bearing capacity and are widely used in many defensive residential buildings, and can resist attacks from the enemy and cold weapons [41]. At the same time, it also has great advantages in energy saving and environmental protection. The rammed earth wall has good heat storage performance, which has the effect of warming in winter and cooling in summer. As a sustainable resource, it comes from nature, so the impact on nature from the construction process to the demolition of the building is minimal. The used rammed earth can be directly moved back to the original place for recycling after being removed.

In most cases, traditional buildings in southern Shaanxi use a special kind of rammed soil. The production method is based on the weathered soil of stone as the main material, plus a certain proportion of lime, sand, yellow mud or pebbles, and then add glutinous rice water and brown sugar and stir evenly [42]. After cooling, add tung oil thoroughly and evenly. The outer skin of the wall is about 50 cm with masonry, and the inner skin is made of adobe bricks. The lowest end of the wall is built with granite slabs to prevent moisture on the ground and keep the roots of the wall from rain. As a building envelope structure, raw soil can adjust the humidity inside the building to a certain extent due to its porous properties. Rammed earth walls are also called "breathable" envelope structures [43,44].

5.5.2 Wood

Wood has always been preferred as a building material in traditional Chinese houses. From the perspective of environmental protection and energy saving, wood is a renewable resource, and it is green and environmentally friendly and can be recycled. From the perspective of the building itself, the wood is flexible, has a good elasticity, and has a variety of designs [45]. It has incomparable superiority with other buildings. It can be used as a building enclosure and support member.

Although the wood is light, it has a certain degree of elasticity, high strength, strong impact resistance, and the tenon and tenon joints of each node have a certain degree of flexibility [46]. Even if an earthquake occurs, the integrity of the building can still be maintained. In terms of seismic resistance, it has certain advantages. The unique flexibility of wood makes the layout and shape of wood structure buildings flexible and convenient for maintenance and renovation. As the most common form of traditional dwellings, wooden structures are very strong [47].

5.5.3 Bamboo, grass, reed

Bamboo has good toughness and elasticity, and is easy to process. It is generally used as a building envelope or directly as a load-bearing structural material [48,49,50]. Because bamboo is poorly robust and not resistant to corrosion, the life span of buildings using it as a structure is relatively short [51]. In the traditional method, the bamboo is baked and dried, and then quickly smoked or directly coated with slaked lime on the surface of the bamboo [52]. Through proper treatment of bamboo, the durability of bamboo construction can be greatly increased, and the service life can be up to 30 years [53,54].

Bamboos are used in the roofs, stairs, and walls of the Dai family bamboo buildings in Yunnan, China. The Dai people mostly live in areas with abundant rainfall all year round, with an average temperature of 21°C and no four seasons. The floor slab made of bamboo is good for ventilation and heat dissipation. It has the characteristics of warm in winter and cool in summer, which is good for preventing extreme heat and humidity, and is very suitable for the local climate [55].

Humans have used grass and reeds as building materials for a long time. As a building material, grass is mainly used for roofing, decoration materials or mixing soil and grass to make bricks, which can enhance the flexibility of bricks [56]. The overall energy efficiency of the straw brick house is 72% higher than that of the traditional brick house, and it has a greater advantage over ordinary brick houses in terms of thermal insulation [57]. Reed is also a good environmentally friendly material and is known as the second forest. It is easy to plant and grows fast. It is not only moisture-proof, it can be used as a basic moisture-proof layer, and it has good sound insulation and heat insulation effect. After mixing cement and reeds, mineralizers are added to make reed cement bricks, which can be used as roofing materials and have the effect of roof insulation. Bamboos are used as beams and columns, and neatly arranged bamboos are used as the walls of the building. Finally, the facade of the building is made of thatch, which can shading and waterproofing. The bamboo used in the construction adopts traditional Chinese construction methods. The bamboo used as a structure will be immersed in the mud for several months and smoked to enhance the anti-corrosion and insect-proof properties of the bamboo. Heat treatment makes the bamboo reach the desired degree of curvature. Due to the large number of structural nodes, the cost advantage will be lost if metal components are used for connection [58]. Therefore, low-cost bamboo buildings generally use traditional organic connection methods such as rope tying, bamboo nails, and bamboo bolts to build bamboo structures. This pursuit also reflects the true essence of architectural art returning to nature.

5.5.4 Stone

Stones of different shapes and sizes that are mined from natural rock masses that are processed or not processed are called stone. The various minerals in the stone originated from the natural rock mass have been hydrated and hydrolyzed, and the corresponding components are dissolved and then returned to the ground. Generally used in mountainous areas rich in stone, it has the advantages of high compressive strength, good water resistance and good durability [59].

Because stone buildings are subject to ancient productivity, heavy weight and high transportation costs, this requires a lot of labor in ancient times, so the utilization rate of stone is not high [60]. In addition, the density of the stone is large, the weight is large, and the thickness of the wall is large, so the area used in the building is not much. Most of the stone is used for the enclosure structure to play a solid defense role, and has good thermal insulation properties. As a building material, because of its extremely low tensile strength, block material is only suitable for pure compression structure. For example, the main load-bearing part of the main building in the Chaoshan area of Guangdong is made of stone [61]. Plates are generally used for roof tiles and the ground in gardens. In addition, they can also be used for partial wall decoration in interior decoration.

In the choice of building materials, compared with synthetic materials, native materials are natural materials that have evolved over hundreds of millions of years, and are more environmentally friendly, safer and have good natural cycle characteristics. On the one hand, the use of these energy-saving materials reduces the burden on the earth and reduces the severity of air pollution. On the other hand, vernacular materials are the most harmonious materials between man and nature. The unique affinity in vernacular materials can give buildings a sense of intimacy between man and nature.

5.6. Application of natural energy saving of traditional houses in modern buildings

5.6.1 The development of traditional building materials to green materials

Innovation from native materials to green materials is an inevitable trend [62]. With the rapid development of science and technology, it is the correct development method to innovate some backward forms in the past on the basis of respecting tradition. In the past traditional houses, a large number of native materials were used as enclosure materials, such as the use of plants. However, the porous characteristics of plants often bring a lot of inconvenience in modern houses. With the development of science and technology, the porous material of the building is designed by using the characteristics of the porous ventilation of plants, which avoids the defects of plants as building materials [63]. As a building material, porous materials are also divided into porous ceramic materials and porous metal materials, etc., which are all new types of environmentally friendly materials composed of a variety of materials. Porous materials have a certain number of pores with adjustable size and an internal porosity of 90%, so as a building material, it has a strong ability to absorb noise. Porous ceramics are widely used as sound-absorbing materials in outdoor road sound-absorbing barrier materials. Porous metal material has good permeability, and its filtration and separation can well purify the air, inhibit the growth of bacteria in the air, and replace some air filter equipment. From the perspective of building energy conservation, this new type of porous material not only inherits the characteristics of traditional material forms, but also designs products that are more suitable for modern environments through technological innovation and development, which is in line with today's environmental protection trends.

In the past, many traditional houses used rammed earth to build rammed earth walls. Although the cost is low and the technology is simple, but often due to low strength, it will collapse and collapse when exposed to water erosion and soaking, and lose the load-bearing capacity, which affects the durability and service life of the building. Grass brick walls can be a good substitute for rammed earth walls. The discarded crop straws are compressed and made into straw bricks for building houses. The wall composed of straw bricks and plastering layer forms an enclosure structure.

Straw bricks make full use of discarded plant stalks and are a recyclable natural resource. There are a lot of crop straws in rural areas, but most of them are burned and not fully utilized [64]. Nowadays, turning waste into treasure can not only save manpower and energy consumption, but also greatly improve the insulation effect of the wall. The specific method of straw bricks is to squeeze the straws of similar crops, such as straw, wheat straw and other hay according to a certain size, and bind them with a metal mesh to make embryos, and then spray plaster outside the embryo bricks to form straw bricks with basically the same specifications. The main purpose of applying a layer of plaster is to fill up the gaps in the grass bricks, prevent the natural grass fibers from decay and deterioration when exposed to oxygen, and play a protective role in fire prevention, insect prevention and moisture prevention. With the rise of green, environmentally friendly, and low-carbon construction concepts, all kinds of straw-and-brick buildings are becoming a fashion and becoming the focus of attention.

The development of the grass and brick wall material industry is an unstoppable trend in China. The main reasons are:

- The innovation of China's emerging wall materials. At present, most of the clay bricks used in the wall construction of Chinese buildings, the annual loss of cultivated land caused by the burning of clay bricks has reached more than 40,000 hectares, and the occupation of a large amount of cultivated land has seriously affected the living environment of people. Some new wall materials using industrial and agricultural waste as raw materials gradually occupy the market. The new wall material not only does not occupy arable land, does not use clay, but also does not destroy the ecological environment at the expense of it. It is an energy-saving and land-saving green material [65].
- It is of great significance for the development of green wall materials in my country and the construction of a new energy-saving society. The traditional brick and tile industry is a high energy consumption industry, accounting for 23% of the total energy consumption in the building materials industry. A large amount of clay and coal are consumed every year. Sulfur dioxide caused by burning coal is currently one of the main causes of air pollution in my country, which is very harmful to the environment [66].

Choosing straw bricks as my country's new green wall materials has the following energy-saving significance [67,68,69]:

- It can reduce the weight of the house and the amount of reinforced cement, and reduce the pollution to the environment after the straw is burned.

- Good heat preservation effect, saving building energy consumption. The use of straw bricks is made from local materials. The price is low and the source of raw materials is wide. Compared with the thermal insulation effect of brick walls, it is more than 6 times that of the same thickness.
- Straw bricks are renewable resources. After the building has reached its service life, the straw bricks can be reused and have no impact on the environment.
- As a building wall material, straw brick has good elasticity and good seismic effect due to its light weight.
- Has certain fireproof, heat preservation and sound insulation properties. As the interior wall material of the building, it has the advantages of moisture resistance, humidity adjustment, and easy disassembly.

Therefore, straw bricks are an inevitable choice for emerging green wall materials, and are of great significance to China's construction of an energy-saving society.

In the past, building materials pursued good performance requirements, but now they face such serious environmental problems. In addition to the good performance of building materials, it is also necessary to achieve a harmonious symbiosis with nature from the selection of building materials to the use of the final disposal process to minimize the ecological impact. In the use of building materials, the linear mode was mainly adopted in the past for building materials. After the original materials were obtained, they were processed and used, and most of the buildings and components were discarded when the building was demolished. These building materials become unprocessable residues after being discarded, causing environmental pollution and great waste. Now the way of use has been improved to increase the recycling rate of building materials. For example, most of the construction waste left in the city can be dismantled, crushed, etc., and then added to building bricks, and then turned into a new type of energy-saving building material again [70]. Singapore generates nearly 2 million tons of construction waste every year [71]. For Singapore, where land is scarce, how to deal with demolished buildings is an important environmental issue. There is a Sanhe Environmental Building in the Singapore Industrial Zone. The biggest feature of this building is the use of a large amount of concrete construction waste, which is crushed and screened, and finally recycled into concrete aggregates. Use recycled concrete aggregates to replace natural stones, including large concrete blocks, and recycled stones and fragments of various sizes. This change in usage mode is also a way of transforming local materials into green materials from another perspective, making building materials a truly sustainable industry.

5.6.2 The evolution from the patio of traditional dwellings to the modern atrium

The "patio" created by the ancients of China, which is fully suitable for the geographical and climatic environment and humanistic spirit, is a unique layout method [72]. In ancient times, it was generally used for lighting, ventilation, and the meaning of gathering wealth and blessing. This traditional design method has gradually developed. In addition to the above functions, it also has a certain decorative nature in modern times. In modern buildings, the patio has gradually evolved into a modern atrium design. Planting ponds are set up in the atrium to plant flowers and plants, or as flower walls and flower stands, full of vines. In addition to being beautiful, it also plays a role in dividing space.

"Atrium" refers to the courtyard space inside the building. This concept originated in courtyards (patios). The Greeks first introduced the concept of an open-air courtyard in the architectural design, and later improved by the Roman design, and added a roof above the courtyard. This is the earliest prototype of the atrium now. Its design is very popular in public building spaces and is widely used in shopping malls, offices, exhibitions and other public buildings. The unique glass roof in the atrium design not only ensures natural lighting and natural ventilation, but also serves as a shelter from wind and rain. What's more, install adjustable mirrors on the walls of the atrium. On the one hand, it enlarges the overall sense of space, on the other hand it plays a role in reflecting natural light. In addition to natural light, the internal lighting also has diffuse reflection light formed by interface reflection, successfully solving the problem of insufficient local natural light. Both low cost and energy saving.

The atrium can be said to be a place that communicates the indoor and outdoor spaces, and introduces the external space of the building into the interior, creating a state of accommodation and isolation from the external space. As a place for the exchange of natural climate between indoor and outdoor spaces, the atrium can be regarded as a "climate transition zone". Firstly, the air climate of the outdoor space acts on the atrium, and after the transition of the atrium, it acts on the internal space. This can slow down the heat exchange rate between indoor and outdoor spaces, play a role in climate control and regulation, and reduce waste of energy consumption. Regarding the adjustment of the microclimate, the environment can also be modified. For example, by planting plants and setting up water bodies to cool down and increase humidity, and absorb exhaust gas to clean indoor air. It not only has a good ecological impact on the microclimate of the atrium, but also greatly improves the quality of the ecological environment. These are all improved and designed on the basis of the construction of small patios in traditional houses, which are more suitable for modern people's lives without increasing energy consumption. Any traditional craftsmanship will have vitality only after the transformation of modern technology. The evolution from the traditional patio form to the modern atrium is the best proof.

5.6.3 The development of large roof shading to sun visor

Sunlight is essential to people and is the main source of energy in daily life. However, excessive sunlight radiation affects people and furniture to a certain extent. Excessive exposure will cause glare in the room and hinder the normal work of vision. The increase in indoor temperature will also damage the furniture. In this case, long-term use of refrigeration equipment not only reduces the body's resistance, but also consumes a lot of unnecessary energy [73].

In modern houses, due to the overall planning and layout requirements of the community, many buildings cannot sit south and face north. Often many houses are facing east-west, and it is inevitable that there will be rooms in the west. The disadvantages of the western sun exposure are obvious. In summer, due to the long sunshine hours in our country, the western sun room has direct sunlight from 1 noon until sunset, and the temperature in the room is at least 2-3°C higher than other rooms. It accelerates the aging of wooden furniture, carpets, curtains, etc., and greatly reduces the service life of the furniture. In addition, due to lack of ventilation, the house is sultry in summer. In winter, the room is invaded by northwest wind, which endangers the health of the human body. Therefore, the evolving ecological treatment of shading issues is helpful to the efficient and reasonable use of resources, and is of great significance to environmental protection.

In traditional dwellings, the use of eaves extension to create a touch of coolness in the shadow of the eaves is a common way of shading. In the design of modern buildings, it is obviously not enough to use the extension of the eaves on each floor as shading measures, especially now that buildings tend to be high-rise development. The shading methods of modern buildings are roughly divided into two types: one type of external shading; the other type of internal shading. Sun visor is a form of building exterior shading, and it is the most intuitive way of shading. Compared with internal sunshades, sun visors have three advantages [74,75,76]:

- Energy efficient. The indoor shading method mainly adopts sunshade curtains. The sunlight shines on the curtains through the glass, and the fabric becomes a heat source, and the hot air actually enters the house. However, the outer sun visor can directly block the sunlight outside, and the heat generated by the sun on the sunshade layer stays outside the building, and the heat dissipation is good.
- Economical. The external sunshading investment is relatively small, but the energy-saving effect is very significant.
- Artistic. Through the selection of sun visor materials and color modeling, the perfect combination with the facade of the building improves the overall effect of the building.

There are four main types of sun visors:

- Horizontal shading, mainly used to block sunlight from above the window, suitable for south-facing windows with large sun height angles.
- Vertical sunshade, used to block the sunlight on both sides of the window, suitable for east and west windows with small sun height.
- Mixed sun shading, shading the sun above and on the left and right sides.
- Baffle-type sunshade, used to block the sunlight entering the window, suitable for east and west windows.

Nowadays, sun visors are no longer confined to concrete slabs, but are innovated in materials and technological means, and fully excavate multi-functional and adjustable sun-shading components. The self-adjustable sun visor can move according to the sun's different positions in the sun's altitude angle within a day, avoiding direct sunlight into the room and reducing the impact on people and indoor space. When the sun is low in winter, the sun visor will automatically hide, and the room will show soft sunlight. Today's shading systems focus on the use of solar energy, and active daylight adjustment shading systems, solar absorbers, etc. have begun to be widely promoted and applied. In relatively developed places, it is also possible to organically integrate the building’s shading components with the facade according to the changes in the sun’s altitude angle during the day. The building facade can adjust its own angle at different angles of sunlight, which can block the sunlight to the maximum.

Compared with traditional buildings, modern building shading methods have changed a lot, with diversification of shading forms, innovations in materials and methods. However, we can still see that designers express their respect for traditional buildings through the use of these shading methods. The meticulous handling of shading components and architectural forms is worth learning from.

5.6.4 Transition from courtyard-style building to sun room

The courtyard house in Beijing is the representative of courtyard-style architecture. It strictly follows the theory of Feng Shui in the overall layout and site selection [77]. At the same time, the natural ventilation, daylighting and shading of the building are handled very appropriately through the ingenious ideas of the designers.

The walls of the traditional courtyard house, the depth of the house and the size of the house have been calculated through fine proportions for hundreds of years, so as to ensure good ventilation and lighting. For example, if the wall is 3 m high, the depth of the room can only be 3.6m, and the yard cannot be less than 10m. The courtyard covered in this way can ensure sufficient sunlight at noon in winter. In summer, the sun can only reach the gate, which not only guarantees the daylight but also plays the role of shading [78]. In other words, the ratio of the height of the wall to the depth of the room is a controllable factor for sunlight to enter and exit. At the same time, the courtyard in the middle has also created a good microclimate for the entire building, and good natural ventilation is organized for the bays through the setting of the courtyard. It is precisely because of this that a lot of land resources need to be used in the design of the courtyard house. However, facing the scarcity of land resources and the majority of high-rise buildings in modern buildings, this courtyard-style building is destined to not be able to adapt to the current form of social development.

The term solar house originated in the United States. In the 1990s, the first active "solar house" was born in the laboratory of the Massachusetts Institute of Technology in the United States. The solar collector is used as the heat source for heating, so that the heating in the house can be self-sufficient. However, due to the high cost and complex technology, its development has certain limitations. Until the emergence of the "passive solar house", solar energy was also used, but it did not require power, and was easy to manage and low in cost. Its heat collection methods are mainly divided into three types:

- Direct benefit type. Open the windows on the south side as large as possible to absorb sufficient sunlight radiation. Through the exchange of air, part of the heat raises the indoor temperature, and part of the heat is stored on the ground or wall to maintain a certain indoor temperature.
- Through the wall with heat storage function, sunlight first shines on the heat storage wall under the glass cover between the house and the sun, and then slowly enters the room. However, this effect is slower, and generally needs to be used in conjunction with other other methods.
- Attach a sun room [79], which belongs to one of the heat storage walls mentioned above. The interlayer between the glass and the wall is widened to form a small space. The heat collection system in the front sunroom space has the same working principle as the first direct benefit type. The heat storage method of the space behind is the same as the working principle of the second heat storage wall. Nowadays, in many traditional farm houses in our country, the architectural form adopted is "passive solar house".

The solar house also has the same sloped roof as the courtyard-style building. In the past, designers used the angle of light and shadow in winter and summer. Take Beijing as an example. In winter, the sun’s altitude angle is about 27 degrees, and in summer it’s about 76 degrees. Based on this angle, the ratio of eaves to wall is designed. The width of the eaves is lengthened by the height of the wall to achieve the effect of lighting in winter and shading in summer. However, in the design of the sun room, a sloping roof is also adopted. In summer, since the heat is running up, it can gather the heat on the top, and at the same time, the heat preservation performance is also good, and the energy saving effect is very considerable.

5.7. Chapter summary

This chapter mainly expounds the principle of natural ventilation and cooling of traditional houses in southern Shaanxi. First introduced the natural energy-saving methods of traditional houses. Secondly, it summarizes the influencing factors of natural ventilation and cooling of residential buildings. The factors affecting the natural ventilation and cooling of residential buildings mainly include residential site selection, building orientation, reasonable use of patios, reasonable organization of internal air circulation paths in buildings, and the organization of hot-pressure ventilation. In the past, residential buildings coexisted with the surrounding environment, and various energy-saving methods reached the model of the best effect in the social environment at that time, and many experiences worthy of our reference can be extracted from them. However, the change of lifestyle, the increasingly harsh environment, and the lack of resources prompt us to find some energy-saving methods suitable for the development of modern buildings in traditional residential buildings, and to innovate and transform on this basis. Regardless of whether it is technological innovation or conceptual perfection, we should adopt an inherited attitude and apply it to modern architecture to meet the needs of modern social development. Combining the two in a comprehensive way can bring more beauty to our lives. This will be a continuous process. However, as the times change day by day, some energy-saving methods in residential buildings can no longer be used for direct reference.

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Chapter 6. Energy-saving mode of cold alleys in modern settlements in southern Shaanxi

6.1. Transformation of the original case

In China, the research methods of cold lanes and patios are diverse. [1] expanded the theoretical horizon of settlement climate adaptability, and scientifically revealed the spatial construction logic and scale laws of settlements in Southeast Fujian to adapt to different climatic conditions. [2] Through the heat measurement of three cases in different seasons for two years, it was first proved that the middle corridor has cold lane effect. Secondly, the influence of wall materials on the cooling effect is discussed, which proves that heavy materials are more favorable to cooling. Finally, the influence of the day-night opening and closing mode between the room and the middle corridor on indoor temperature in each season was explored, and the season and day-night optimal control mode of the middle corridor was summarized. [3] based on the effective verification of ENVI-MET software, three typical traditional villages in Guangfu were selected to conduct microclimate simulation with physiological equivalent temperature (PET) as thermal comfort evaluation index. The paper summarizes the spatial scale and architectural type of the courtyard space system of cold alley in Guangfu traditional village and its good adaptability to climate. [4] Through research and discussion, cold alley is advocated to be integrated into modern buildings, providing effective climate-adaptive design techniques. And encourage people to consciously introduce cold alley technology in the creation of subtropical modern architecture, continue the traditional spirit, reflect the regional architecture.[5]through the analysis of numerical simulation, it is found that increasing the height-aspect ratio and depth of the cold roadway is beneficial to the natural ventilation effect of the cold roadway, but the height-aspect ratio should be controlled within 36:1. Using the method of field test and numerical simulation to analyze the natural ventilation mode of chenjiaci cold alley, not only can evaluate the influence of cold alley on the regional microenvironment, but also has certain reference significance for architectural planning and design.

After understanding the research on cold lanes and patios in China, we need to conduct a detailed investigation of this research case. Figure 6-1 shows the first floor plan, second floor plan and roof plan of the study case. Figure 6-2 shows the front elevation, side elevation and cross-sectional view of the study case. Figure 6-3 shows the detailed method of the wall and floor of the study case.

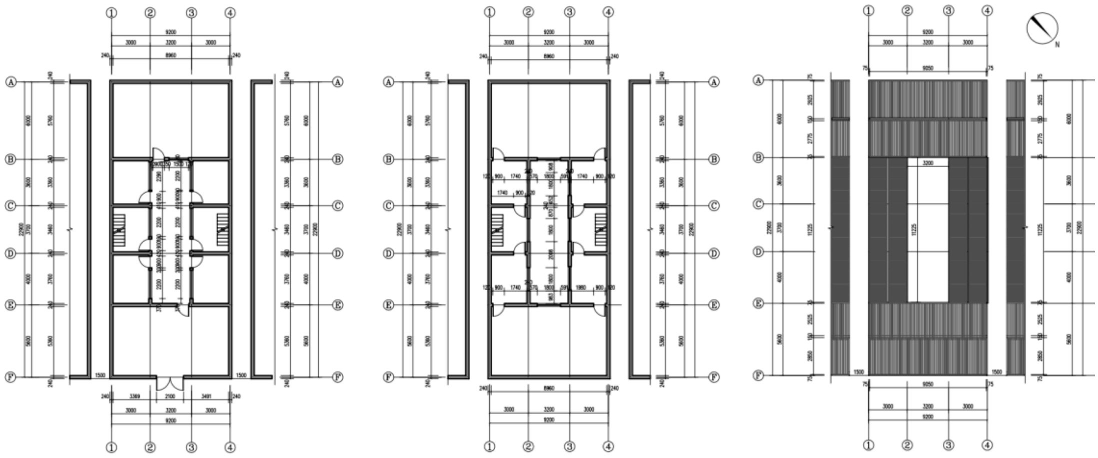


Figure 6-1 First floor plan, second floor plan and roof plan of the study case.

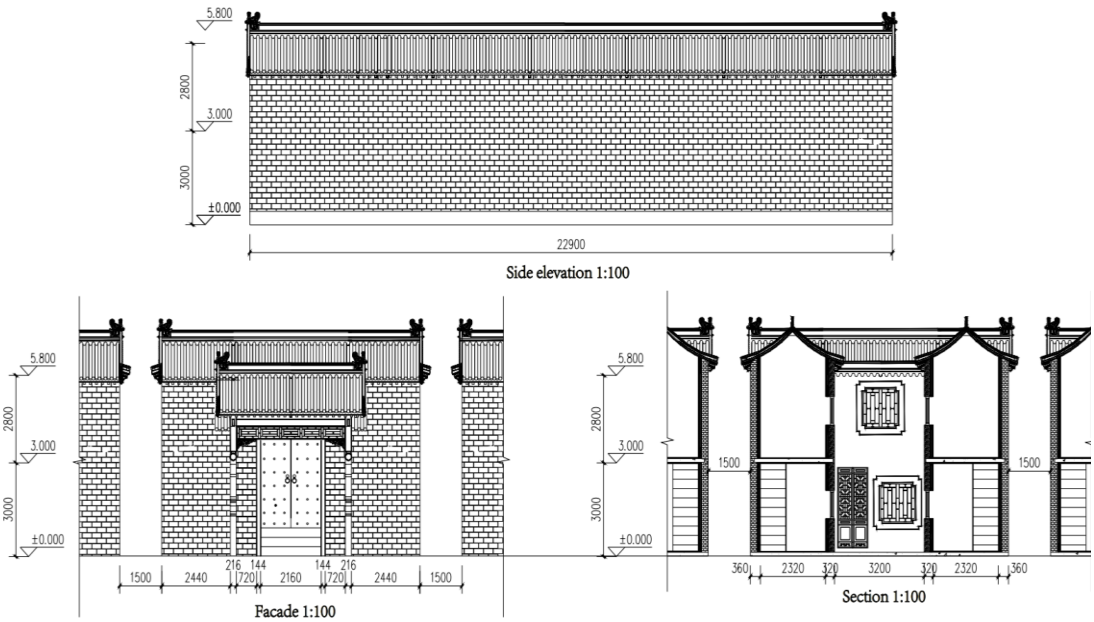


Figure 6-2 The front elevation, side elevation and cross-sectional view of the study case.

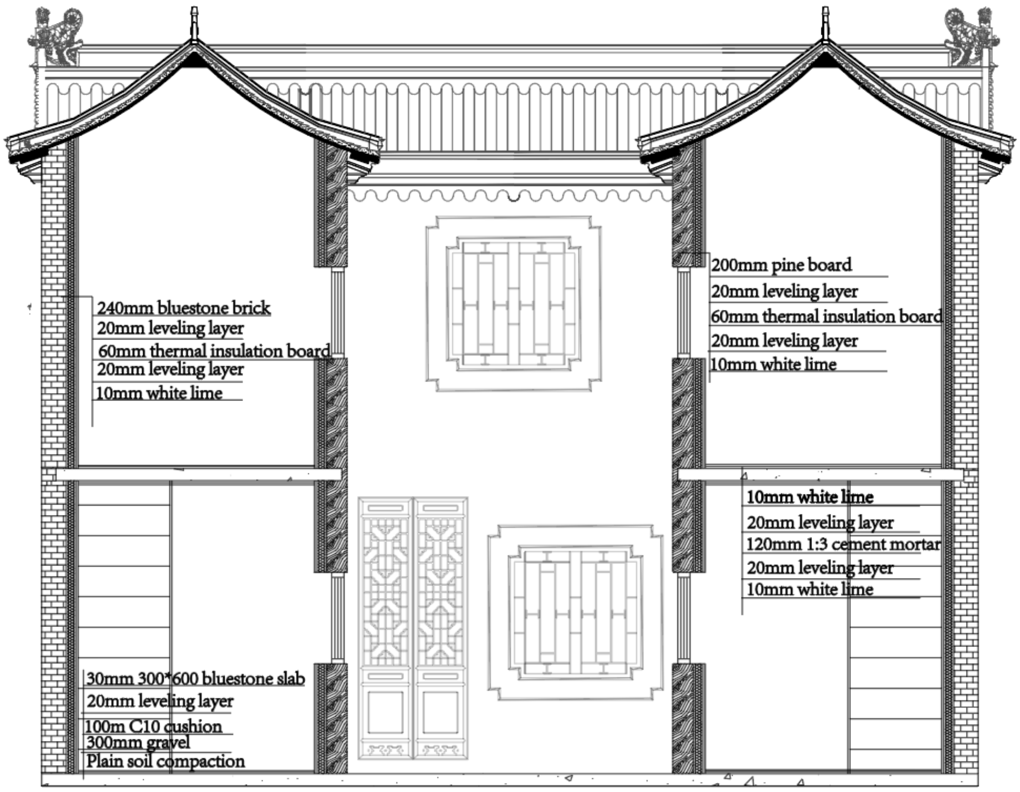


Figure 6-3 Detailed method of the wall and floor of the study case.

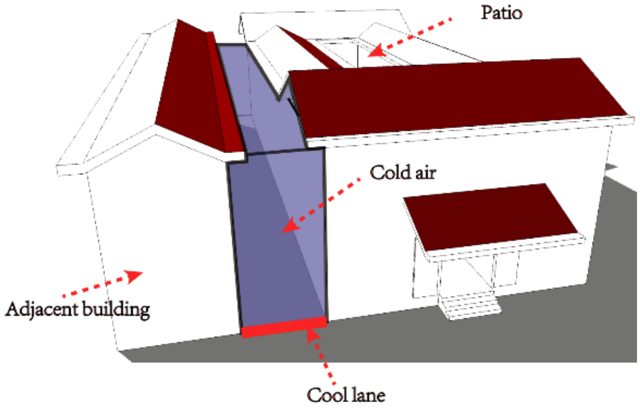
If the cold air in the cold alley could be introduced indoors using a passive method, the Heat pressure ventilation method could be considered; accordingly, the temperature difference between the cold alley and building indoors was used for the indoor and outdoor heat exchange. Simultaneously, the patio of the building was connected to the interior through doors and windows, and the accumulation effect of the patio air was combined with the cold air to form a new integrated passive ventilation and cooling system. While introducing the cold air, the rooms on the second floor on both sides of the courtyard were connected by pipes to provide more efficient cooling. Notably, most of the previous studies on air heat transfer did not consider the heat radiation from the exterior surface of the building. The influence of this heat radiation on the indoor temperature cannot be ignored. Therefore, in this study, the presence or absence of WHR was specifically cited as a separate item, aiming to show its degree of importance. In addition, in winter, the pipes for connecting indoors could be used as supports, i.e., to facilitate the installation of glass roofs. After adding a glass roof above the patio, the patio would store a significant amount of heat after receiving solar radiation, and could then transfer this heat through the doors and windows to heat a room. The new system mainly covered three aspects of passive design. In summer, air partition walls were used to block the direct heat transfer between the exterior surface of the building and interior. Heat pressure ventilation was used to introduce cold air from the cold alleys into the rooms, to provide passive cooling, and to improve ventilation. In winter, the glass roof was used to improve the heat storage capacity of the patio so as to ultimately increase the indoor temperature. The introduction to the transformation of the study case is divided into the following four parts:

- Introduction of basic study case, which will be compared with the reconstructed building.

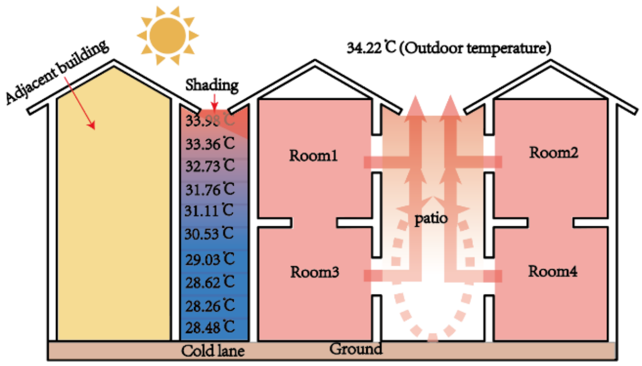
- Analysis of the operation principle of heat transfer of the heat insulation wall in summer. It is mainly used to introduce the cold air in the cold alley into the room and slow down the heat transfer.
- Introduction of the operating principles of the new system when the wall heat radiation is considered and when the wall heat radiation is not considered.
- After adding a glass roof above the patio in winter, analysis of the heat storage capacity of the courtyard and the operating principle of heat transfer to the room.

6.1.1. Natural ventilation cooling (base case)

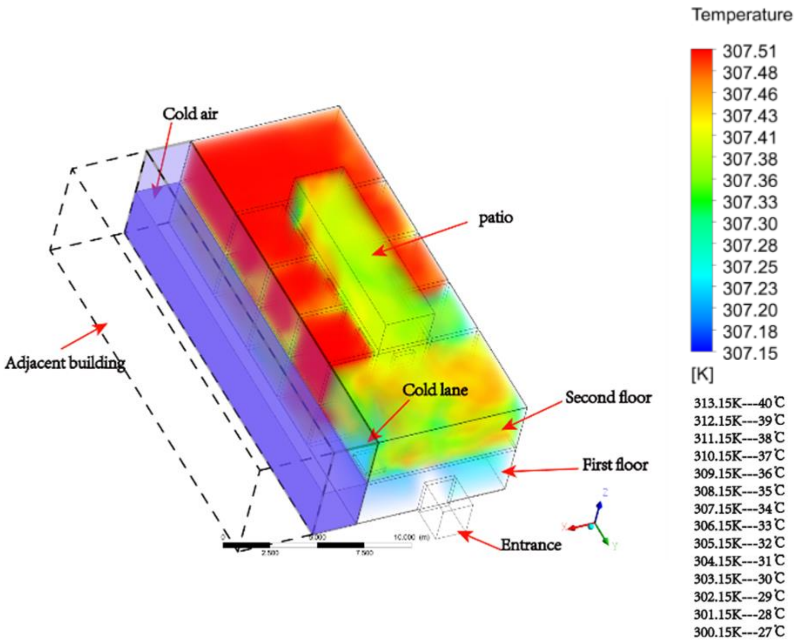
The heat transfer and ventilation methods for the base case are shown in Figure 6-1. The overall building mainly relies on the ventilation from the patio for improving the temperature of the building. The outdoor air first enters the patio through the gate, circulates to a certain extent, and is discharged from the top of the patio. At this time, the indoor temperature is higher than the courtyard temperature, and a small part of the heat is exchanged through the doors and windows. However, as shown in Figure 6-1c, the entire process of ventilation and heat exchange mainly occurs in the patio, and the improvement in indoor temperature is very small, or even negligible.



(**a**) Base case.



(**b**) Ventilation and heat transfer conditions before reconstruction.

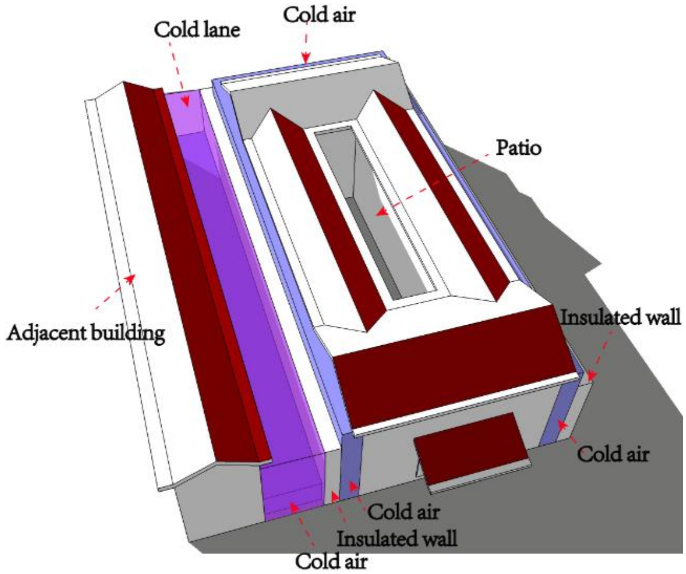


(c)The heat flow of the building before renovation.

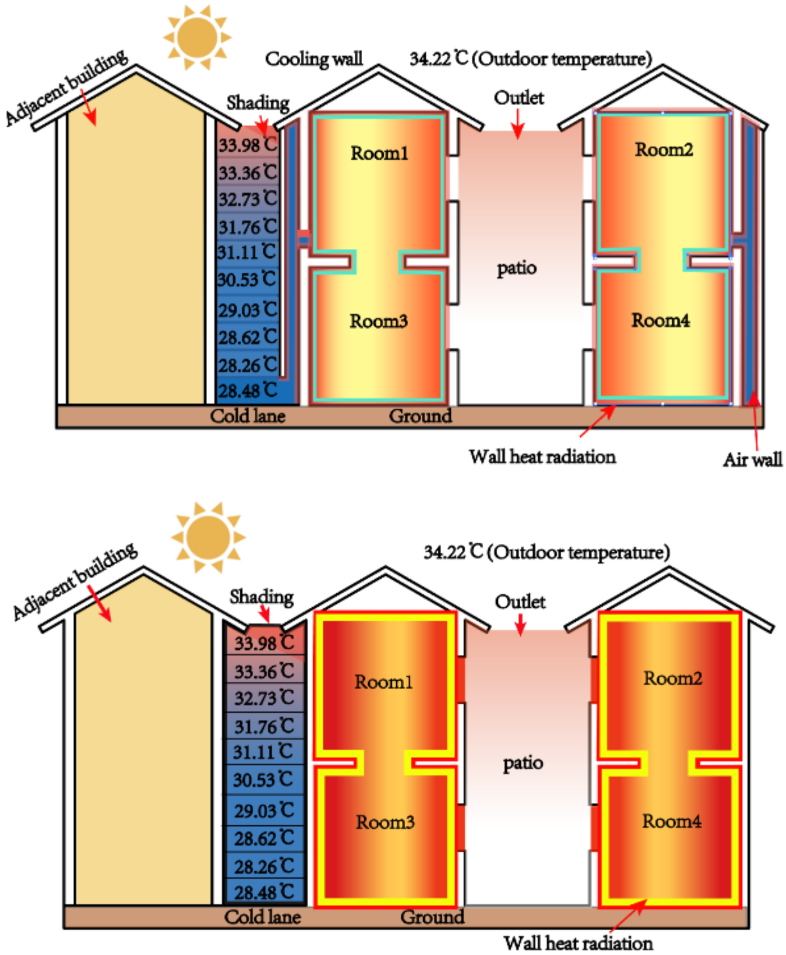
Figure 6-4. Ventilation and cooling conditions of the original case. (a) Base case. (b) Ventilation and heat transfer conditions before reconstruction. (c)The heat flow of the building before renovation.

6.1.2. Summer air insulation wall

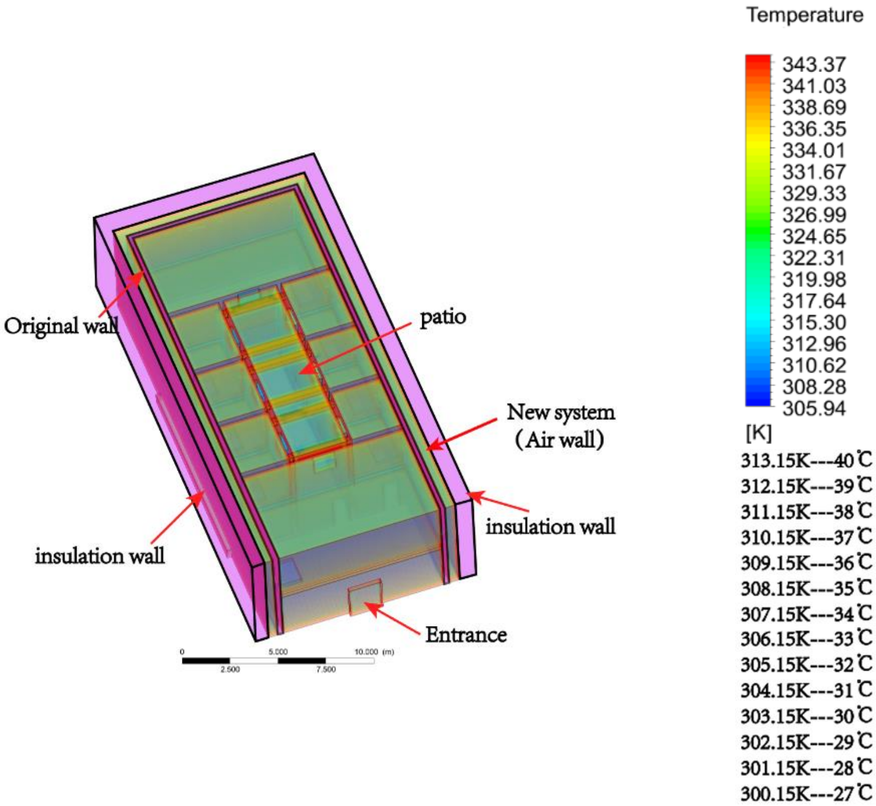
In summer, the outer surface of a building is exposed to the sun for a long time, and the amount of received solar radiation is large. This radiation is transmitted through the wall materials and is an important cause of the increase in the indoor temperature. If a barrier can be set on the outside of the wall to hinder the transmission of heat, the growth rate of the indoor temperature will be significantly reduced. As shown in Figure 6-2a, in this study, the air wall was constructed as an important part of the new system and provided three main functions. First, it was used as a carrier to introduce cold air from the cold alley into the building interior, playing a role similar to that of a pipe. Second, the cold air could be stored in the wall for a long time, which could cool down the interior wall to a certain extent. Finally, the air wall was used as a barrier to hinder the heat transfer between the outer and inner walls.



(**a**) Location relationship between cold alleys, air walls, and buildings.



(**b**) Comparison of indoor heat transfer before and after renovation.



(c) Schematic diagram of air barrier heat resistance.

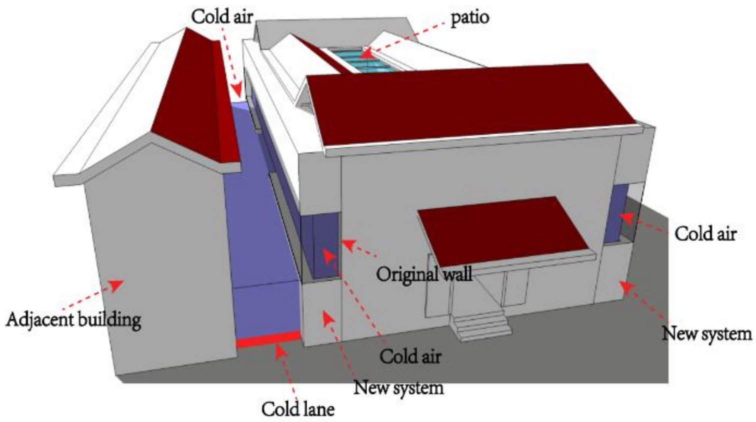
Figure 6-5. Introduction of the air insulation wall. (a) Location relationship between cold alleys, air walls, and buildings. (b) Comparison of indoor heat transfer before and after renovation. (c) Schematic diagram of air barrier heat resistance.

The principle was similar to that of an "insulation cup," but the function of an insulation cup is to preserve the loss of internal heat, which is the opposite of the function of the air wall in this study. Figure 6-2b shows the heat transfer of the indoor wall before and after installation of the air wall in the building. It can be seen that owing to the combined action of the three functions mentioned earlier, the amount of radiation on the wall near the cold alley is greatly reduced; in contrast, the wall near the courtyard has no air wall, and the heat radiation effect is stronger. Figure.6-2c shows the connection between the air wall and indoor air. The pink part represents the original wall of the building on which and the new system is constructed, and the green part represents the air.

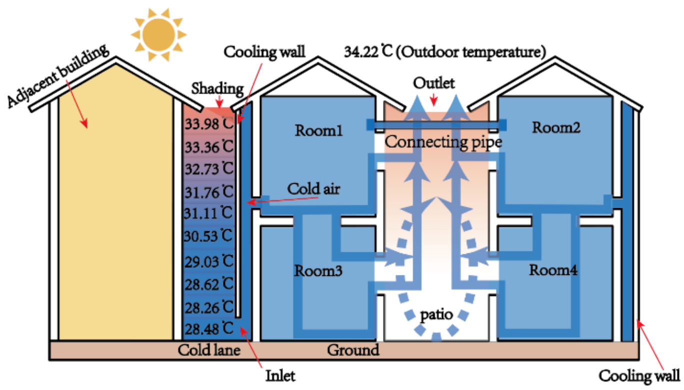
6.1.3. Using cold alleys to cool buildings in summer (without wall heat radiation (WHR))

Figure 6-3a shows the positional relationship between the cold alley and building, as well as a schematic diagram of the changes to the exterior wall of the building. First, a new layer of wall was built on the outer wall of the original building, leaving a space in the middle for introducing the cold air. Second, a hole was opened at the bottom of the new wall to allow cold air to enter the space between the walls. Third, the space was connected with the rooms on both sides so as to ensure that the cold air in the cold alley could enter the rooms. Finally, the rooms on the second floor on both sides of the courtyard were connected by air ducts. The purposes of this were to shorten the cooling time and improve the cooling efficiency. The interior and patio were connected by doors and windows. Owing to the difference in the air temperature between the patio and cold alley, a pressure difference arose between the two ends. When the airflow started to move, it was also accompanied by the beginning of the heat exchange process

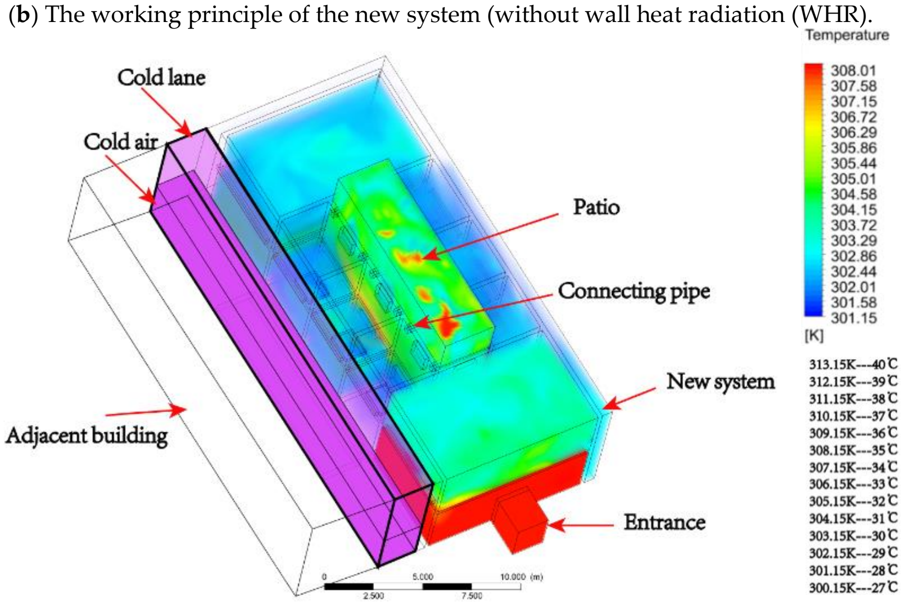
(Figure 6-3b). It can be seen from Figure 6-3c that after the new system was installed, the building had two air intakes: the inherent patio door of the building and the wall hole set by the new system in the cold alley. As mentioned above, under conditions of natural ventilation, the outside air first enters the patio through the patio gate. It only exchanges heat with the room through the doors and windows after it completes the heat exchange in the patio. However, if the cooling capacity of the outside air is not sufficient to cool the patio, the indoor temperature will not be improved. Therefore, as shown in Figure 6-1c, a large amount of air enters the patio first and the temperature drops there first; thus, the cooling gains in the room are minimal. After a period of time, the patio temperature is approximately 34 °C, and the indoor temperature is approximately 35 °C. However, as shown in Figure 6-3c, when using the new system from this study, the air in the cold alley could directly enter the room for cooling, thereby avoiding the patio and significantly improving the cooling efficiency. Thus, after a period of time, the indoor temperature dropped to approximately 30 °C, whereas the patio temperature was approximately 35 °C. The temperatures in most of the first and second floors were significantly lower than that of the patio. The room near the patio gate was far away from the cold alley and was affected by the higher-temperature air entering from the patio gate. Thus, the temperature drop was not significant, and the air temperature was close to the normal outdoor temperature of 36–37 °C.



(**a**) New system settings.



(**b**) The working principle of the new system (without wall heat radiation (WHR).

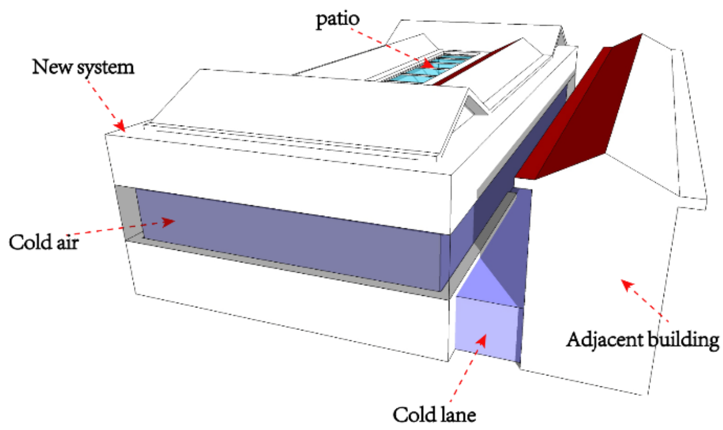


(**c**) Heat transfer process of new system (without WHR).

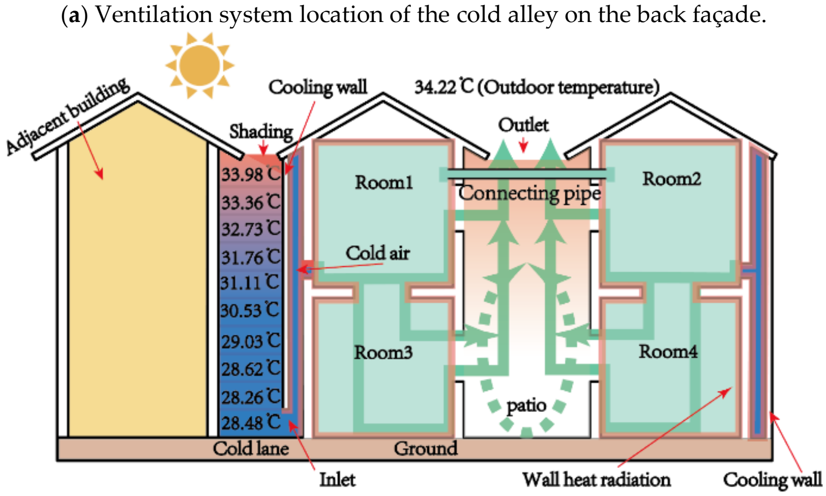
Figure 6-6. Introduction to cooling (without WHR). (a) New system settings. (b) The working principle of the new system (without wall heat radiation (WHR). (c) Heat transfer process of new system (without WHR).

6.1.4. Using cold alleys to cool buildings in summer (with WHR)

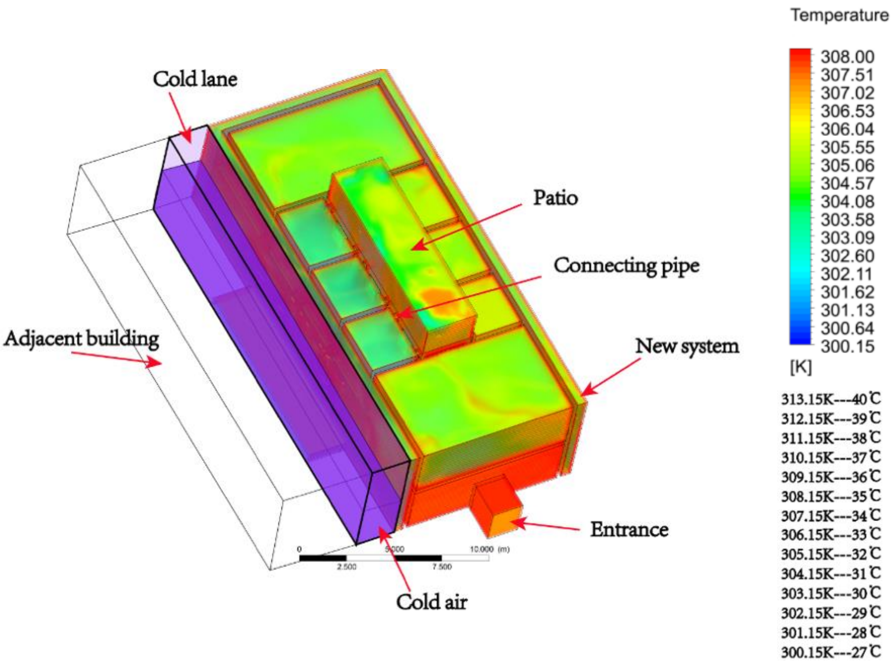
If the effect of the WHR on the indoor temperature is considered, the cooling efficiency will decrease. In summer, the outer surface of a building receives direct solar radiation for a long time, and the wall material acts as a medium for heat transfer from the outside to the inside. As shown in Figure 6-4b, in this study, the heated wall was similar to a constant-temperature source of heat and continuously provided heat to the room from the surroundings of the room. The cold air entering the room from the cold alley was already heated in the space between the two walls, and was also heated by the indoor air when it entered the room; this was an important reason for the decline in cooling efficiency. Therefore, as seen in Figure 6-4c, the new system still had a significant cooling effect, but it was much inferior to the case without WHR (Figure 6-3c). After a period of heat exchange, the indoor temperatures of the first and second floors were approximately 32–33 °C. The temperature in the patio was between 36 °C and 37 °C. The temperature of the room near the courtyard door remained close to the normal outdoor temperature.



(**a**) Ventilation system location of the cold alley on the back façade.



(**b**) Working principle of the new system (with WHR).

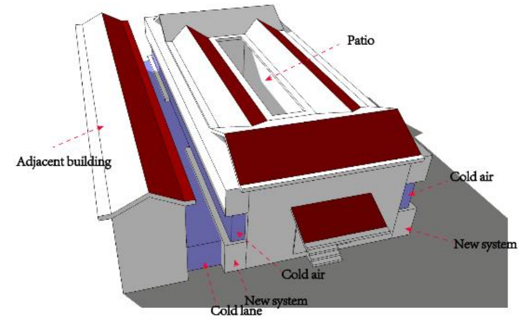


(c) Heat transfer process of the new system (with WHR).

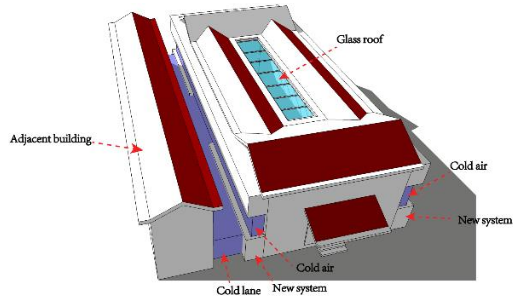
Figure 6-7. Introduction to cooling (with WHR). (a) Ventilation system location of the cold alley on the back façade. (b) Working principle of the new system (with WHR). (c) Heat transfer process of the new system (with WHR).

6.1.5. Installation of the glass roof in winter

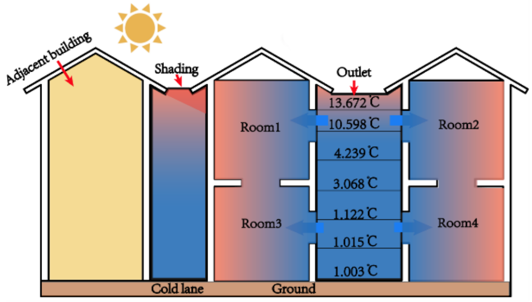
As shown in Figure 6-5a, b, in winter, the new system uses the interconnecting pipes between the rooms as a support frame to build a glass roof above the patio that can help the patio store heat. As shown in Figure 6-5c, the courtyard without a glass roof had no heat storage capacity, and the temperature of the patio was basically the same as that of the outdoors. The cold air penetrated into the room through the doors and windows of the room, greatly reducing the temperature in the room. However, after adding a glass roof, the patio had the capacity to store heat. Affected by solar radiation, the air in the patio was first heated from top to bottom, and the temperature was arranged from high to low in the vertical direction. After the patio air was fully heated, it could exchange heat with the low-temperature indoor air through the doors and windows, thereby increasing the room temperature. By comparing Figure 6-5e, f, we can clearly see the effect on the courtyard from installing the glass roof. After heating, the courtyard was equivalent to a constant-temperature heater which continuously delivered heat to the room during the day. The courtyard without a roof showed the opposite effect.



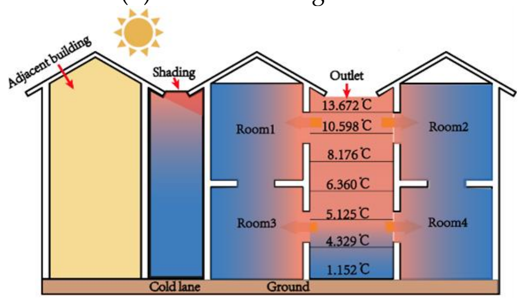
(**a**) Patio without the glass roof.



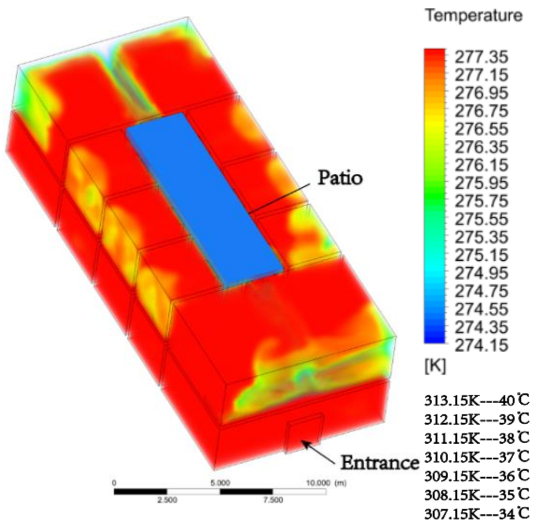
(**b**) Patio with the glass roof.



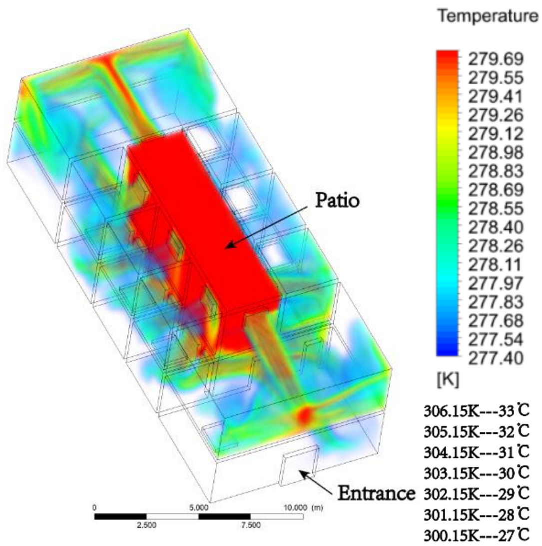
(**c**) Heat exchange in the courtyard without the glass roof.



(**d**) Heat exchange in the courtyard with the glass roof.



(**e**) Heat transfer in the courtyard without the glass roof.



(**f**) Heat transfer in the courtyard with the glass roof.

Figure 6-8. Introduction of the glass roof. (a) Patio without the glass roof. (b) Patio with the glass roof. (c) Heat exchange in the courtyard without the glass roof. (d) Heat exchange in the courtyard with the glass roof. (e) Heat transfer in the courtyard without the glass roof. (f) Heat transfer in the courtyard with the glass roof.

6.2 Simulation steps and related software

To obtain a clearer understanding of the research process and the reduced cooling load of the new system, the increase in ventilation efficiency, the time the system is suitable for opening, and the number of days in the year in which the indoor comfort increased, software is needed for accurate calculations and expressions. The thermal insulation wall simulation for the new system used the steady-state thermal module in ANSYS, which can very accurately simulate a masonry structure and the heat transfer process of air. The Fluent module in ANSYS was used to simulate the indoor cooling and ventilation using cold alleys. The large eddy simulation could accurately calculate the indoor transient ventilation situation, and radiation algorithms were used to calculate the heat conversion process between building interior walls and indoor air, as well as to calculate the heat conversion process between cold air in the cold alleys and indoor hot air. For the solar radiation analysis of the entire village and simulation of the cooling load of the new system, "Ladybug" and "Honeybee" in "Grasshopper" were mainly used. "Rhinoceros" was used to build the building model, "Ladybug" was used to calculate the weather parameters, and "Honeybee" was mainly used to input the related thermal environment parameters and connect to an Energy Plus system.

6.2.1. Model building and grid setting

In the geometry module of CFD, the reconstructed building model was built according to the actual scale, and the grid was divided according to the method provided by Arturs S. et al. [8], and the finite element simulation method was used to analyze the distribution of indoor temperature and airflow. The second-order upwind advection scheme was used in the model, which is conducive to the discretization of variables. In order to increase the reliability of the simulated data, it was necessary to establish a convergence criterion for the case study. The convergence standard for energy and temperature is 10−6 and the convergence standard for other parameters is 10−4. Reasonable setting of the mesh grid plays a vital role in the accuracy of the solution and will have a huge impact on the simulation time and the degree of convergence. Arturs S. et al. [8] used 0.34, 0.55, 0.98, 1.54, 1.92, and 2.09 million hexagonal grids in the simulation during the simulation, and performed local encryption processing in the details of the model. In this study, the division method of the overall division and partial encryption was also adopted. Meshing uses the proximity and curvature of the surface grid to divide the model into 5.409 million units. The number of grids is controlled by changing the maximum and minimum values of the grid and the growth rate of the grid size change. This will significantly speed up the calculation time and can more finely process the details of the interior of the building, thereby making the simulated results more accurate. For the setting of wall layers, it was necessary to ensure that all wall layers were evenly distributed in the model. The uniform wall layer distribution will make the radiation heat transfer more accurate. In this study, five wall layers were set up; the layer coefficient was 0.65, the level was 1.3, and the difference between two adjacent grids was kept at about 5%. According to the verification of Arturs S. et al. [8], after considering the configuration of the computer and calculating the deviation of each parameter, it was found that the deviation of the average wind speed was within 2.8%, and the deviation of the temperature was only 0.8%.

6.2.2. Boundary condition

The equation conditions, including the airflow and energy distribution, were established, which were mainly composed of the turbulent kinetic energy k_{inlet} at the entrance and the energy dissipation rate ε_{inlet}:

$$k_{inlet} = 1.5(v_{inlet}Tu)^2 \tag{16}$$

$$\varepsilon_{inlet} = \frac{C_\mu^{3/4} k_{inlet}^{3/2}}{0.07 D_{h.inlet}} \tag{17}$$

6.2.3. CFD and energy plus co-simulation simulation

According to the method provided by Rui Z. et al. [4], the coupling method between CFD and Energy Plus can be divided into three types:

- Fully internally coupled, in which the nodal model and CFD model equations are solved iteratively together.
- Iterative external coupling, in which the nodal model and the CFD model equations are solved separately, and the variables are exchanged through an iterative process until the convergence state is reached.
- Progressive replacement external coupling, in which the set of variables is exchanged after each model reaches the state of convergence at each time step.

Rui Z. et al. obtained the benefits of external coupling through systematic research in three aspects: 1. Lower computational cost; 2. Nodes and CFD models can be maintained and updated separately; 3. Configurable exchange variables. This method is the most suitable method for studying building natural ventilation. Therefore, this research will implement a gradual replacement of the external coupling strategy. The exchange variables will be exchanged after each model, node, and CFD model reaches the convergence state at each time step. The simulation steps were mainly divided into five items, and the main analysis method was a comparative analysis. First, the basic case and building energy consumption after the insulation wall was added were simulated and compared to determine the reduction in the cooling load. Second, the passive cooling process of the building using the cold alleys in the new system was simulated with and without WHR, and the results were compared with the base case to obtain the cooling load reduction, thermal equilibrium temperature, and cooling efficiency. Third, after simulating the ventilation performance of the new system, the results were compared with those of the basic case to determine the increase in ventilation efficiency. Fourth, the heating situation of the building in the winter after adding the glass roof to the courtyard was simulated and compared with the basic case to obtain the heating load and heating time of the winter system. Finally, by summarizing all of the results, the reduction in the cooling load in summer and the heating load in winter were calculated. Simultaneously, the time that the system could be used in a year was calculated, along with the amount of time that the comfort level increased after using the system.

6.2.4. Simulation scheme

In order to estimate the cooling load reduction in the new system with and without WHR, the time it takes to cool the room, and the final temperature after cooling, some simulation tools are needed to present the results. To simulate the indoor and outdoor ventilation, temperature, and heat conversion of buildings, the main tool used is the large eddy simulation and radiation algorithms in Fluent. The large eddy simulation algorithm can accurately calculate the time it takes for natural ventilation and heat conversion of the air, and present the ventilation status. The radiation algorithm is used to calculate the heat radiation of the wall and the details of the heat exchange process between the wall and the indoor air. The simulation tool for calculating building cooling load includes Grasshopper, Ladybug, and Honeybee. Rhinoceros is used for modeling, and then Ladybug is used to import weather data and Honeybee to set the building-related thermal parameters, and finally connect to Energy Plus for simulation calculations related to energy consumption.

The simulation in this study was mainly divided into four stages. The first stage is to simulate natural ventilation. After modeling based on the measured data of the building, the model is set according to local summer climatic conditions, including outdoor air temperature and dominant wind direction. According to the actual situation of the building, the wall, roof, doors and windows, ground, and other structural materials are set to simulate a set of natural ventilation data as a benchmark for comparison. The second stage is to set up the cold alley ventilation and cooling system, simulate with and without WHR, and collect and process the data of overall ventilation effect, temperature, and time. In the third stage, the cooling load reduced with and without WHR based on the new system is calculated, and the two conditions are compared and analyzed. Finally, the overall ventilation efficiency of the entire building, the temperature at the equilibrium point, the time consumed, and the total cooling load reduced throughout the year after adding the cold alley ventilation and cooling system are calculated. Table 6-1 contains the basic information of the study case, including the area, quantity, and location of the building, the climate zone, and the total area of each room. According to the China Affordable Housing Design Code [7], the minimum living area is 4 m^2/person, or 0.25 people/m^2. However, considering that the rural population base is relatively small and the per capita building area is relatively large, there are only three households in the study case. If three people are evenly allocated to 16 rooms, the population density will be too small. Therefore, setting the population density parameter to 1.1 persons will help improve the accuracy of the simulated data. Table 6-2 introduces the detailed construction method of the building and the materials used; Table 6-3 lists the density of building materials, thermal conductivity, heat storage coefficient, and specific heat.

Table 6-1. Basic information of the study case.

Courtyard Parameter	Detailed Description
Building location	Shuhe, Ankang, Shaanxi Province, China (32.9357°N, 109.7037°E)
Climate zone	Hot summer and cold winter
Simulation time	All times throughout the year when the temperature exceeds 28 °C
Room information	5.6 m (w) × 9.22 m (l) × 3 m (h) × 4; 3 m (w) × 4 m (l) ×3 m (h) × 12
Total surface area	349.04 m^2
Population density	1.1 people per room

Table 6-2. Detailed structure of the study case.

Building Material Parameters	Details
Exterior wall	Cement mortar (15 mm) + Masonry structure (240 mm) + Cement mortar (15 mm) + White lime (2 mm)
Floor	Ceramic tile (10 mm) + Cement mortar (10 mm) + Reinforced concrete (100 mm)
Internal partition	White lime (2 mm) + Cement mortar (15 mm) + Masonry structure (120 mm) + Cement mortar (15 mm) + White lime (2 mm)
Glass	Thickness (6 mm); solar transmittance at normal incidence: 0.775; front side solar reflectance at normal incidence: 0.071; back side solar reflectance at normal incidence: 0.071; visible transmittance at normal incidence: 0.881; front side visible reflectance at normal incidence: 0.08; back visible reflectance at normal incidence: 0.08; front side infrared hemispherical emissivity: 0.84; back side infrared hemispherical emissivity: 0.84; conductivity: W/m k
Roof	Bluestone tile (6 mm) + Waterproof mortar (6 mm) + Ceramic tile (10 mm) + Cement mortar (15 mm) + White lime (2 mm)

Table 6-3. Related parameters of building materials.

Material	Density(ϱ) kg/m^3	Thermal Conductivity(λ) W/m·K	Thermal Storage Coefficient (S) W/(m^2·K)	Specific Heat Capacity (C) kj/(kg·K)
Cement mortar	1800	0.93	11.37	1.05
Masonry structure	1700	0.76	9.96	1.05
White lime	1600	0.81	10.07	1.05
Reinforced concrete	2300	1.51	15.36	0.92
Bluestone tile	2000	1.16	12.56	0.92
Waterproof mortar	600	0.17	3.33	1.47

6.3 Results and discussion

In this part of the content, for the air insulation wall, the heat transfer process of the basic case and the new wall in the cold alley system is compared and analyzed. For passive cooling, the heat transfer process in the building is simulated and compared between the base case and building without WHR. Secondly, the with WHR and without WHR scenarios were compared and the room cooling time, cooling efficiency, and thermal equilibrium temperature were calculated. For the ventilation performance of the building, we compared the basic case with the building after the new system was installed and explained the impact of the new system on the building's ventilation. For the glass roof of the patio, we compared the heat storage capacity of the courtyard before and after the renovation and the process of indoor heat transfer.

6.3.1. Comparison of the air insulation wall and the basic case

During the temperature test of the case study, it was found that the external surface of the building receives long-term direct solar radiation in summer, which causes the external surface temperature to be much higher than the normal outdoor temperature. After measuring the indoor wall temperature and indoor room temperature, the wall temperature was found to be positively correlated with the indoor temperature and indoor wall temperature. As shown in Figure 6-6, the three temperatures of the building have a parabolic distribution. During the day, between 0:00 and 8:00, the temperature of the outer surface of the building was lower than the indoor temperature, but with the increase in solar radiation, the temperature of the outer surface rose rapidly, exceeding the two indoor temperatures at 8:00. At 15:00, the external surface temperature of the building reached a parabolic peak at a temperature of 67.1 °C. It took a certain amount of time for heat to transfer from the outer surface to the room, so the temperature of the indoor wall reached its peak at 16:00, at 37.8 °C. In the same way, the heat transfer between the indoor wall and indoor air also took time. The indoor temperature was not only affected by the wall temperature; the air in the courtyard also transferred heat to the room through the doors and windows. Therefore, under the common influence of the various temperatures, the indoor temperature reached its peak at 18:00, and was 38.63 °C. Therefore, it can be concluded that the indoor wall surface temperature and indoor air temperature change with the outer surface temperature of the building, and the delay time between them was approximately 1 h.

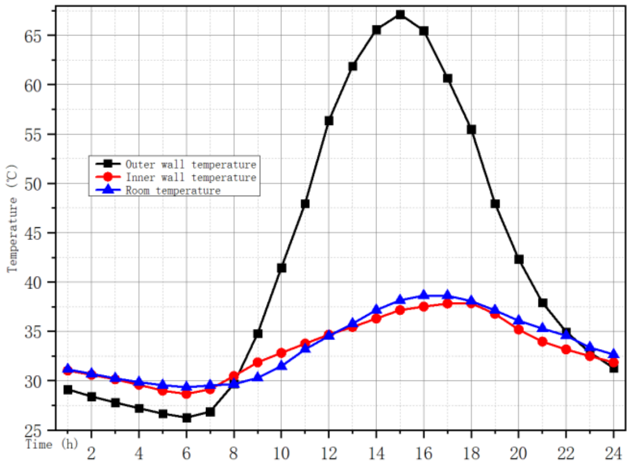
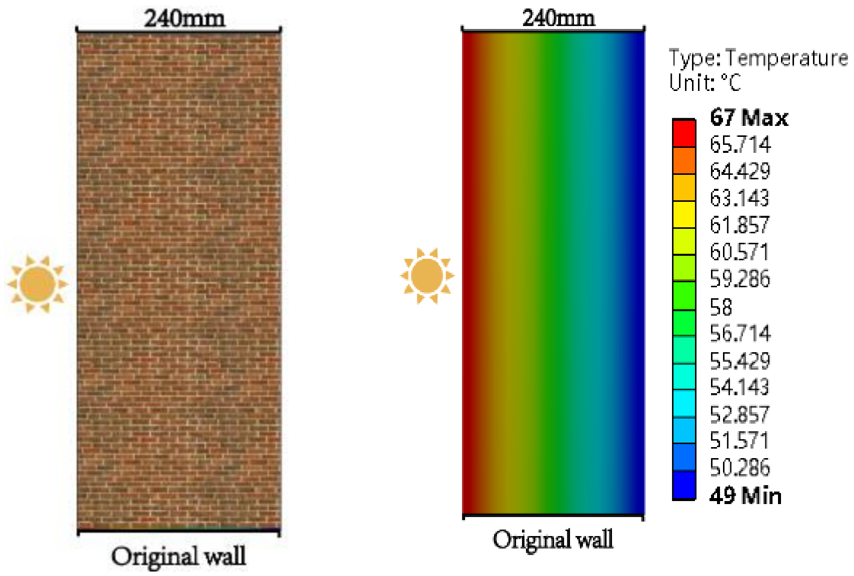
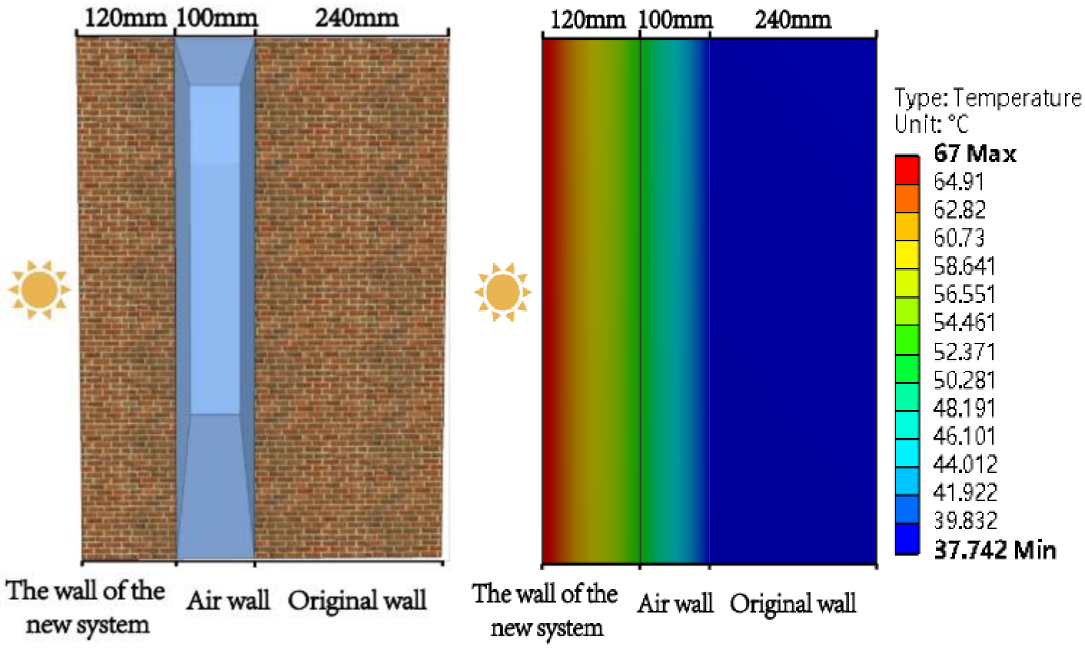


Figure 6-9. Comparison of the building exterior surface temperature, indoor temperature, and indoor wall temperature.

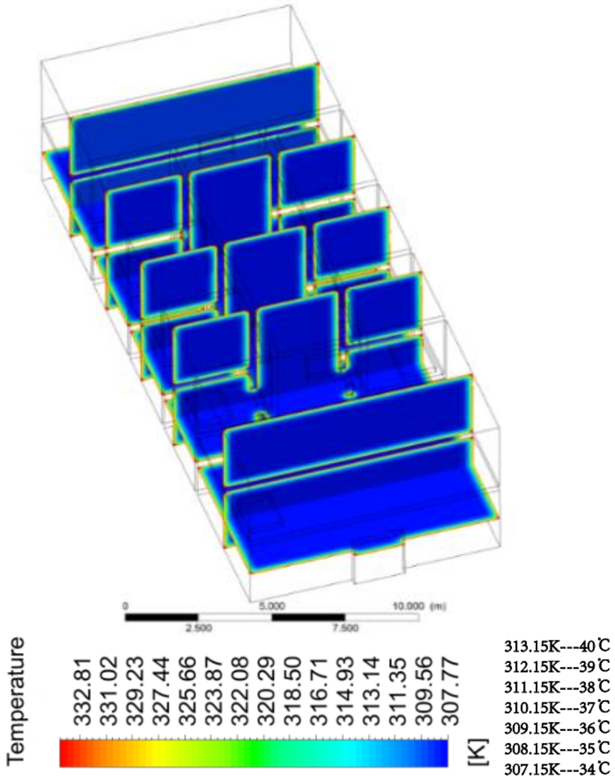
After the new system was installed in the building, the heat transfer of the wall was simulated and analyzed. Figure 6-7a shows the original wall heat transfer process for the case study. The outer surface temperature was 67 °C, and the heat reached the room after being transmitted through the wall material. The temperature of the inner wall of the room was 49 °C. This heat continued to exchange heat with the air in the room, causing the indoor temperature to continue to rise. However, as shown in Figure 6-7b, before the heat from the outer surface entered the room, it was first cooled by the cold air from the cold alley; then, it reached the original wall of the building and finally entered the room. Under the combined influence of the reduced heat consumption through the air wall and passive cooling effect of the new system, the temperature of the inner wall of the room was 37.74 °C. Thus, the temperature dropped by 11.26 °C. Figure 6-7c, d show the heat transfer on the walls and ground of the case study and that of the new system. The building not only transferred heat to the outer surface, the wall near the courtyard was also affected by solar radiation and transferred heat indoors. Between the first and second floors, a heat exchange occurred through the floor.



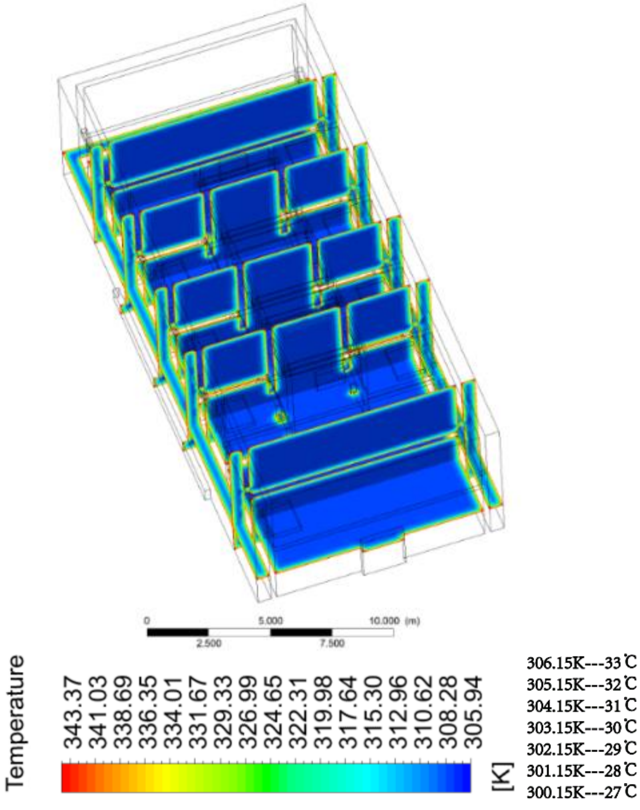
(**a**) Wall heat transfer analysis of the study case.



(b) Analysis of the heat transfer of the air insulation wall in the new system.



(**c**) Schematic diagram of the overall wall heat transfer.



(**d**) Schematic diagram of the overall wall heat transfer of the new system.

Figure 6-10. Comparative analysis with and without the air insulation wall. (a) Wall heat transfer analysis of the study case. (b) Analysis of the heat transfer of the air insulation wall in the new system. (c) Schematic diagram of the overall wall heat transfer. (d) Schematic diagram of the overall wall heat transfer of the new system.

6.3.2. Passive cooling of the new system and base case

6.3.2. a. Comparison of passive cooling of the new system with that of the base case

After setting up the new system for the case study, the situation without considering WHR is analyzed in detail. Figure 6-8 shows the passive cooling process of the base case and that of the new system without the WHR. At 4 min, the base case uses the patio entrance as the main air inlet of the building to transport airflow into the building. In contrast, in the new system, there are two air inlets for the building: the patio entrance and the opening connected to the cold alley. The air temperature at the entrance of the patio was 34 °C, and the air temperature in the cold alley was 28 °C. When the time reached 50 min, it can be seen that in the basic case, the outdoor air entered the building through the courtyard, which initially reduced the courtyard temperature. When the courtyard temperature stabilized, it exchanged heat with each room through the doors and windows. By contrast, at the same time of 50 min, when the passive cooling was conducted based on the cold alley ventilation, the cold air in the cold alley avoided the patio and directly introduced cold air into the room, significantly improving the cooling efficiency. Moreover, the second-floor rooms on both sides of the patio are connected by air ducts; therefore, when the temperature of the second-floor room on the side of the cold alley reached the thermal equilibrium point, part of the cold air passed through the stairwell to reach the first floor, and another part of the cold air passed through the air duct entering the opposite room. The air wall surrounding the outside of the building also introduced cold air from the cold alley into the room on the other side; thus, the interactive cooling method can also increase the cooling rate of the room far away from the cold alley. In the ideal state without WHR, all rooms in the base case reached the thermal equilibrium temperature after 6 h. Because the courtyard is used to cool the room, the courtyard temperature is equal to the indoor temperature. The building mainly relies on the normal outdoor temperature for cooling, and the temperature drops by approximately 1 °C. The final room thermal equilibrium temperature was 34 °C, and the cooling rate was 0.166 °C/h. In contrast, when using the new system for passive cooling, the utilization rate of the cold air was improved, as the heat exchange with the courtyard air was avoided. The entire room reached the thermal equilibrium temperature after 1.66 h. The courtyard and indoor temperatures were quite different. The temperature of the courtyard was 32 °C. The indoor temperature was 28 °C, and the indoor cooling rate was 3.61 °C/h. However, the temperature of the room near the entrance of the patio was affected by the normal outdoor temperature, and thus, its temperature was higher than that of other rooms, at approximately 33 °C.

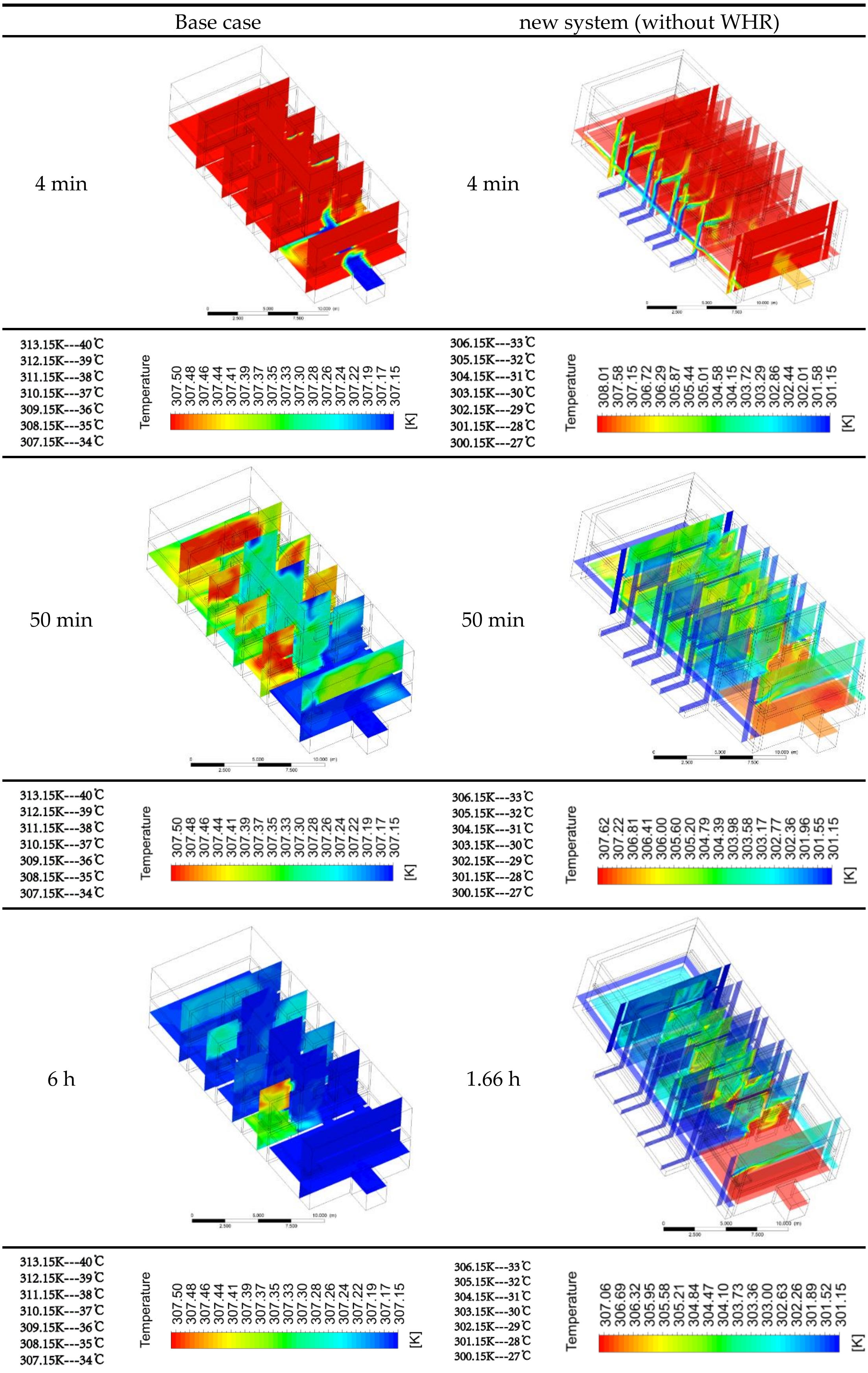


Figure 6-11. Comparison of passive cooling of the new system with the base case (without WHR).

6.2.3.2. b. Cooling time and thermal equilibrium temperature of the new system with and without WHR

When considering the WHR, the cooling time of the new system and temperature of the heat balance point were affected to a certain extent. As shown in Figure 6-9, during the first 4 min, the heat transfer conditions with and without WHR were roughly the same. However, when the air in the cold alley entered in the new system, part of the air was affected by the solar radiation and was heated by the envelope structure. At 50 min, the air in both rooms on the side of the cold alley reached the thermal equilibrium temperature and began to flow to the first floor and the room on the side away from the cold alley; the thermal equilibrium temperature changed. In the absence of WHR, the thermal equilibrium temperature of the room near the cold alley was approximately 30 °C, whereas the temperature of the room with WHR was approximately 32 °C. The new system was also affected by the solar radiation. As cold air flowed into the room far from the cold alley, the air storage space in the wall was heated. Therefore, the purpose of cooling the far room could not be achieved within a certain period of time. At this time, the air ducts connecting the rooms on both sides played an important role. They directly introduced cold air into the room on one side of the cold alley and into the room on the other side, reducing the cooling time and improving the cooling efficiency. All of the rooms without the influence of WHR reached the thermal equilibrium point after 1.66 h. The average indoor temperature was 28 °C, and the cooling efficiency was 3.61 °C/h. In the case with WHR, the temperature of all rooms reached the equilibrium point after 1.94 h. The temperature was 32 °C, and the cooling efficiency was 1.03 °C/h. Although the cooling efficiency of the new system was reduced when considering the WHR of the wall, it was still closer to reality. Nevertheless, this shows that, in the indoor heat transfer simulation, the influence of the WHR on the indoor temperature cannot be ignored.

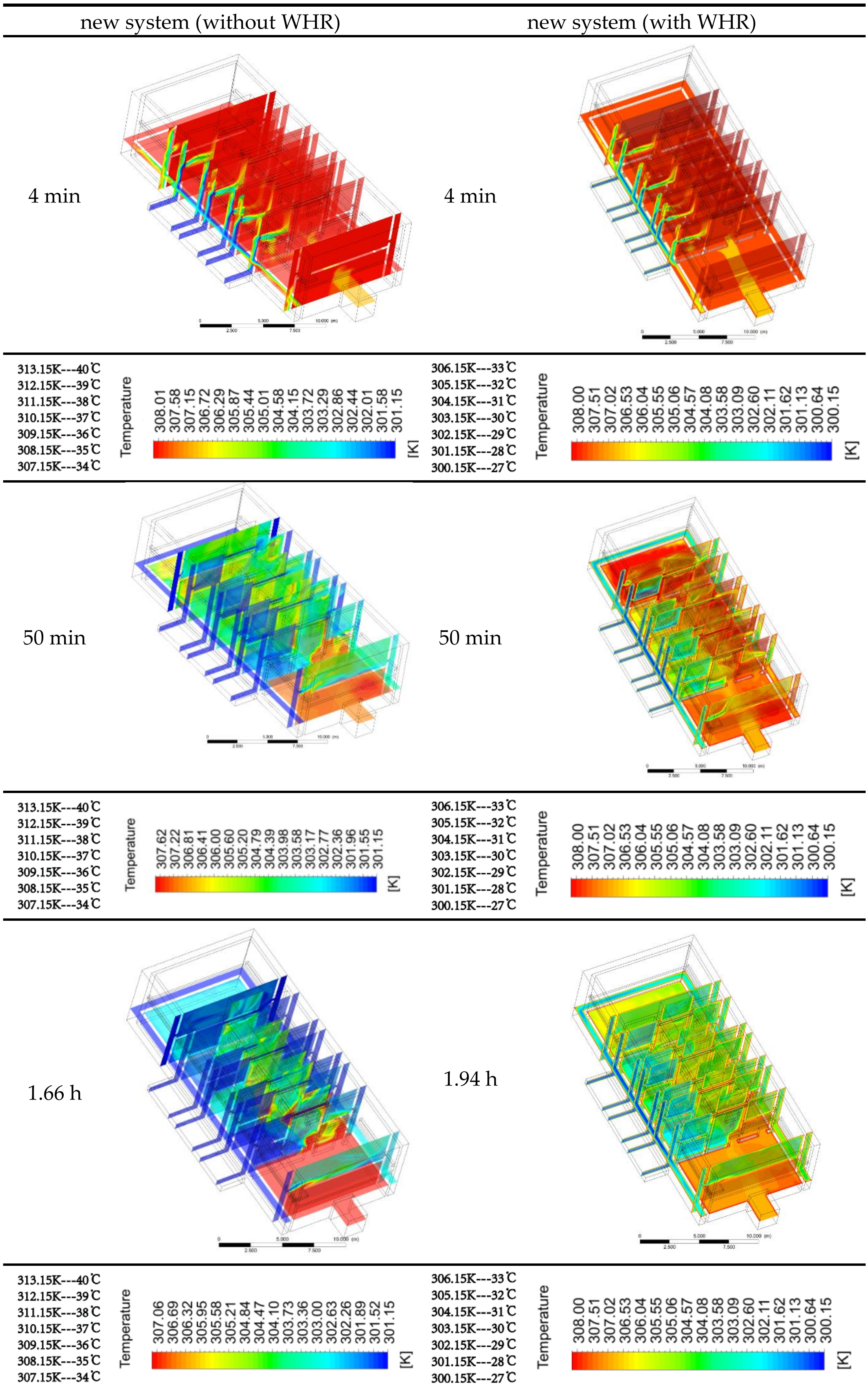


Figure 6-12. Cooling time and thermal equilibrium temperature of the new system with and without

WHR.

6.3.3. Comparison of the natural ventilation of the new system and the base case

Figure 6-10 shows a comparison between the ventilation efficiencies of the new system and the base case. It can be seen that within 4 min–2.22 h, the air flow in the base case room was slow, and the effect of the ventilation through the patio was not ideal. For the new system, during the period of 4 min–1.38 h, the air passed through the cold alley, the top of the patio, and the patio entrance for ventilation. In the courtyard, the air flow in the room was intense and the frequency of air exchange was high. An ideal ventilation effect was achieved within 4 min.

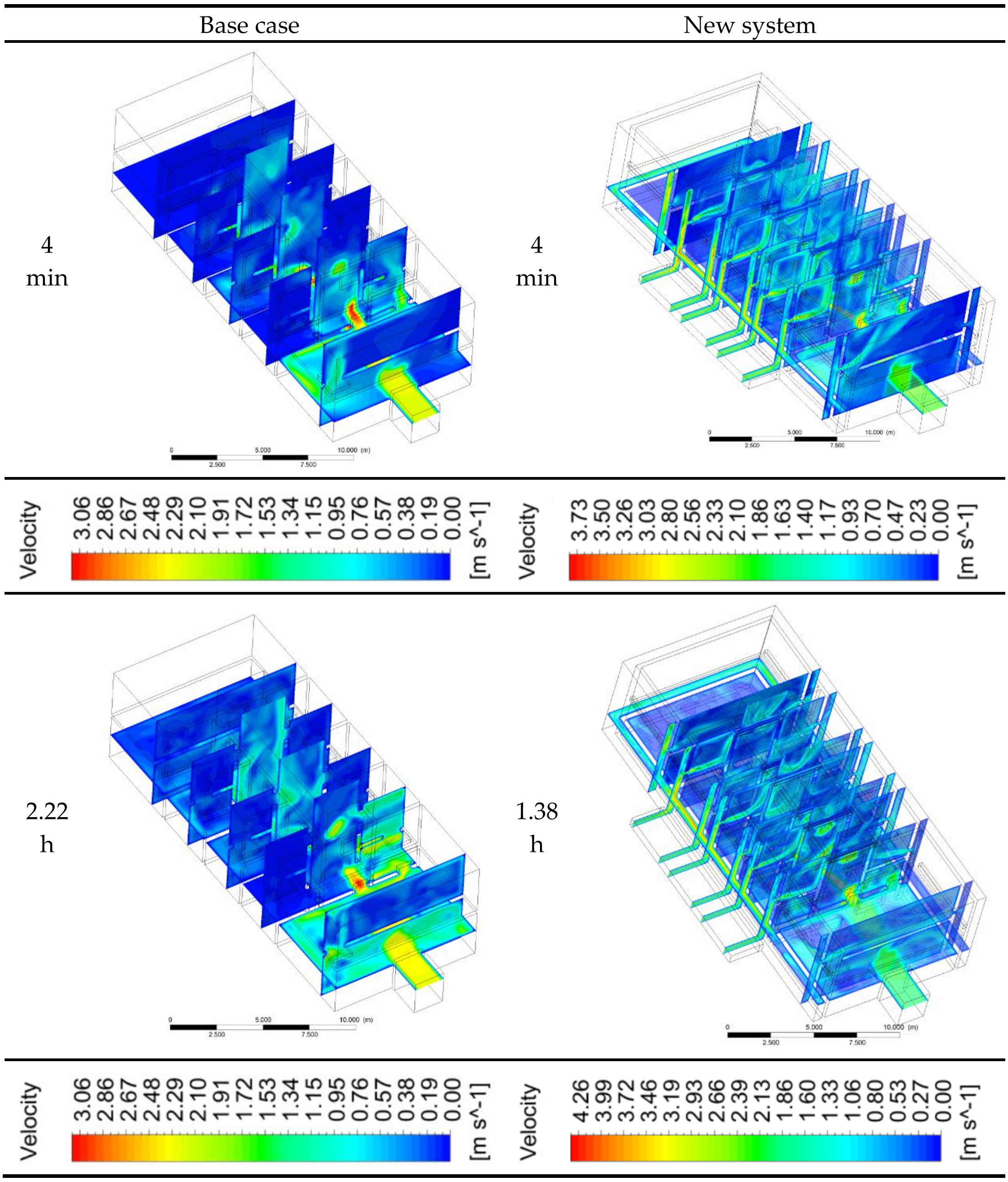


Figure 6-13. Comparison of the natural ventilation of the new system and the base case.

6.3.4. Patio glass roof in winter

The location in the building that can receive the maximum solar radiation per day is the roof. As shown in Figure. 6-11, after measuring the roof temperature, indoor temperature, and outdoor temperature during the winter solstice, it was found that the outdoor temperature at night was the lowest, the indoor temperature was the highest, and the roof temperature was somewhere in between. However, as the sun rose, the solar radiation gradually increased, and the temperatures at various locations also gradually increased. The three temperatures were the same at 10:00. Then, the temperature of the roof rose the most, reaching a peak of 19 °C at 15:00. The second-highest was the indoor temperature, which reached a maximum of 9 °C at 17:00. With regard to the passive insulation strategy for winter buildings, solar radiation was the largest heat source and avoided any energy consumption. If the solar radiant heat on the roof of the building can be effectively collected, it can be stored and then transmitted into a room through the doors and windows, effectively increasing the indoor temperature. To improve the heat storage capacity of the courtyard in winter, it is necessary to install a glass roof at the top of the patio. Therefore, in this study, the air ducts used to connect the rooms on both sides of the courtyard in summer were used as the supporting members for the glass roof, i.e., to facilitate its construction.

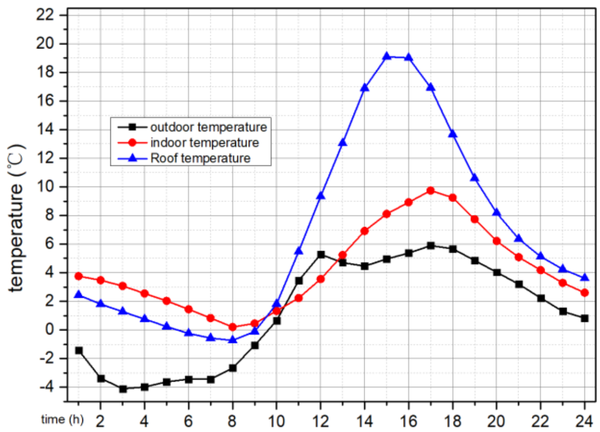


Figure 6-14. Comparison of the roof temperature, indoor temperature, outdoor temperature.

June 21 is the summer solstice, and this day's sunshine time is the longest in the year. Thus, the temperature of the case study was measured on this day. In this research, we tried to treat the patio as a constant-temperature heat source which could store heat within a certain period of time and transfer heat to the room. Figure 6-12 shows a comparative analysis of the heat storage patio with the glass roof and the basic case. At 4 min, the two patios show different effects. In the basic case, the patio has no heat storage function. After entering the patio, the cold air from the outside flowed downward and passed into the room through the doors and windows. However, the patio with the heat storage function played the opposite role. Its existence helped to increase the indoor temperature. After 28.3 min, the patio without the glass roof gathered a large amount of cold air, which continued to enter the room. At this time, the courtyard temperature dropped from 4.18 °C to 1 °C. For the patio with a glass roof, the temperature started to increase down from the top of the courtyard, and the heat storage was completed after 33.3 min, and the temperature rose from 4.18 °C to 6.45 °C. For the entire building, this is equivalent to adding a constant heat source with a temperature of 6.45 °C for continuously heating the rooms near the patio, thereby reducing the heating load of the building.

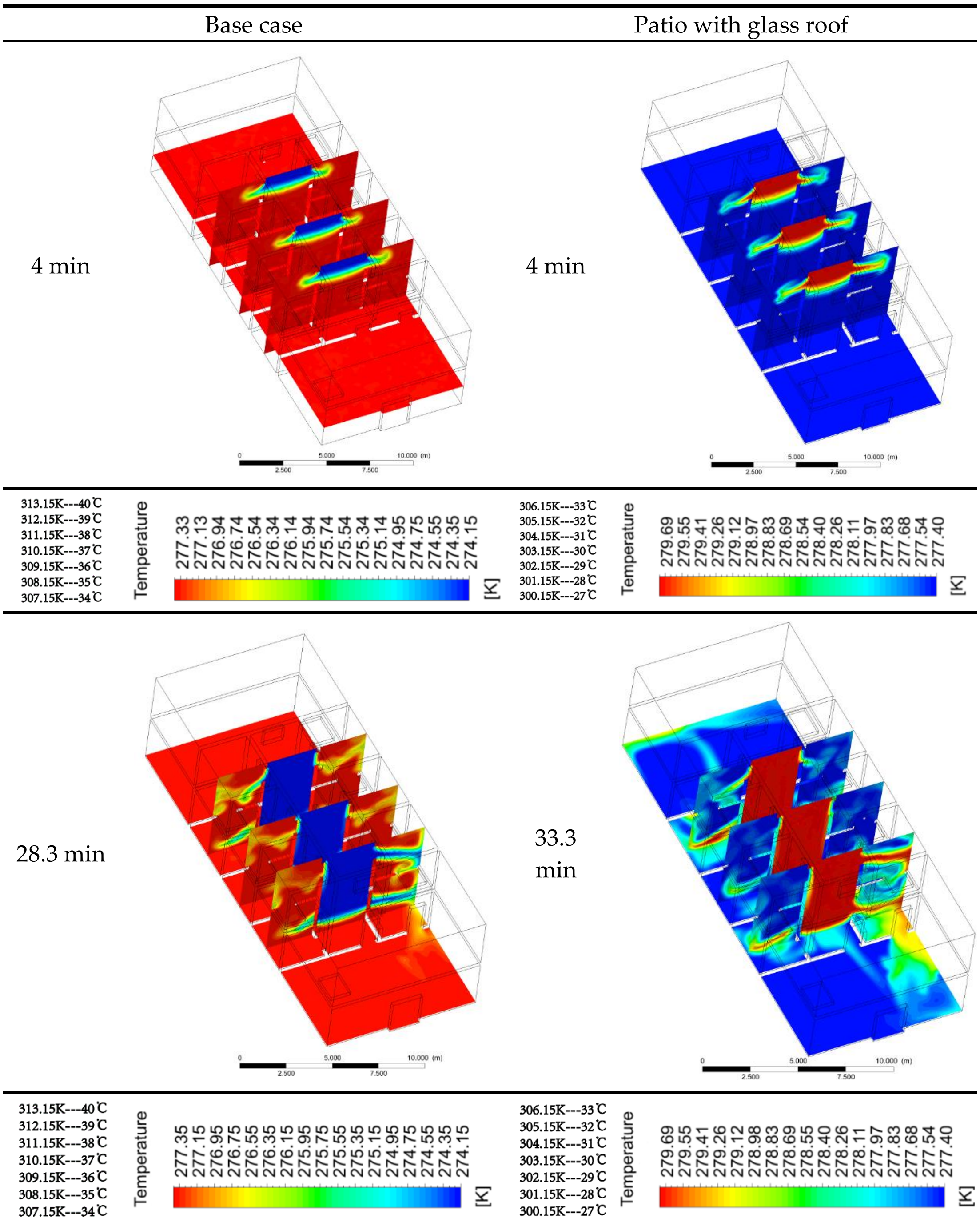


Figure 6-15. Comparison of the heat transfer with and without the glass roof patio in winter.

With reference to the above analysis and simulation, the load of each part of the new system and the thermal comfort time of the building will be calculated next, and they will be compared with the base case. By comparing the effects before and after adding thermal insulation walls in traditional residential buildings, we estimated the annual cooling load reduction from using thermal insulation walls in summer. The cooling effects of a base case and of a building using the passive system were examined without considering the WHR, aiming to calculate the cooling efficiency inside the building, thermal equilibrium temperature, and reduction of the cooling load for the entire building throughout the year. The cooling effects of the new system with and without WHR were compared, in addition to the room cooling rate, thermal equilibrium temperature, and annual cooling load reduction for the entire building. Based on comparing the heating effects of a courtyard with or without a glass roof in winter, we estimated the time required for a patio to meet the required heating conditions and reduce the total heating load throughout the year. The appropriate utilization time for the new passive system over a year was calculated. According to a local comfort temperature standard, the annual time required to meet the comfort temperature requirement for the base case was estimated, and the annual times required to meet the comfort temperature standard after using the new system with and without WHR were compared.

6.3.5 Cooling load reduction by the air insulation wall

Figure 6-13 shows a comparison of the cooling load of the building with and without an insulating wall during the year. It can be seen from the figure that the cooling load reduction of the building without the insulating wall for the entire year was 56551.03 kWh. When the air insulation wall was installed, the reduced cooling load was 55417.33 kWh. The difference between them was the cooling load reduction of the air insulation wall, i.e., 1133.7 kWh.

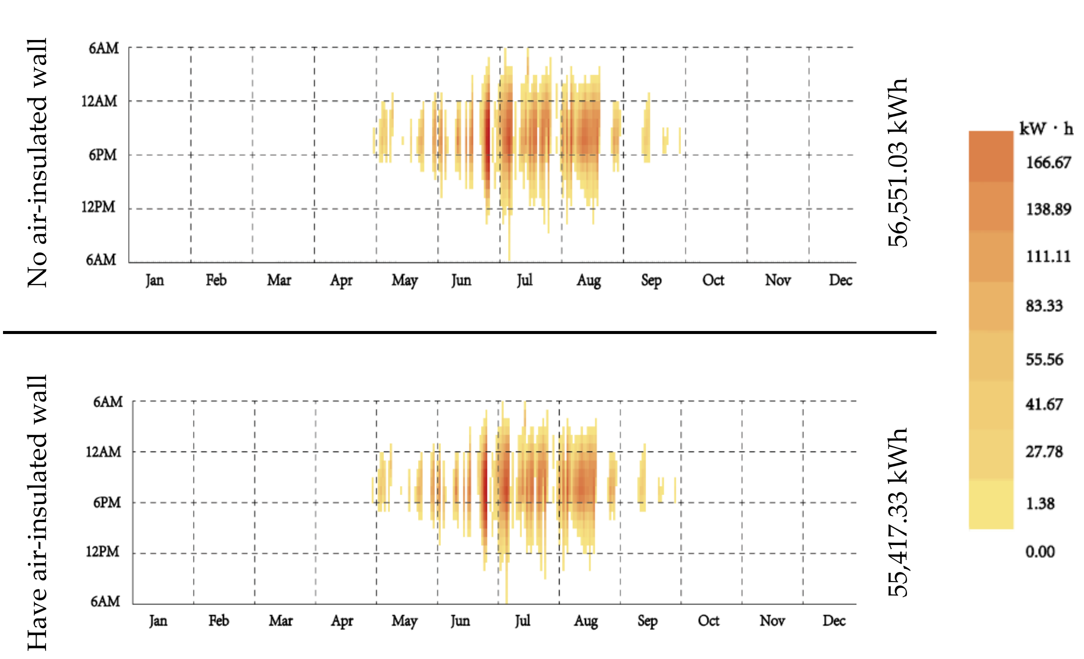


Figure 6-16. Comparison of the cooling load with and without the air insulation wall.

6.3.6. Comparison of whether the new system with WHR reduces the cooling load in summer

Figure. 6-14 shows the reduction in the cooling load of the building during the year with and without WHR. Without WHR, the cooling load reduction of the entire building was 55,417.33 kWh. With WHR, the cooling load reduction was 28,537.57 kWh. The difference between the two was 26,879.76 kWh.

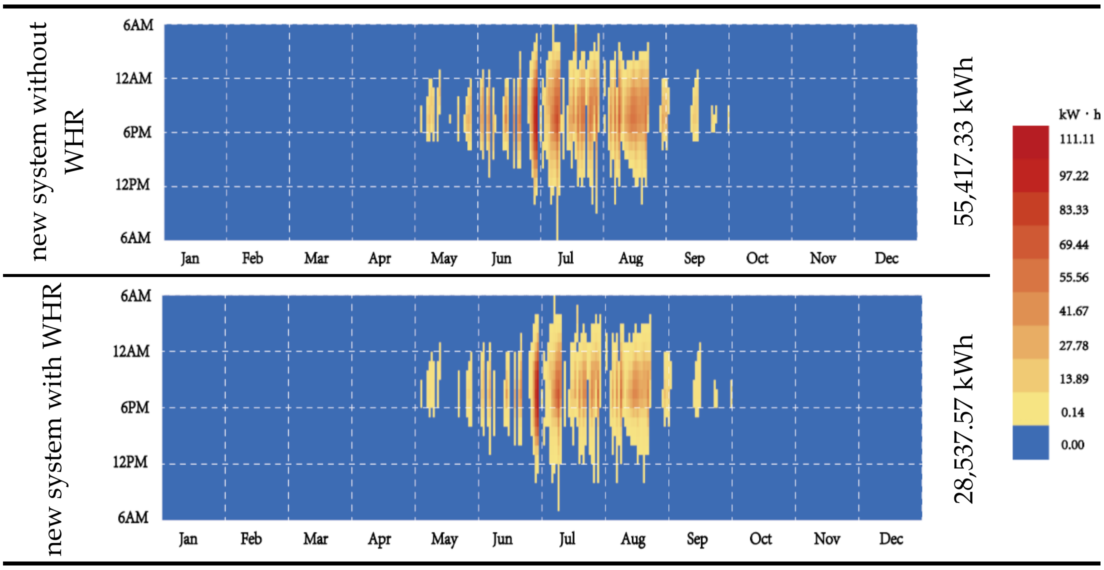


Figure 6-17. Reduction in the cooling load of the building during the year with and without WHR.

3.7. Patio glass roof reduces the heating load in winter

Figure 6-15 shows that the winter heating load, as reduced by using the glass roof to increase the heat storage capacity of the patio in winter, was 54,537.78 kWh.

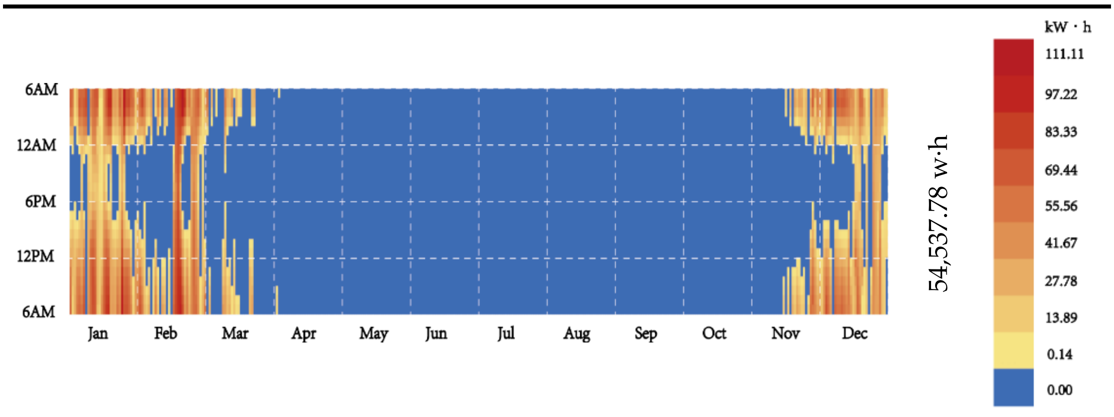


Figure 6-18. Reduced heating load from the glass roof.

6.3.7. Suitable time for the new system throughout the year

The indoor temperature in summer was higher than 28 °C, and the temperature in winter was lower than 6.45 °C; these were used as reference standards for calculating the available time for the new system throughout the year. Figure 6-16 shows the times when the new system was suitable for use within a year, both with WHR and without WHR, as benchmarks for comparison. It can be seen that with WHR, the suitable time for the new system to be open throughout the year was 2722 h, accounting for 31.07% of the total time of the year. Without WHR, the suitable time for the new system to be open throughout the year was 2666 h, accounting for 30.43% of the total annual time. The difference between the two was 56 h.

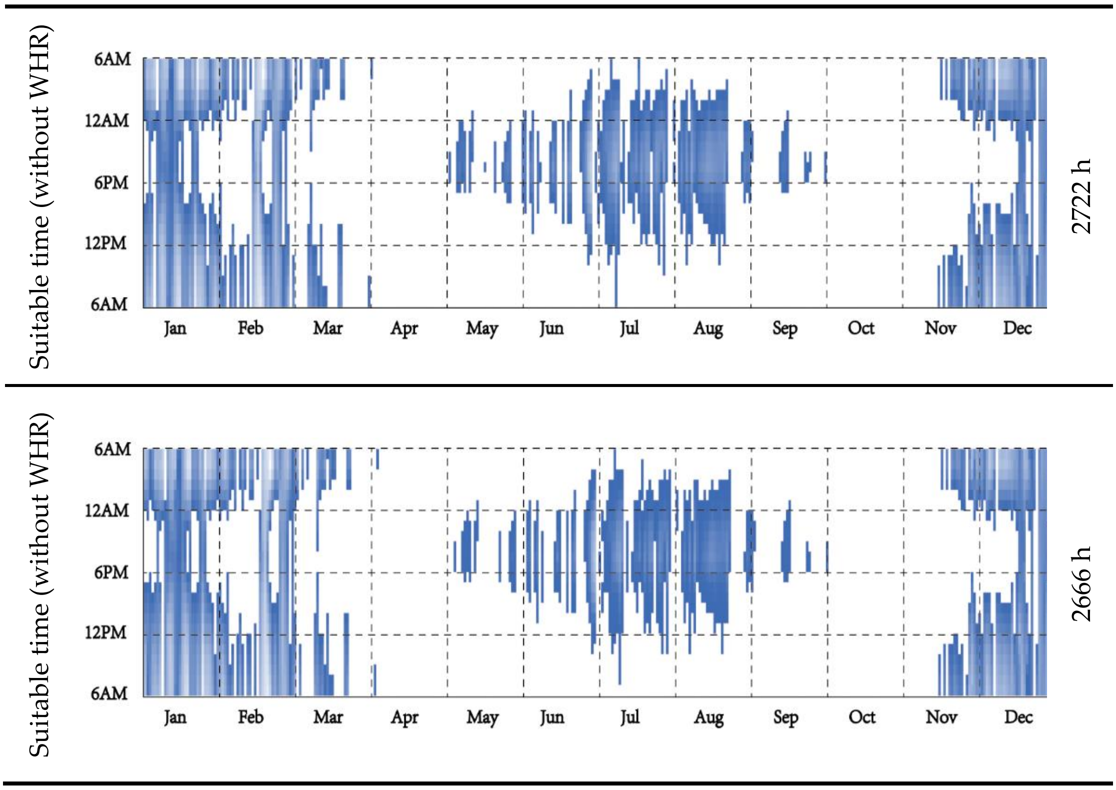


Figure 6-19. Suitable time for the new system throughout the year.

6.3.8. Time suitable for the building to meet the thermal comfort temperature after using the new system

The thermal comfort temperature range obtained after the comfort analysis for Shuhe is shown in Figure 6-17 It can be seen that under the comprehensive influence, the comfortable temperature range for Shuhe is between 18 °C and −25 °C. In this study, the time for the room to meet the thermal comfort zone was counted for the base case, for the case without WHR, and for that with WHR. As shown in Figure 6-18, the time for the base case to meet the thermal comfort temperature range in a year was 2349 h, accounting for 26.81% of the year (Figure 6-18a). After setting up the new system without WHR, the time to meet the thermal comfort temperature range was 2455 h, i.e., an increase of 106 h and accounting for 28.02% of the year; thus, the proportion increased by 1.21% (Figure 6-18b). With WHR, the time to meet the thermal comfort temperature range was 2420 h, i.e., an increase of 71 h and accounting for 27.62% of the year, an increase of 0.81% (Figure 6-18c). In addition, the time that each room in the building was within the thermal comfort range was calculated separately, as shown in Figure 7-296-18d. It can be seen that the comfortable temperature time differed according to the different locations of the rooms. The comfort time of rooms 1–8 with WHR increased significantly, but without WHR, the time was approximately the same as that of the base case. For rooms 9–16, the result was the opposite. However, as compared with the base case, after adding the new system, the time within the comfort range of each room increased, regardless of whether the WHR was considered.

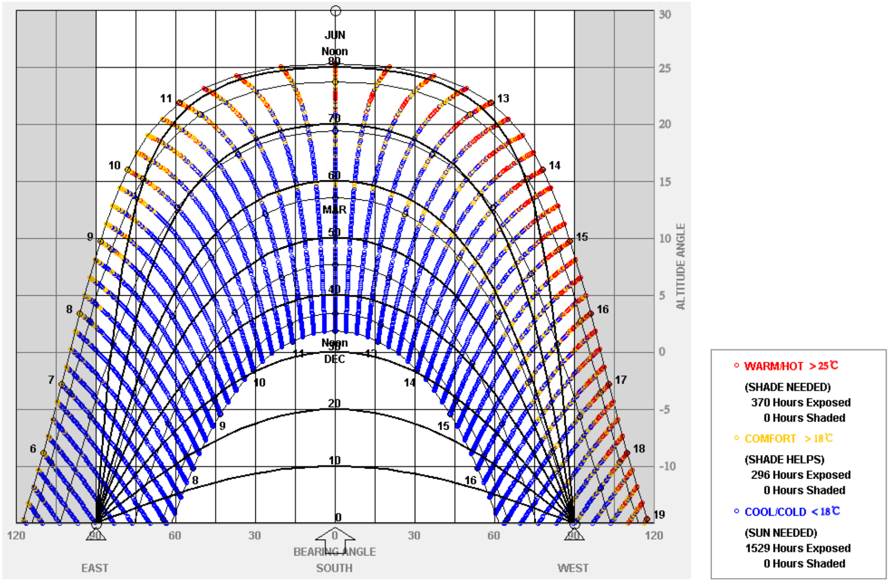
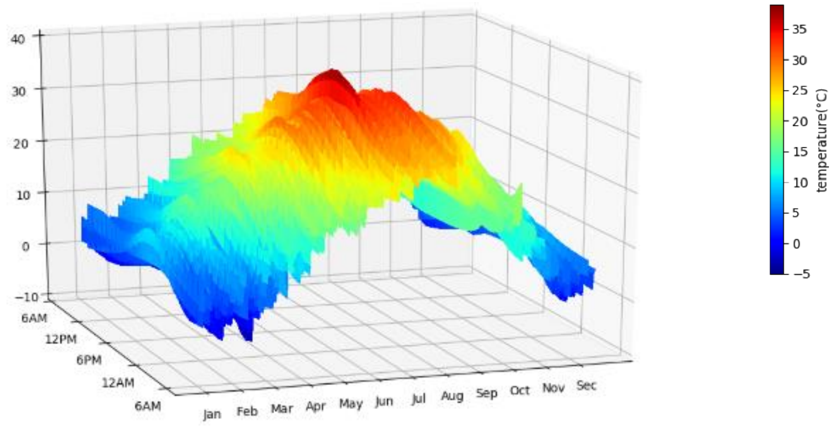


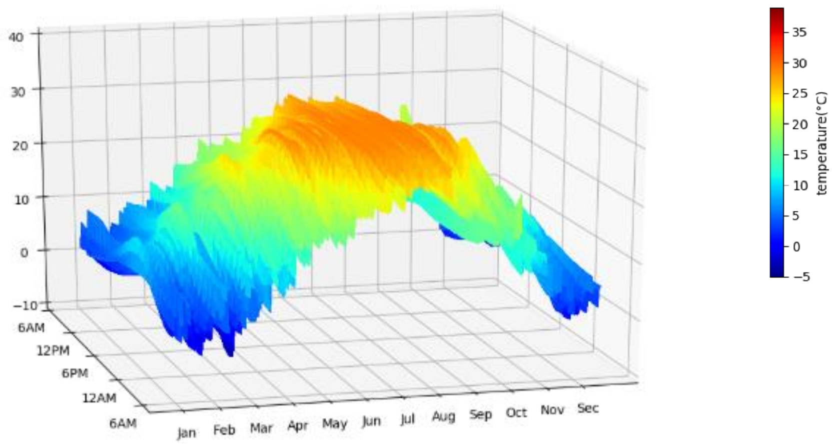
Figure 6-20. Shuhe thermal comfort temperature range.

2349 h

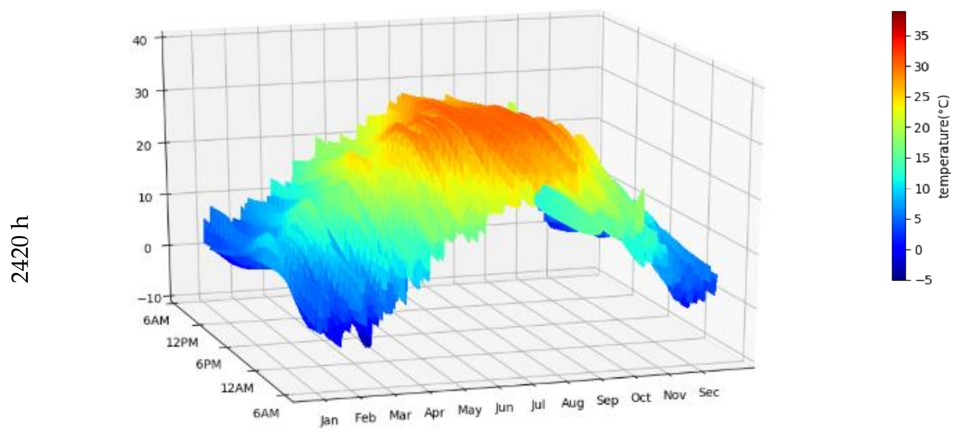


(**a**) Thermal comfort time of the base case.

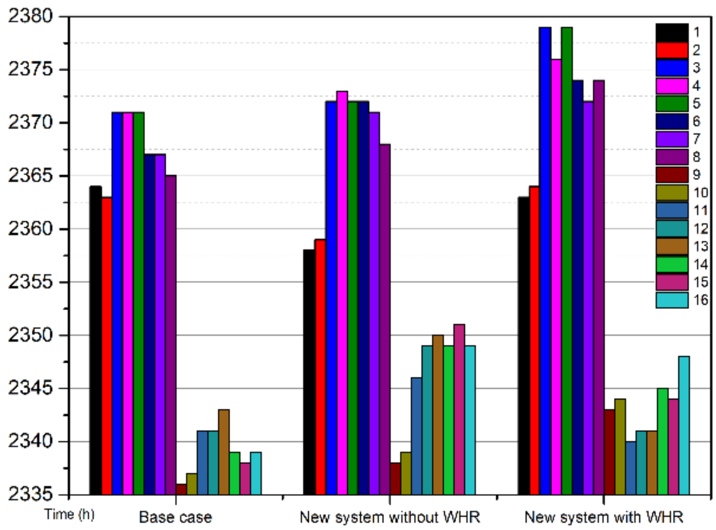
2455 h



(**b**) Thermal comfort time of the new system (without WHR).



(**c**) Thermal comfort time of the new system (with WHR).



(**d**) Thermal comfort time of each room of the new system.

Figure 6-21. Thermal comfort time comparison. (a) Thermal comfort time of the base case. (b) Thermal comfort time of the new system (without WHR). (c) Thermal comfort time of the new system (with WHR). (d) Thermal comfort time of each room of the new system.

6.3.9. Relative humidity

Figure 6-22 respectively shows the indoor relative humidity distribution whether the cold lane system is used in the building, and the corresponding percentage of thermal comfort within a year. When the cold lane system is not used, the indoor relative humidity is very high, and the annual thermal comfort time is only 16.42%. However, when the cold lane system was used for ventilation, the indoor relative humidity dropped significantly, and the annual thermal comfort time increased to 17.22%.

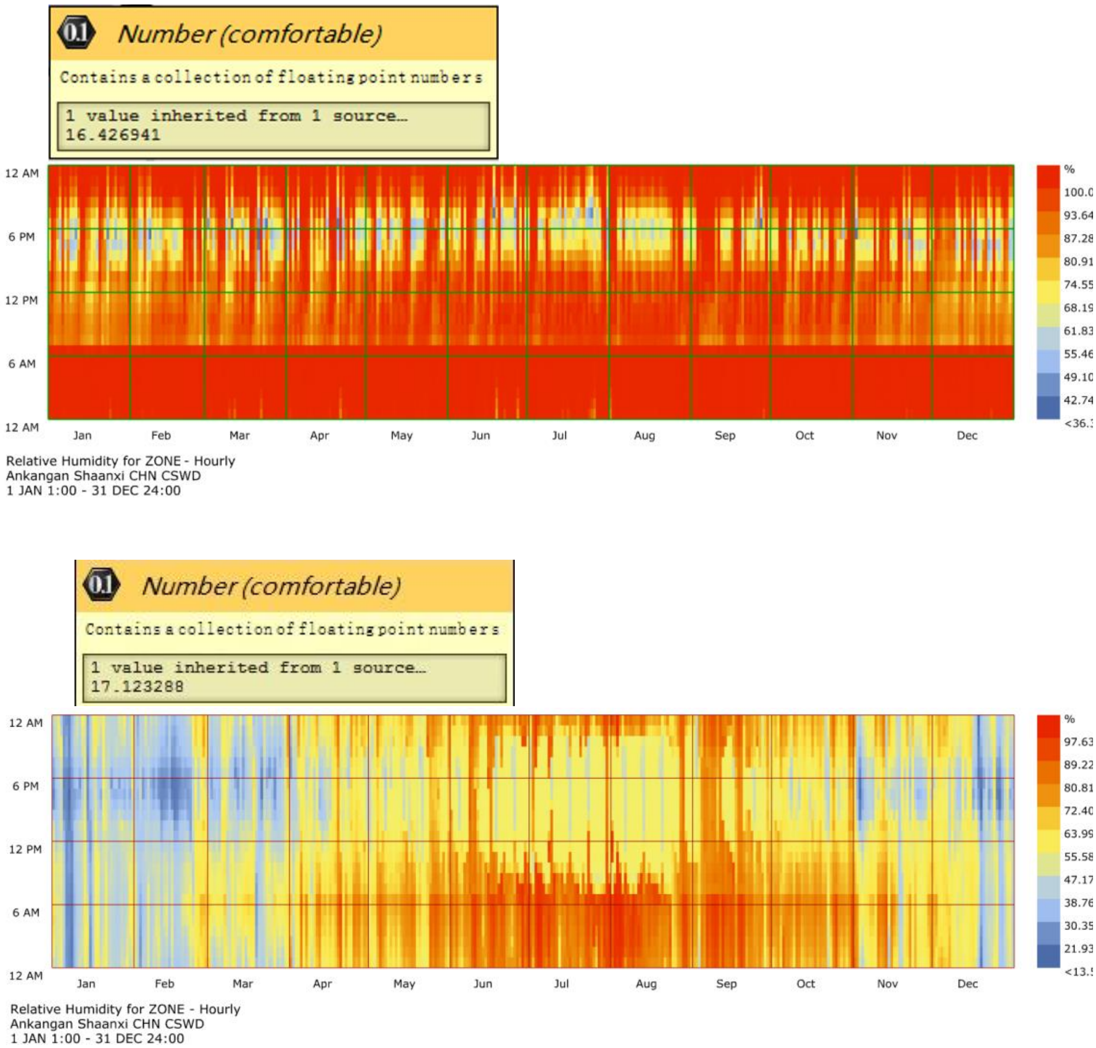
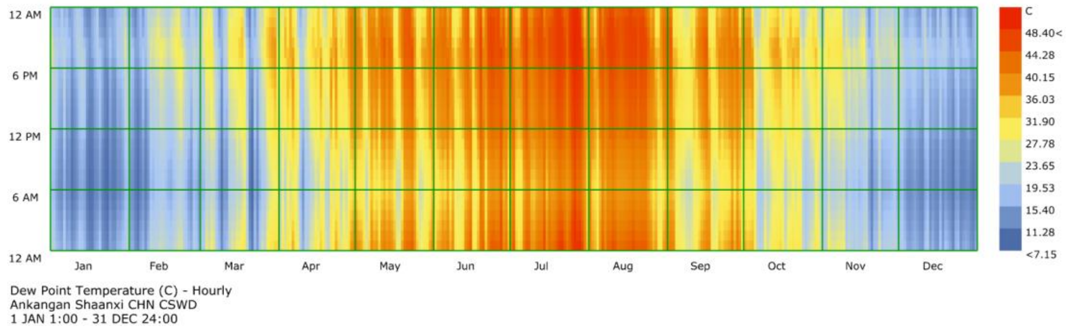


Figure 6-22. Comparison of indoor relative humidity whether using cold lane system.

Figure 6-23 shows the indoor dew point temperature of the building before and after the cold lane system is used. It can be seen that when the cold lane system is not used, the indoor dew point temperature is between 48.4°C and 7.15°C. However, when the cold lane system is used, the indoor dew point temperature becomes between 26.3℃~-12.92℃.



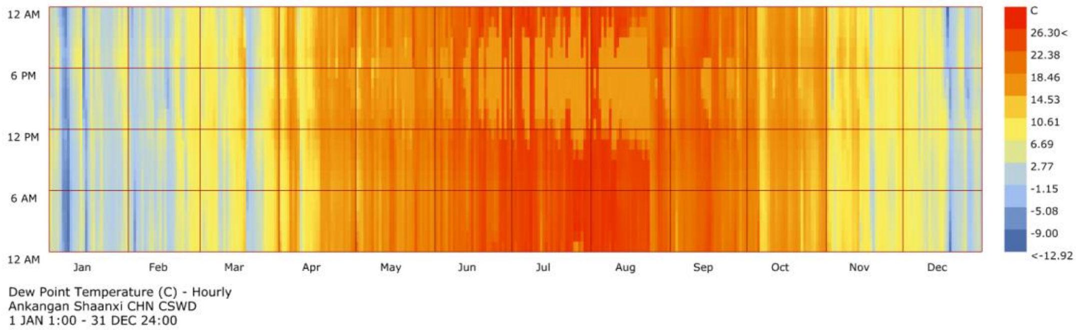


Figure 6-23. Comparison of indoor dew temperature whether using cold lane system.

6.3. Chapter summary

This chapter mainly introduces the energy-saving mode of modern settlements in southern Shaanxi through cold alleys. It mainly includes two aspects: the individual effect of cold alleys on the natural ventilation of residential buildings and the comprehensive application of cold alley passive energy-saving systems and other building energy-saving methods. It introduces in detail how cold alleys are combined with residential buildings, and calculates the time for ventilation and cooling. Statistics of the total building energy saving throughout the year and the appropriate time to use the system.

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Chapter 7. Conclusion and prospect.

1. Conclusion

This study verified the accuracy of the CFD software and found a solver suitable for simulating the wind environment of a village with a complex architectural layout. Summarizes the method of constructing cold lanes and applies this method to the design of cold lanes in modern buildings. A new passive cooling and energy saving system for traditional Chinese buildings has been established. This system is based on cold lanes. Above all, the conclusions of this research can be summarized as following:

In chapter one, **Introduction.** Discusses the background and purpose of the research. Through settlement ventilation, pollutant diffusion path tracking, simulation solver accuracy verification, passive cooling of buildings, comprehensive application of settlement environment and passive energy saving, building energy saving measures, building ventilation, glass roof and sun room settings as the main content, Conducted a literature review. Through the understanding of previous related research, find some methods that can be used for research. Combining the found method with its own research direction, trying to find the correct method to solve the wind environment simulation of traditional Chinese settlements, and how to choose a suitable solver. Discovered the existing problems in traditional settlements and residential buildings about ventilation, cooling, and energy saving in settlements and buildings, and explored the rational use of passive energy-saving technologies in modern buildings in traditional Chinese residential buildings.

In chapter two, **Investigation on the Characteristics of the Layout of Traditional Settlements in Southern Shaanxi.** Firstly expounds the causes of settlements in southern Shaanxi through three aspects: natural factors, social factors, and human factors. A detailed description of the geographical location and natural conditions of southern Shaanxi in China. Introduced the formation process of the cultural characteristics and social structure of Southern Shaanxi in China. Subsequently, Shuhe Town, a representative settlement in southern Shaanxi, China was taken as the main research object. From a macro perspective, the layout of the building groups and the organizational structure of the streets and lanes of Shuhe Town are analyzed. Finally, it takes the buildings in the settlements as an independent research content to illustrate the characteristics of traditional residential buildings in southern Shaanxi.

In chapter three, **Analysis of Related Theories and Choice of Research Method.** Describes the research methods and related theories used in the research. Research methods include: related theoretical research, investigation and research on research cases, and research on software simulation and comparison methods. Theoretical research mainly includes: the characteristics of wind environment and its influencing factors, the superiority of natural ventilation, the basic way of traditional residential ventilation, the basic principles of CFD simulation and the evaluation index of building comfort. Investigation and research is a macro-survey of the overall layout and planning methods of settlements and a micro-survey of related parameters of settlement buildings. For software simulation, it mainly explains the choice of solver and the verification of simulation accuracy.

In chapter four, T**he Mechanism of the Cold alley in the Traditional Settlement of Southern Shaanxi.** It mainly explains the mechanism of the role of cold alleys in traditional settlements in southern Shaanxi, China. The first is a detailed introduction to the cold alleys of traditional settlements in southern Shaanxi. The content of the introduction includes the definition and technical points of cold alleys, the spatial form of cold alleys, the types of cold alley spaces, the materials used in cold alleys, the definition and development prospects of modern cold alleys, and the classification of modern cold alleys. Secondly, through the research of traditional cold alleys and modern cold alleys, the design method of cold alleys and the design strategies of its reasonable application in modern buildings are summarized.

In chapter five, **Natural ventilation and cooling in traditional settlements in southern Shaanxi.** It mainly expounds the principle of natural ventilation and cooling of traditional houses in southern Shaanxi. First introduced the natural energy-saving methods of traditional houses. Secondly, it summarizes the influencing factors of natural ventilation and cooling of residential buildings. The factors affecting the natural ventilation and cooling of residential buildings mainly include residential site selection, building orientation, reasonable use of patios, reasonable organization of internal air circulation paths in buildings, and the organization of hot-pressure ventilation. In the past, residential buildings coexisted with the surrounding environment, and various energy-saving methods reached the model of the best effect in the social environment at that time, and many experiences worthy of our reference can be extracted from them. However, the change of lifestyle, the increasingly harsh environment, and the lack of resources prompt us to find some energy-saving methods suitable for the development of modern buildings in traditional residential buildings, and to innovate and transform on this basis. Regardless of whether it is technological innovation or conceptual perfection, we should adopt an inherited attitude and apply it to modern architecture to meet the needs of modern social development. Combining the two in a comprehensive way can bring more beauty to our lives. This will be a continuous process. However, as the times change day by day, some energy-saving methods in residential buildings can no longer be used for direct reference.

In chapter six, **Energy-saving mode of cold alleys in modern settlements in southern Shaanxi.** Introduces the energy-saving mode of modern settlements in southern Shaanxi through cold alleys. It mainly discussed the comprehensive application of cold alley passive energy-saving systems and other building energy-saving methods. It introduces in detail how cold alleys are combined with residential buildings, and calculates the time for ventilation and cooling. Statistics of the total building energy saving throughout the year and the appropriate time to use the system.

In chapter seven, **Conclusion and prospect**. The conclusions of the whole thesis was summarized and the future work have been discussed.

General conclusion:

Reasonable selection and accuracy verification of simulation solver:

- In the simulation of the village wind environment with a complex building layout, among the three steady-state solvers of FLUENT, the wind speed and turbulence intensity values obtained by the SKE solver have the highest reliability, and the degrees of fit are 0.8625 and 0.9088 respectively. The reliability of the RNG simulation is the lowest: the fit of the wind speed distribution is 0.7881, and the fit of the turbulence intensity is only 0.2473. Therefore, for villages with complex building layouts, the SKE solver should be the first choice when simulating wind speed distribution and turbulence intensity distribution.

- When using the RNG solver, the overall obtained turbulence intensity value is higher than the measured value. The simulated value at a height of 1.7m differs from SKE and RKE by 42.61%. The main reason for this is that RNG over-represents the vortex and underestimates the airflow rate in the building interval.

- In the vertical direction, RNG cannot capture the complex wind flow structures that appear in the wake of high-rise buildings and narrow-span streets in complex building areas well, which leads to an overestimation of turbulence intensity values in these locations.

Comprehensive application of cold alley passive energy-saving system and other building energy-saving methods:

- After the building used the new system, the total cooling load, as reduced by the air insulation wall throughout the year, was 1133.7 kWh. After cooling through the cold alley without WHR, the cooling efficiency of the new system was 3.61 °C/h, and the total cooling load in the building in one year was reduced by 55,417.33 kWh. With WHR, the cooling efficiency of the new system was 1.03 °C/h, and the total cooling load was reduced by 28,537.57 kWh. This shows that the WHR has a negligible effect on the indoor temperature.
- Adding a glass roof above the patio can increase its heat storage capacity. The patio completed heat storage after 33.3 min, and then began heating the indoor areas. After using the glass roof for a year, the total heating load of the courtyard for the building was 54,537.78 kWh.
- After the building used the new system without WHR, the time it took for the room to reach the thermal equilibrium temperature was 1.66 h, and the thermal equilibrium temperature was 28 °C. With WHR, the time for the room to reach the thermal equilibrium temperature was 1.94 h, and the temperature was 32 °C. The ventilation time was shortened from the original 2.22 h to 4 min; this also shows that the indoor heat transfer rate of the room has nothing to do with the ventilation rate.
- The temperature range for thermal comfort in Shuhe is 18–25 °C. The total time in the base case meeting the thermal comfort temperature over a year was 2349 h, accounting for 26.81% of the total time of the year. After using the new system without WHR, the annual time meeting the thermal comfort temperature was 2455 h, accounting for 28.02% of the annual time, and an increase of 106 h relative to the base case. With WHR, the annual time meeting the thermal comfort temperature in a year was 2420 h, accounting for 27.62% of the year, an increase of 71 h relative to the base case. The location of the room affects the temperature in the room, and the thermal comfort time of all rooms decreases after considering the WHR.

2. Prospect

In this study, a village with a complex distribution of buildings was selected to simulate the distribution of wind environment, and the steady-state solver most suitable for the village was selected. However, this does not represent all villages with a complex distribution of buildings. Subsequent research is also dedicated to finding the optimal steady-state solver, which will be more detailed, organized, and logical. It will provide a reference for the accuracy and reliability of the simulation of the village wind environment with a complex building layout. At the same time, for the passive energy-saving system of cold alleys, it also needs follow-up improvement work. In the future, we still need to pay a lot of work to accomplish the above goals. we will continue to study as follows:

- More villages need to be selected and classified according to the characteristics of building layout, climate division, topographical conditions, number of buildings, and street size.
- Summarize the characteristics of villages presented by different classifications, use three solvers to calculate the same type of villages, and find out the relationship between similar villages and solvers.
- Summarize the calculation results and find the most suitable steady-state solver corresponding to different types of villages.
- This research needs to be verified in actual operation. The detailed renovation design of buildings will be the focus of future research. It will consider the heat insulation and air-tightness of the materials, minimizing changes to the original building shape, and retaining the unique regional characteristics of traditional buildings.
- This study was mainly aimed at completely passive cooling. Owing to the limitations of the air temperature in the cold alley, the room temperature did not reach a comfortable range. In the future, it will be necessary to combine passive cooling with air conditioning to make the room reach a comfortable temperature and calculate the energy consumption of the air conditioning so as to save the energy used by air conditioning to the greatest extent.