RESEARCH ON THE SPACE-CLIMATE CONFIGURATION CASE OF SHANGHAI SHIKUMEN RESIDENCE

A Thesis Submitted to

Politecnico di Torino

For the Degree of Master of science program in

ARCHITECTURE CONSTRUCTION CITY

BY

YU Yang

Supervised by

Prof. Marco Trisciuoglio (DAD)

Prof. ZHANG Tong

Senior Architect LI Bao-tong

College of Architecture

Politecnico di Torino

June 2023

Abstract

In the process of long-term interaction with the natural environment, traditional dwellings have formed a construction wisdom based on "space" and "construction" to deal with the climate. With the development of urbanization, the regulation of modern buildings on the environment has gradually changed to air conditioning which brings huge energy consumption.

Shikumen is a typical representative of the urbanization transformation of traditional folk houses. In the face of the change of the background environment to high density block, the construction strategies inherited from traditional houses to deal with the climate have also been adapted. This research divides Shikumen into early and late types according to the classification of Shikumen, and sorts out the types of residential buildings that are closely related to Shikumen. Two types of dwellings are included in the research scope together with the above two types of Shikumen dwellings. Four types of typical samples are representative from the perspective of time and space which is basis for exploring the space-climate configuration of Shikumen.

Based on the inherent four levels of Shikumen dwellings, reasonably divide the scope, level and object of sample research, extend the vision of space-climate regulation from individual to group, and explore the complete Shikumen environmental regulation spatial sequence. From the synergistic perspective of "climate-space-energy", combined with the means of interactive verification between actual survey and simulation, from the dimensions of space climate selection, physical space type, space climate gradient, climate control interface, and performance-oriented structure, horizontally compares the advantages and disadvantages of sample in space climate regulation. Based on the sample with the best performance, quantitatively analyze the relationship between the spatial construction elements of the sample and the performance of wind, light, and thermal environments, and combine the advantages of the remaining samples to limit the range of spatial construction elements for Shikumen climate adaptability, and explore Shikumen Lilong dwellings climate configuration.

On the basis of the prototype, the innovative technical method of the energy configuration diagram is used to couple the section diagram showing the characteristics of the classic modern structure with the simulation calculation analysis of the prototype performance, realizing the key transfer of green building research from theory to method. Provide "Shikumen samples" for the selection of space-climate configurations in hot summer and cold winter climate regions.

Keywords: space-climate construction, space-climate mechanism, Shikumen Lilong dwellings, environment regulation, energy configuration diagram

Content

Chapter1. Introduction

1.1 Origin of the subject

1.1.1 Research Background

Human construction behavior can be divided into two basic processes, one is space construction following the "law of gravity of form", and the second is environmental regulation following the "law of energy of form" [1]. A large number of residential buildings, as the main body of human construction behavior, have undergone long-term interaction with the natural geography, climate environment, folk culture, and construction techniques of the region, which contains the mechanism of adapting space and climate. It is an important traditional wisdom of folk houses to save and transfer energy through space, and to adjust the indoor climate environment to meet the needs of space comfort. Some of the characteristics of the dominant form type of houses are the expression of climate adaptability.

However, since the industrial revolution, with the accelerated exploitation and utilization of natural resources, the wisdom of traditional residential space climate regulation has been ignored, and the regulation of the environment by buildings has shifted from the space regulation dominated by "space" and "construction" to the equipment system. The transformation of air-conditioning has brought about huge energy consumption and the loss of the autonomy of the architectural discipline. Since the beginning of the 21st century, the scale of Chinese green building construction has continued to expand, but the actual benefits are not satisfactory. Due to the long-term goal of saving energy and reducing consumption, the development of green buildings is mostly reflected in the innovation of energy types and the improvement of energy efficiency of equipment systems, especially in hot summer and cold winter regions in my country, where urban population is dense and energy consumption is huge. How to make the development of green buildings return to "space" and "construction" are urgent problems to be solved for green buildings.

The advancement of the research for this research was done under the joint supervision of Prof. Marco Trisciuoglio (Politecnico di Torino) , Prof. ZHANG Tong(Southeast university) and Senior Architect LI Bao-tong(Southeast university).The research direction of this thesis is based on the Natural Science Foundation of China project " Research on the Archi-climate Model of Space Configuration in Hot-summer and Cold-winter Zone Based on the Principle and Adaptive Analysis of Energy Formation " hosted by Professor Zhang Tong. (project

[1] Zhang Tong. Environment Regulation and Space—conditioning：the Disciplinary Autonomy and Design Methodology of Sustainable Architecture [J]. Architect, 2019(06):4-5.

approval number: 52178007). The project research directly points to the "climate adaptation-spatial form-energy construction" synergistic mechanism that drives the development of architecture, crosses the knowledge boundary between architectural space form, climate, and energy, and reveals the physical changes caused by energy flow and the structural adjustments. The translational structure between the environmental changes brought about, constructs a mechanism model of the interrelationship of "climate-space-energy", which is defined as "space-climate configuration". The sub-task "Building a space-climate sample library for hot summer and cold winter climate regions" focuses on selecting typical representative dwellings in hot summer and cold winter regions, studying their space-climate mechanism, constructing energy structure diagrams, and choosing the correct space for hot summer and cold winter regions Climate configurations provide a clear and systematic sample library. This research undertakes the research of the space-climate configuration case of SHANGHAI Shikumen residence.

1.1.2 Research Significance

This research starts from the perspective of the combination of the architectural environment regulation theory and the related theory of architectural form typology, based on the Shikumen residential buildings in Shanghai, one of the typical residential representatives in the hot summer and cold winter regions, through the study of the architectural space and thermal comfort of the Shikumen residential buildings. In order to conduct qualitative and quantitative analysis on the space-climate mechanism of Shanghai Shikumen residential buildings, clarify the relationship between the spatial form characteristics of Shanghai Shikumen residential buildings and the adaptability of bioclimate, draw the energy configuration diagram of Shanghai Shikumen residential buildings, and realize the key transfer of green architectural research from theory to method promotes the development of green building design dominated by space adjustment, and plays a role in regulating and guiding the practice of green building by revealing the type of "climate-space-energy" relationship; Refining and constructing the energy configuration diagram of Shikumen dwellings provides a "Shikumen type sample" for the correct selection of space-climate configuration in hot summer and cold winter regions.

1.1.3 Research object

During the modernization of Shanghai, the rapid development of the city and the construction industry resulted in the birth of many subdivided Lilong in a short period of time. Shikumen Lilong are one of them. In addition, there are New-style Lilong, Cantonese-style Lilong and other kind of Lilong building in modern Shanghai. The research object of this Thesis is the Shikumen Lilong, as well as the Cantonese-style Lilong and New-style Lilong that have a close relationship with them[2].

Shikumen Lilong are urbanized Jiangnan dwellings, with obvious urban characteristics, and the number of general Shikumen Lilong is huge, carrying the "main body" of the urban population; its unique location characteristics in the urban environment. This makes Shikumen different from other typical traditional dwellings in terms of environmental regulation. Based on the above reasons, and for the purpose of focusing on the performance of the climate adaptability of residential spaces under the urban environment, Shikumen Lilong and two types of Lilong dwellings closely related to it are selected as the research objects.

1.2 Concept analysis and term explanation

1、Environmental regulation

Environmental regulation is to seek a balance between climate and body. There are two main forms: space regulation and equipment regulation. Building environment regulation is to regulate the relationship between the internal environment of the building and the natural environment through the enclosure and opening of space to achieve the comfort of the internal space. This motivation makes the building show regional characteristics such as different degrees of dispersion and differences in the degree of interface opening in different climate zones; and equipment regulation is a way to control the indoor environment by relying on the air-conditioning equipment system.

2、Space-climate mechanism

Architecture is the form solidification and orderly expression of saving, releasing and transmitting energy[3]. From the perspective of "climate-space-energy" synergistic association, the space-climate mechanism refers to the mechanism by which buildings realize the reasonable flow and transformation of internal and external energy in the climate environment through the shaping and organization of space, revealing the translational structure between space form changes and environmental changes. The space-climate mechanism mainly includes the following five dimensions:

（1）Space climate selection

Climate is a representation of the flow of atmospheric energy on the surface, and the site selection, orientation and layout of buildings (groups) affect the energy flow between buildings and the environment. Environmental climate selection refers to the specific response measures for buildings to select favorable climatic elements, weaken or avoid unfavorable climatic elements in site selection, positioning and building group combination.

[2] The relationship between the morphological evolution of Shikumen Lilong, Cantonese-style Lilong, and New-style Lilong is discussed in Section 3.2

[3] Zhang Tong. Environment Regulation and Space—conditioning：the Disciplinary Autonomy and Design Methodology of Sustainable Architecture [J]. Architect, 2019(06):4-5.

（2）Physical space type

Reasonable building shape and spatial organization are the way, medium and result of building adapting to climate and realizing environmental regulation. The physical space type is the form solidification and orderly expression of the energy accumulated, transmitted and released during the long-term climate-form-energy interaction. It is mainly reflected in the type characteristics of the energy shape efficiency and the ratio of virtual and solid spaces formed in the process of climate adaptation of buildings in various places.

（3）Space climate gradient

According to the energy and comfort differential requirements of different spaces inside the building, the climate gradient inside the building is constructed through reasonable space configuration, so that the areas with strict environmental control requirements are surrounded by non-strict control areas and climate buffer zones. It is reflected in the reasonable form and distribution of thermal regulators and thermal receptors with different spatial functions and levels of thermal comfort requirements.[4]

（4）Climate control interface

Refers to the strategy and technology of design of the material, structure, shape and organization of the building envelope, buffering and regulating the internal and external climate, and dynamically balancing the process mechanisms of wind, light, and heat to improve comfort and reduce energy consumption.[5]

（5）Performance-oriented structure

Aiming at heat transfer methods such as conduction, convection, radiation, and evaporation, through the form and opening and closing methods of building structures, it is a technical strategy to strengthen or inhibit energy flow and regulate indoor and outdoor climate environments.

3、Morphological type

Morphological type was first applied in the study of urban morphology, which combined the typological theories of the British M.R.G. Conzen school and the Italian Muratori school. It is an important theoretical method for the western cognition of urban form formation and evolution.

Morphological typology is based on the diachronic and synchronic evolution of architectural forms to recognize and study cities and buildings, as opposed to functional typology, which describes buildings on the basis of functions.

4、Space-climate configuration

[4] Xiao Wei, Zhang Tong. Performance Mechanism of Building Formation and Key Strategies of Adaptive Formation Design [J]. Architect, 2019(06):16-24.

[5] Cai Shiran, Zhang Tong. THE NATURAL DIMENSION AND SUSTAINABLE DESIGN STRATEGIES OF GREEN INTELLIGENT BUILDING [J]. Urb Arch, 2018(16):5.

Space-climate configuration is a form and space prototype that embodies climate rationality formed by the long-term interaction between buildings and the environment in various regions. It comprehensively reflects the energy flow, transformation and utilization process of climate adaptability inside and outside the building, and is a material configuration that reflects the overall balance of regional resources. Through energy configuration diagrams and numerical analysis techniques, the translation structure between the physical changes caused by energy flow and the environmental changes caused by configuration adjustments is visualized.

5、Shikumen Lilong

Shikumen dwellings are often called Shikumen Lilong, and Shikumen refers to doors with stone masonry as the door frame. Later, "Shikumen" is used to refer to residential buildings in Shanghai with such characteristics. Its spatial form is inherited from traditional Jiangnan dwellings, and it is equipped with introverted outdoor spaces such as courtyards and patios. According to the different construction time, there are early and late points. The main differences are reflected in the arrangement of the general plane orientation of the group and the scale of individual bays. The Cantonese-style Lilong and new-style Lilong that appeared at the same time as Shikumen are closely related to Shikumen Lilong in terms of spatial form, and the two present more characteristics of urbanization transformation.

1.3 Related Research Status

1.3.1 Research on bioclimaticism

Bioclimatology is a discipline that studies the relationship between the characteristics of biological activity and the characteristics of the climate environment in the region. The Olgyay brothers' Application of Climatic Data to House Design (1954), looking at the solar analysis table from the perspective of the silhouette of a human face, seems to represent a challenging proposition: Architectural Elements that accurately respond to environmental elements can become as important a design paradigm as classical style was once.[6]

Victor Olgyay first proposed the theory of "bioclimaticism" in his 1963 book " Design With Climate: Bioclimatic Approach to Architectural Regionalism ". He combined architecture with biology, meteorology and other disciplines, explored the relationship between architecture and climate, and finally formed a complete architectural design theory. He invented the "bio-climate map", which is an important manifestation of the comprehensive integrity of his theory.

Baruch Givoni continued and further promoted the development of Orgoya's design method in the book "Man Climate and Architecture", He introduced human comfort and passive

[6] David Leatherbarrow and Richard Wesley, Performance and style in the work of Olgyay and Olgyay[J]. arq, 2014, 18(2): p170.

design strategies into the bioclimate design diagram, forming the "bioclimate design method" (Givoni method).

Gail S. Brager, from University of California, Berkeley, argues that architecture is an active agent of human-environment interaction in his article " Thermal adoption in the built environment: A literature review ".

Bernard Rudofsky emphasized the passive regulation of architecture and the autonomy of architecture in his book "Architecture Without Architects: A Brief Introduction to Unorthodox Architecture";Hassan Fathy's book "Designing Architecture for the Poor" believes that the form of architecture is the embodiment of local materials and local technology. Architecture should absorb local culture and use local materials and construction techniques. And show the characteristics of adapting to the regional climate.

In the book " Bioclimatic architecture ", Professor Yang Liu systematically expounded the basic principles of the influence of my country's climate on architectural design, as well as the classification methods of climate. The book also introduces the climate regulation strategies of representative dwellings and their application in design, and sorts out the priorities and regulation capabilities of various regulation measures in different climate zones. These contents provide a theoretical basis for how to use the relationship between buildings and natural climate to build low-energy ecological buildings.

Min Tianyi, Ph.D. of Southeast University, conducted a research on the response of the "open" paradigm of the rural architectural construction system in the Taihu Lake Basin to the climate in the article "Research on the "Opening" Paradigm of Architecture in Response to Climate——Taking the Construction System of Local Architecture in the Taihu Lake Basin as an Example". It is believed that the "opening" paradigm of architecture embodies the regulation of architecture on the natural and human environment from three aspects: the prototype paradigm, the technical paradigm and the cultural paradigm.

1.3.2 Research on Energy Construction and Environmental Regulation

The Greek architect Vitruvius first discussed the relationship between climate principles and architectural design in " De Architectura". British modern architectural historian Reyner Banham put forward the view that the history of architecture is the history of environmental regulation. He proposed a "selective" mode of environmental regulation, that is, the artificial environment and the natural environment adapt to and utilize each other, rather than being self-contained.

Dean Hawkes divided architectural climate interface into "selective interface" and "isolated interface" in his book "The Environmental Tradition: Studies in the Architecture of Environment" and " In The Selective Environment: An Approach to Environment entail Responsive Architecture " , and the relationship between building interface and the climate environment is studied.

Professor David Leatherbarrow discussed the relationship between environmental regulation and architecture in " Architecture Oriented Otherwise ", and believed that only relying on technical equipment to isolate buildings from the environment would lead to the decline of architectural space, and the comfortable perception of people require the interaction between architecture and the environment. At the same time, the construction of the architectural environment should not only be the construction of form, but also the construction of expressing the way of life.

In the book " Holistic regionalism of architecture", Professor Zhang Tong of Southeast University pointed out that architecture is closely related to the natural ecology, cultural resources, people and technology of the region. He called on people to consciously explore the possibility of combining with the local wisdom of the local natural environment, culture, technology and art while developing architecture, so as to realize the sustainable development of human settlements in both natural ecology and social ecology. In addition, Professor Zhang Tong attributed the purpose of human construction to space creation and environmental regulation in the paper " Environment Regulation and Space—conditioning：the Disciplinary Autonomy and Design Methodology of Sustainable Architecture " in the environmental regulation column of the journal "Architects", and combined the "energy law of form" with "the law of gravity of form" emphasizes the autonomy of the discipline of architecture in space creation and environmental regulation.

Professor Song Yehao from Tsinghua University analyzed the purpose and strategy of ecological design in " Holistic design with nature-research on the ecological approach of architectural design ", and discussed it from both macro and micro levels. Professor Li Linxue of Tongji University believes that architecture is a kind of material organization in "Air through the Lens of Thermodynamic Architecture Design Against Smog ", which forms the order of energy flow through organizational structure and maintains the balance of material forms.

Dr. Zhong Wenzhou from Southeast University emphasized the importance of the energy law of architectural form in his doctoral dissertation "Form and Energy: Research on Architectural Model of Environmental Regulation", and reconstructed the context of architectural development from the perspective of environmental regulation from the perspective of energy, and Using interdisciplinary knowledge, the mathematical relationship between architectural form factor and energy flow is revealed, and a thermodynamic model reflecting the architectural environment regulation strategy is extracted through numerical simulation and quantification.

1.3.3 Research on Townhouses in China and the UK

In 1982, British architectural historian and writer Stefan Muthesius focused on the differences in the origin, development and geographical distribution of British Terraced houses in the Georgian and Victorian periods in his book "The English Terraced house".Explain the background and origin of the earliest terraced house in the UK, and introduce the impact of social needs, industrialization transformation, regulatory regulations, indoor comfort and health and hygiene on townhouses. Then combined with typical cases from the plane, elevation and regional distribution characteristics of standard townhouses and small townhouses. The book comprehensively discusses the differences in the time distribution and spatial distribution of terraced houses, and it is an in-depth study of the development and changes of British terraced house types in the 18th and 19th centuries.

In 2002, Nie Lansheng mainly discussed the origin and development of Townhouse in Europe in the article "THE ORIGINS AND DEVELOPMENTS OF TOWN HOUSES", and focused on its dissemination and promotion in Japan and China. He briefly described the differences in the morphological characteristics and naming methods of Townhouses in different historical periods and regions, and list the Terraced house in the United Kingdom, the Row house in the United States, and Lilong in China as local interpretations of Townhouses.

In the article "Evolution and Development of Townhouse" in 2003, the author Liu Erxi traced the historical origin of Townhouse in the article, classified and explained the characteristics of the location, function, shape, courtyard and interface of Townhouse, summarized the laws, and explored its role in human settlements. The value from the perspectives of environment, urban form, ecological environmental protection, etc. It led to the discussion of the practical significance of Townhouse, and discusses the evolution direction of Townhousefuture ecology and personalization. Finally, analyze the current situation and shortcomings of the Chinese Townhouse represented by Lilong, and think about the direction and resistance of its development.

In 2004, Zhou Yihu of Tsinghua University published her book " Townhouse & condominium ", focusing on the planning and single design of townhouses and condominium built in Europe and the United States, as well as their development history. At the same time, the example of Shikumen Lilong, the earliest mass-built row house in China, is sorted out. From the overall planning of low-rise and multi-storey residential areas and the functional requirements of modern residential units, combined with the analysis of examples of low-rise multi-storey houses. It is a good for the planning and design paths and methods of townhouse.

In the 2007 article "Research on Collective Housing in the United Kingdom", the author Li Xin took time as a clue to sort out the three main development stages of collective housing in the UK: the embryonic period, the large-scale construction period and the diversified period, and discussed the social background of three stages. And also sorting out the role of factors such as economy, politics, and planning trends in the process of changing the shape of collective housing in the UK, and exploring the essential factors that determine the collective housing in the UK.

In the book "Housing in Britain : progress and patterns" published in 2011, the author Sato Takemasa briefly described the formation of townhouses and square development models, the traditional urban living model in Britain from the 17th to the 19th centuries. And then he outlined the developments of Residential construction, housing under the influence of modern Utopia mode, housing between the two world wars, housing after World War II, housing that deviates from the modern mode under the influence of the Public Health Act. He focused on sorting out the model and process of British housing development from 18^{th} to 19^{th} century.

In 2011, " Research on Stylization of Collective Residence & Related Structural Application ", the author Wu Xijia briefly described the style of British collective housing in the article. The collective housing that began to be built in large quantities in the Victorian period was divided into high-density housing for workers and investment housing according to the type of development. Among them, investment housing can be divided into villas, detached houses, semi-detached houses and terraced houses according to the volume. Among them, terraced houses are the most economical in land use, and they are also the British town houses.

In 2014, in the book " British housing and living environment ", Li Lingyun divided British dwellings into six types. At the same time, the development of British housing from the Middle Ages to modern society is regarded as the return of the pastoral. It also discusses the climate and environment characteristics of the UK from the aspects of natural conditions, sunshine, etc, and analyzes the layout logic of British residential streets, and then lists the existing housing examples in the UK in detail, records the plane, the general layout and other information. Discuss the characteristics of British houses in terms of backyards, facade details, etc.

In 2016, British architectural art historians studied the changes in the physical form of British residences from 1000 AD to 1945 in the book "Vernacular Architecture in the United Kingdom", and took climate factors and address factors as the main factors affecting the form of vernacular architecture. Describe the medieval (1100-1600) wooden houses of box-framing and cruck-framing ,two-room dwellings brought by the popularization of new sliding windows in the 17th century, Georgian (1660-1830) masonry terraced houses, Victorian (1830-1900) sprawling terraced houses, Edwardian and interwar Suburban houses (1900-1945) and low-rise and high-rise houses built after 1945. He focused on the development and changes of British vernacular architecture, but also the source and destination of townhouses,one of the types of British vernacular architecture, are discussed in a more macro timeline.

1.3.4 Research on climate adaptability of residential buildings

Willi Weber, an architect and professor of architectural physics at the Institute of Environmental Sciences of the University of Geneva in Switzerland, took the climate adaptation of vernacular architecture as the research object in the book Lessons From Vernacular

Architecture (2014) , he believes that the construction of buildings should be aimed at adapting to the environment rather than confronting the environment. The book studies the climate adaptability cases of typical vernacular buildings around the world, draws experience from traditional and vernacular buildings, and contributes to the creation of new climate adaptation architecture.

Dr. Zhao Qun from Xi'an University of Architecture and Technology, in the article "Research on the Experience of Traditional Residential Ecological Architecture and Its Model Language", used the typology method to analyze the prototype of the traditional residential building form, extracted the prototype of the climate regulation technology of the traditional residential building, and traditional dwellings can be macroscopically divided into two types: enclosed type and sheltered type.

In the article " The Research of Architectural Thermodynamic Model of Huizhou Vernacular Architecture ", Dr. Shou Tao from Southeast University started from the architectural environment control theory, took Huizhou Vernacular Architecture as the research object, established a "building thermodynamic model" composed of five layers, and explored the logic of architectural form construction and its thermodynamic mechanism from the perspective of environmental regulation.

Liu Qiao and Chen Bin, masters of Southeast University, research on the regulation mechanism of the building environment in hot summer and cold winter regions, hot summer and warm winter regions, cold regions and severe cold regions, and generated a building thermodynamic model driven by performance regulation and form generation interaction through numerical quantitative analysis of thermodynamic models in " THE ANALYSIS OF THERMODYNAMIC MODEL OF ARCHITECTURE IN CLIMATE REGION OF HOT SUMMER AND COLD WINTER , CLIMATE REGION OF HOT SUMMER AND WARM WINTER " and " A RESEARCH ON THERMODYNAMIC MODEL OF ARCHITECTURE IN COLD REGIONS AND SEVERE COLD REGIONS ".

1.3.5 Research on Shanghai Shikumen Lilong

In 1986, Wang Shaozhou and Chen Zhimin focused on the generation, development, type characteristics, design processing, and construction methods of the residential types of Lilong buildings that appeared in modern Shanghai, Tianjin and other places in the book "Lilong Architecture".Among them, Shikumen Lilong dwellings are taken as a typical representative, and detailed descriptions are made in terms of space characteristics, environmental treatment, and structural materials. Divide Lilong in Shanghai area into early old-fashioned Shikumen, later old-fashioned Shikumen, new-style Shikumen, Cantonese-style and new-style. Explain the differences between the five, and for the first time extract some typological characteristics of Shikumen Lilong in terms of overall layout and individual shape.

Wang Shaozhou and Zhang Ming, in their "Shanghai Modern Architecture History Draft" in 1987, investigated the time and space background of Shanghai city and divided the Lilong into Shikumen Lilong, new-style Lilong, garden-style Lilong and apartment-style Lilong. They further divided Shikumen Lilong into old-style and new-style, and evaluated the group layout of different types of Shikumen dwellings from the perspective of architectural space comfort.

In 1989, in the book "Shanghai Modern Urban Architecture", Wang Shaozhou recorded the development and changes of the Shikumen Lilong dwellings from the opening of Shanghai to the hundred years before the founding of the People's Republic of China with pictures and texts, expounding the historical changes of Shikumen dwellings vertically, expressing horizontally the typological characteristics of different Shikumen dwellings in the same period.

In 1993, in the book "Shanghai Lilong Houses", Shen Hua briefly sorted out the history of the development of the Lilong and the distribution of the existing Lilong, and provided detailed examples of 42 typical Shikumen Lilong dwellings, including technical drawings such as horizontal and vertical sections which provided detailed data for the follow-up research on Shikumen Lilong.

In 1996, Yang Bingde described the typical Shikumen Lilong dwelling samples in Shanghai, Wuhan and Tianjin in his book "Shikumen Lilong Residential Houses", analyzed the social background of Shikumen's birth, and sorted out the development of new urban residential buildings in China at the turn of the century. From the aspects of architectural space, the human touch of inner alley space, architectural details and architectural cultural phenomena, it expounds the significance of Shikumen dwellings in reflecting the Chinese people's ability to absorb foreign culture, internalize it into the needs of the nation, and incorporate it into the traditional way of life.

In "Shanghai Longtang" written by Luo Xiaowei and Wu Jiang in 1997, starting from the artistic value of the houses in Lilong, they summarized and sorted out the artistic characteristics of the houses in the Lilong, such as their culture and decorative construction methods.

In 1997, in the book "History of Shanghai Architecture: 1840-1949",Professor Wu Jiang from Tongji University conducted a comprehensive analysis of the historical process and background of Shikumen residential buildings in modern Shanghai.

In the book "Old Shanghai Shikumen" in 2004, the authors Lou Chenghao and Xue Shunsheng took Shikumen as the research object and discussed the process of its origin and evolution.And from the aspects of space form, structure characteristics and form characteristics, it makes a detailed analysis of the material space composition of Shikumen Lilong by category. Combined with a large number of case studies to analyze the unique charm of Shikumen Lilong. A large number of early Shikumen cases in the book have been dismantled, and the precise drawings and real-time photos preserved in this book have become important materials for studying the spatial characteristics of early Shikumen Lilong.

In the book " Conservation and renewal of LiLong Housing in Shanghai " in 2004, Fan Wenbing sorted out the origin, development and decline of Lilong from the perspective of historical building protection.And put forward the basic principles of lilong protection.

In 2004, Dr. Cao Wei from the Faculty of Engineering of the University of Tokyo summarized the relationship between Shanghai housing and Chinese and Western traditional buildings in his book "Shanghai housing after its opening to foreigners".Reviewing the twists and turns of the development of modern architecture in Shanghai. At the same time, the distribution and current situation of the existing houses in the Lilong were sorted out, and a large number of surveying and historical background materials of Shikumen houses were formed.

In her 2007 master's thesis "The Evolution and Inheritance of Shanghai Lane Residences", Luo Shanshan, starting from Shanghai's geographical climate and historical and cultural background, classified and summarized the architectural morphological characteristics of Shanghai Lilong Residences and analyzed their morphological evolution. It is pointed out that the development direction of Lilong is compact layout, detailed functions, and open and modern appearance.

In 2009, Deng Qingtan gave a concise overview of the emergence and evolution of the Shikumen Lilong Residence in the book "Illustration of the history of China modern architecture". He describes the multi-level development and evolution of Shikumen Lilong dwellings, such as the spatial shape and structural details resulting from the advancement of social processes. And he formed a clearer evolution from Jiangnan dwellings to Shikumen Lilong dwellings.

In 2015, Associate Professor Liu Gang from the School of Architecture and Urban Planning of Tongji University wrote in the article " FROM INDIVIDUAL CONSTRUCTIONS TO URBAN CLUSTERING:AN EMPIRICAL STUDY ON A GROUP OF RESIDENTIAL BUILDINGS OF EARLY MODERN SHANGHAI " , carried out an empirical study on the urban morphology of the typical Shikumen Lilong "Chengdeli", define the heritage value of Shikumen Lilong dwellings, and propose a reasonable way to protect them. In the following year, in his article " Reflection on Shanghai Shikumen Lilong Rehabilitation ", he analyzed the spatial characteristics of Shikumen Lilong, the type of housing and the termination of development and construction, and the process of social space change. And other aspects to discuss the important issues of "preservation" and "abolition" in Shikumen Lilong.

In 2017, in the article " Residential Building Spectrum in Early-Modern Shanghai in the Context of Urban Spatial Evolution", Associate Professor Liu Gang expounded on the background of the modern urbanization of Shanghai and explained the main line of residential architecture in modern Shanghai is based on the development of Shikumen Lilong-New-style Lilong-New villages, and also discussed the influence of local houses, Shikumen Lilong mansions, verandah-style townhouses and garden houses in this process. Finally constructed the genealogy of modern residential building types.

"Evolution of Shanghai architecture in modern times" written by academician Zheng Shiling in 2020 is a panoramic treatise on the development of modern Shanghai architecture. In the chapter "Traditional Architecture and Chinese Classical Revival" in the book, the Lilong dwellings are regarded as the representative of the intersection of Eastern and Western architectural cultures, and the research is focused on the early Lilong houses and the later Lilong houses. Combining representative sample cases to discuss the morphological characteristics, architectural style characteristics, evolution process and social background that promote the evolution of the house shape in the early and late Lilong dwellings.

In 2023, Academician Chang Qing re-examined the origin and flow of Shanghai Shikumen Lilong in the paper "Transformation process and regeneration models (in Chinese)".The source and connotation of the word "Shikumen" are traced, and the contradictions and methods of the transformation and activation of the existing Shanghai Shikumen are discussed, and critical design strategies and suggestions are put forward.

1.3.6 Summary

On the whole, the research on architectural environmental regulation theory and bioclimaticism is very rich and has a clear framework; the academic circle has formed a deep understanding of the value of traditional wisdom on the space-climate adaptability of traditional dwellings to green buildings and sustainable development .Domestic research on the space-climate adaptability of traditional Chinese dwellings has been carried out in some areas of the country. The research background information on the history of Shanghai Shikumen Lilong and the types of architectural forms is also relatively rich, but most of them are discussions on the development of Shikumen Lilong based on the integration of political, economic and cultural developments based on time.The research on the climate adaptability of Shikumen Lilong space based on the law of form energy is still blank. In addition, the research on the protection of Lilong dwellings represented by Shikumen is rich, but most of them are limited to the protection and utilization of space, function and form.The research on how to improve the environmental quality of the indoor physical space of Shikumen Lilong dwellings by means of space-climate regulation is still to be filled, and this is also one of the goals of this research. Shikumen dwellings, as one of the typical dwellings in hot summer and cold winter regions, have considerable research value on the space-climate mechanism and the typological characteristics of space-climate adaptability.

1.4 Research methods and technical paths

In order to adapt to the background and significance of this study and ensure that the research method is compatible with the objective conditions, the author will adopt the following five basic research methods:

1. Literature reading method

Read domestic literature and materials related to the bioclimatic characteristics of the Shanghai area, the fusion process of traditional houses in the south of the Yangtze River and Western architecture in Shanghai Shikumen dwellings, the distribution and preservation of Shikumen dwellings, and the shape and structure of Shikumen dwellings. The theoretical background and foundation of the study are then established.

2. Case study method

Aiming at the correlation mechanism between climate factors such as wind environment, light environment and thermal environment of typical Shikumen dwellings and the spatial form of Shikumen dwellings. Select representative cases in the contemporary context to carry out detailed research analysis and research.

3. Fieldwork

Visiting and investigating the existing traditional Shikumen dwellings, from the perspective of architectural morphology and typology, conduct relevant research and analysis on the architectural typology characteristics of existing Shikumen dwellings in different historical periods. Select the most representative residential samples for on-site surveying and data collection, and collect the physical environment comfort data of the main space nodes of the building on typical climate days. At the same time, the subjective feelings of wind, light, and heat in the target building environment are obtained through field investigations, and first-hand information is obtained.

4. Performance simulation analysis

Use EnergyPlus, Openstudio, blueCFD, Ladybug, Honeybee, Butterfly and other performance simulation software to perform quantitative performance simulation of Shikumen space climate mechanism, and provide visual graphic language to provide scientific basis for research results.

5. Energy configuration diagram

The energy construction diagram method is a method that couples the classic section diagram showing the construction characteristics and the performance simulation calculation analysis diagram, and describes the performance diagram from the two dimensions of space and time respectively. Put environmental performance and comfort perception in the dynamic dimension of space and time, and reveal the changes in different areas of the building environment performance in a certain section of heat flow cycle.

The technical path of this research is mainly divided into two parts. The first part is the theoretical analysis of the space-climate mechanism in Shikumen Lilong and the construction of actual measurement and simulation methods, and establishes the theoretical and data basis for exploring the space-climate mechanism. The second part is to verify the space-climate mechanism of Shikumen through numerical simulation and field survey, and to explore the climate adaptability range of Shikumen building configuration factors. Finally, the core result of this research is refined to form a sample of Shanghai Shikumen residential space climate construction.

Chapter2. Analysis and Methodology Construction of the Theory of Spatial-Climate Construction

2.1 Theoretical analysis of space-climate construction

2.1.1 Bioclimatology and bioclimatic design

Bioclimatology was first proposed by Hippocrates. Bioclimatology is an interdisciplinary subject of climatology and ecology, which studies the impact of climate and environment on organisms. In the field of architecture, bioclimatology focuses on the relationship between human beings, climate and architecture, with the main goal of studying how architecture adapts to the law of climate change and meets human needs. Its research explores how buildings in different climates create architectural paradigms with regional characteristics to adapt to the needs of human activities. In the stage of architectural design, the characteristic organization of construction elements is carried out to adapt to the characteristics of regional environment and climate, and the design that meets the needs of human comfort is called bioclimatic design. Bioclimatic design is a specific application of the architectural environment regulation theory.

Bioclimatic design is similar to bionics, that is, buildings imitate the characteristics of bioclimatic adaptability, so that buildings can have biological climate adaptability, and can respond to natural stimuli like living things. Then dynamically control the input and output of matter and energy, and finally achieve the goal of reducing energy consumption. Bioclimatic design provides guidance for building orientation, interface opening degree, sun shading and other design aspects that affect building thermal performance through quantitative analysis of the climate environment in which the building is located. The bioclimatic design of buildings is the product of the combination of bioclimatic adaptation research and architecture.

The key to architectural bioclimatic design is the analysis and research of architectural climate adaptability. The method of quantitative analysis of climate environment was first proposed by Olgyay in 1953, that is, Bio-Climatic Graph (Figure 1), which draws the physical environment performance factors of temperature, humidity, wind speed, solar radiation and human comfort range in a unified chart, and at the same time provides passive adjustment strategies such as sunshade and window ventilation for non-comfortable areas in the chart. In 1969, in the building bioclimatic design chart, Givoni unified the active and passive adjustment methods of buildings such as humidification, passive and active solar energy, traditional heating and air conditioning, and thermal insulation materials into a single psychrometric chart .Clarify the applicability of the above-mentioned environmental control measures in architectural design, and the clear expression of the relationship between architectural control strategies and environmental climate parameters in this chart makes it a mainstream form of space-climate analysis today.This research also adopts the above method in the analysis of environmental performance factors and urban and architectural space comfort in Shanghai.

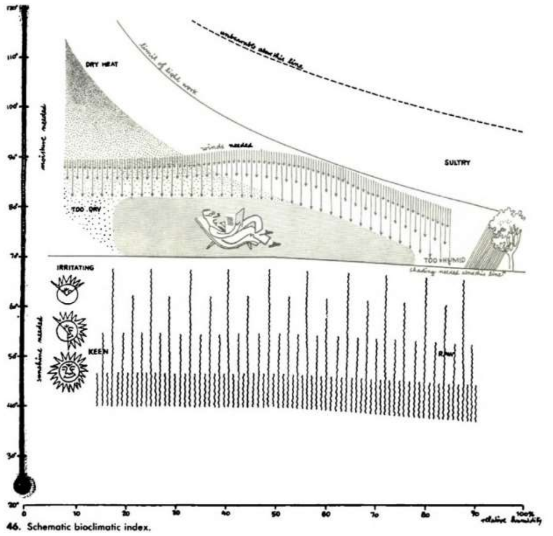


Figure 1 Olgyay Bioclimatic chart (Source: Olgyay V, Olgyay A, Lyndon D, et al. Design with Climate: Bioclimatic Approach to Architectural Regionalism)

2.1.2 Human thermal comfort theory

The natural environment in which the human body lives is composed of many factors with complex relationships, such as sound, light, climate, space, etc., all of which directly affect the human body. The shelter that can reduce the adverse effects of the above-mentioned natural environmental factors has become a key system that regulates the relationship between the human body and the natural environment. Through the regulation of the shelter, its internal environment can be maintained within a range that is relatively in line with the comfort needs of the human body. Cities and buildings are the main types of shelters in modern society. The space environment in which human beings live today can be defined by three levels of thermodynamic systems, namely the external energy system (climate), the city-building control system (city-building), and the human body response system. (comfortable)（Figure 2）。

Human beings have long pursued the thermal comfort of indoor space and urban space. As early as in ancient Rome, Vitruvius discussed in the "Ten Books of Architecture" that urban site selection should consider sufficient light, the relationship between street layout and public buildings etc. The research on the theory of human thermal comfort began when Arbuthnot pointed out the cooling effect of air flow in 1733. In 1914, Theodor W. Adolph first proposed the concept of "effective temperature", which included relative humidity, wind speed and radiation into the discussion of thermal comfort. In the 20th century, the American Society of Heating and Ventilating Engineers (ASHVE) obtained data related to human comfort through a large amount of data, and released the standard "Thermal Environmental Conditions for Human Occupancy" for the first time on thermal comfort. The standard has been revised many times since then, and the latest version 55-2020 defines: in the general living environment of office buildings, the thermal comfort temperature range of the human body is: winter: 20-24°C; summer: 23-26°C (73-79°F); mid-season: 20-26°C (68-79°F), with comfortable relative humidity ranges of 20-40% in winter and 20-60% in summer.

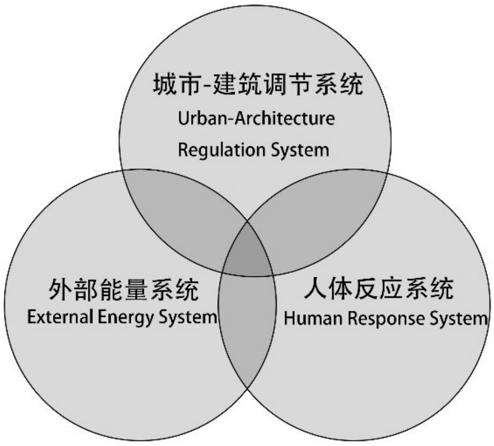


Figure 2 City-Building Environment System Model Source: Self-painted

2.1.3 Human thermal comfort conditions

Human body thermal balance and human body thermal sensation are factors closely related to human thermal comfort. Human body thermal balance is a dynamic equilibrium state in which the human body maintains its normal body temperature by consuming energy and ensures the smooth progress of life activities; The thermal sensation of the human body refers to the subjective feeling of the human body on the influence factors such as environmental temperature and humidity, which is jointly affected by environmental factors, human physiological and psychological factors.

Human thermal comfort is the degree of comfort that the human body feels to a certain hot and humid environment, and it is a degree of subjective satisfaction. It is affected by factors such as external environment temperature, humidity, wind speed and radiation, and is also closely related to subjective factors such as the activity state of the human body, physiology, and psychology.Fanger of the Technical University of Denmark proposed a perfect definition of thermal comfort, including the following three conditions:

（1）The human body must be in thermal equilibrium. Human body heat balance means that the generation and divergence of heat in the human body reach a balanced state, maintain normal body temperature levels and ensure normal and healthy human life activities. The main modes of heat exchange between the human body and the environment are: convection, radiation and evaporation. The heat exchange equation shows that when the human body is in a state of thermal equilibrium, the amount of heat change in the human body tends to zero.

$$M' \pm R \pm C - E = Q \qquad \text{Formula 1}$$

In the formula, M'—total metabolic heat production;

R—radiative heat transfer;

C—Convective heat transfer;

E—evaporative cooling;

Q—The amount of heat change in the human body.

（2）The thermal sensation of the human body is related to the average skin temperature of the human body, that is, the average temperature of the human body corresponding to the thermal comfort of the human body is different under different activity states. When the body's metabolic rate is higher, the corresponding average skin temperature required is lower, and vice versa.

（3）Achieving human thermal comfort requires an optimal perspiration rate.

2.2 Environmental performance factors

2.2.1 Factors Affecting Indoor Thermal Comfort Environmental Performance

The indoor thermal environment, light environment and acoustic environment all affect the thermal comfort of the indoor space. This research studies the thermal comfort of indoor space from the binary perspective of architectural form-energy flow, and mainly discusses the effects of air temperature, average radiant temperature, air velocity and relative humidity on indoor thermal comfort.

（1）Air temperature

Air temperature is a physical quantity that expresses air temperature, in degrees Celsius, usually characterized by dry bulb temperature. Indoor air temperature is an important factor affecting the human body's perception of the indoor environment. According to the domestic standard "Code for Design of Heating, Ventilation and Air Conditioning", the indoor thermal comfort standard air temperature is 26-28°C in summer and 18-22°C in winter. The main factors affecting the indoor air temperature are the heat gain and heat dissipation of the indoor space, the surface temperature of the space enclosure interface, and the air circulation. Due to the fluidity of the air and the difference in the sensitivity of different parts of the human body to the temperature, the distribution of the temperature in the horizontal or vertical direction will have an impact on the comfort of the human body.

（2）Mean radiant temperature

The average radiation temperature refers to the average temperature of the radiation effect of the surrounding surface on the human body, in degrees Celsius, and the average radiation temperature is usually measured with a black ball thermometer. The main factors affecting the average radiant temperature are the surface temperature of the indoor space enclosure structure and the spatial position of the human body.

（3）Air velocity

Indoor air velocity refers to the wind speed, which represents the spatial distance of air movement per unit time, and the unit is m/s. Indoor air velocity can be measured with an anemometer. The main factors affecting the indoor air flow are the pressure gradient and the opening degree of the enclosure interface, and the calculation formula is:

$$u=V/A=w\rho/A \qquad \text{Formula 2}$$

Among them, u refers to the flow rate, the unit is m/s; V refers to the volume flow rate, the unit is m^3/s; A refers to the flow area, the unit is m^2; w refers to the mass flow rate, the unit is kg/s; ρ refers to the gas density, the unit is kg/m^3. The air flow promotes transpiration, accelerates the heat exchange between the human body and the air, and improves the heat dissipation efficiency of the human body. In the state of natural ventilation, the indoor air flow rate is in the comfortable range of 0.5-1.5m/s.

（4）Relative humidity

Relative humidity refers to the ratio of the water vapor pressure in the air to the saturated water vapor pressure at the temperature. It can also be expressed by the ratio of the absolute humidity at the temperature to the maximum absolute humidity that can be achieved, so as to reflect the degree of water vapor in the air from the saturation state. It can be measured by a thermo-hygrometer. The main factors affecting indoor relative humidity are the content of water vapor in the air and the air temperature. Changes in relative humidity bring about differences in the ability of the air to absorb water vapor, which affects the physiological activities of the human body to perspire and dissipate heat, thereby affecting the comfort of the human body. The relatively comfortable indoor relative humidity is 30%-80% at 20-25°C in winter, and 30%-60% at 23-30°C in summer.

2.2.2 Factors Affecting Outdoor Thermal Comfort Environmental Performance

The factors affecting the thermal comfort of outdoor spaces such as streets and alleys discussed in this research mainly include: air temperature, relative humidity, solar radiation, shadow density, and air velocity.

（1）Sun radiation

Solar radiation refers to the energy transmitted by the sun in the form of electromagnetic waves. The surface of the surface material obtains energy by absorbing the short wave of the sun. Different materials have different solar absorption rates, resulting in different outdoor temperatures in different areas under the same solar radiation conditions. Solar radiation directly affects the outdoor surface temperature of buildings and indirectly affects the indoor and outdoor air temperature. Factors affecting solar radiation include latitude, weather conditions, air quality, altitude, etc. For Lilong, the main factors affecting their absorption of solar radiation are: the difference in the length of sunshine time caused by factors such as the orientation and width of the alleys, and the sunshine time is positively correlated with the accumulated radiation.

（2）Shadow density

The shadow density of the alley refers to the proportion of the alley ground covered by shadow within a certain period of time. It reflects the ability of the surface of the inner public space of the alley to receive direct sunlight, and the ability of the shape of the alley to shield solar radiation. The higher the shadow density, the weaker the ability of the alley to receive direct sunlight, and the stronger the shielding ability of the alley to solar radiation. On the contrary, it shows that the alley has a strong ability to receive direct sunlight, and the inner alley has a weak ability to shield solar radiation. The main factors affecting the shadow density include the morphological characteristics of the alley and the orientation of the alley. Generally speaking, under the hot climate in summer, the higher shadow density inside the alley indicates that this type of residential buildings in the alley can better self-shade, thereby reducing the surface and air temperature of the alley, and improving the comfort of the outdoor space. In the cold winter climate, the lower shadow density can increase the absorption of solar radiation heat by the alley and increase the outdoor ambient temperature.

（3）Air velocity

The air velocity in the alley has the same meaning as the indoor air velocity. The main factors affecting the outdoor air velocity in the Shikumen inner alley are the shape of the inner alley, the orientation and scale of the alley. Consistent with the indoor air velocity, the impact of outdoor air velocity on human comfort is different in winter and summer. The larger air flow rate in summer can take away the dirty air in the alley and promote the wind pressure ventilation in the building; while the lower air flow rate in winter can slow down the heat dissipation rate of the human body and ensure the comfort of outdoor activities. Generally speaking, in the outdoor environment, when the average wind speed is lower than 5m/s, it is a relatively comfortable air flow speed, and the minimum wind speed value to ensure good quality of outdoor air is 2m/s.

2.3 Space thermal comfort evaluation index

The human body will show different activity states in the building interior or in the urban street environment. The difference in the external environment and the difference in the human body activity state have a very significant impact on the definition of the human body and comfort. In this research, the evaluation of the space-climate regulation effect of Shikumen

Lilong dwellings is divided into two parts: indoor and outdoor.

2.3.1 Indoor thermal comfort evaluation index

Indoor thermal comfort evaluation indicators include effective temperature E.T, thermal comfort equation PMV-PPD, operating temperature, ASHRAE thermal comfort evaluation standards and other comfort evaluation indicators. In Chinese current evaluation standard "Code for Design of Heating, Ventilation and Air Conditioning" (GB50019-2003), it is stipulated that the physical indicators of comfortable air conditioning indoors are: 18-24°C in winter, wind speed ≤ 0.2 m/s, and relative humidity at 30-60% In summer, the indoor temperature is 22-28°C, the wind speed is ≤0.3 m/s, and the relative humidity is between 40-65%. In the “Evaluation Standards for Indoor Heat and Humidity Environment of Civil Buildings” (GB/T50785-2012), the operating temperature is used as the evaluation index to limit the evaluation level of heat and humidity environment of non-artificial cold and heat sources in hot summer and cold winter, hot summer and warm winter, and mild areas.

Considering the characteristics of hot summer and cold winter climate zone, evaluation indicators and the overall difficulty of evaluation in Shikumen Lilong Residential Area. In this research, the average radiant temperature was selected as the indoor thermal comfort evaluation index. Taking the temperature range satisfying 75% of people's thermal comfort in the "Evaluation Standard for Indoor Thermal and Humid Environment of Civil Buildings" (GB/T50785-2012) as the comfort zone(The indoor temperature in winter reaches 16°C, and the indoor temperature in summer is less than 30°C), the indoor thermal comfort of Shikumen Lilong was initially evaluated.

2.3.2 Outdoor thermal comfort evaluation index

The outdoor environmental conditions are changeable, the average radiation temperature and wind speed are quite different from those indoors, and there are obvious differences in the metabolic level and active clothing of the human body indoors and outdoors, and the subjective evaluation of temperature and wind speed is different. The evaluation indicators of outdoor thermal comfort environment are also obviously different from those indoors, and there are large uncertainties. At present, there are various evaluation indicators for outdoor space comfort. In 1981, Gerd Jendritzky and others at the University of Freiburg improved on the basis of the PMV model, using a human thermal comfort model in outdoor spaces and named it "Klima-Michel model".

In the mid-1920s, Hoppe proposed HEMI, which provided a physiological evaluation model for the evaluation of outdoor thermal comfort. He then proposed the Physiological Equivalent Temperature Index (Physiological Equivalent Temperatur), namely PET, However, this parameter cannot accurately predict outdoor thermal comfort. In 2002, Action 730 of the European Science and Technology Cooperation Program proposed an internationally common outdoor thermal comfort technology index: the general thermal climate index, which is defined as the equivalent ambient temperature at which a reference person obtains a physiological response consistent with the real environment in a reference environment, Consider the impact of multiple environmental factors on human comfort and heat stress risk, including temperature, humidity, radiation, and wind speed. According to the size of the index, it is divided into 10 levels (Figure 3). UTCI is based on the iterative calculation of the thermoregulation model, which can accurately reflect the thermal sensation of the human body that changes with the physical exposure time, and is used in a wide range of climatic conditions [7]。

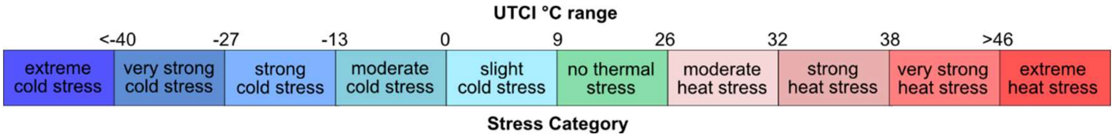


Figure 3 UTCI Level

Source：http://james-ramsden.com/wp-content/uploads/2015/07/UTCI_scale.png

2.4 Building configuration factors of Shikumen Lailong

The building configuration factors related to environmental adjustment in Shikumen Lilong are divided into three levels: shape, enclosure and structure, among which the shape and enclosure level contain a total of 10 influencing factors [8]（Table 1）。Various factors show obvious differences in the four typical samples selected. Through the simulation of the space-climate adjustment of the four typical samples and the differences in architectural configuration factors, the relationship between climate adjustment and architectural configuration factors in Shikumen Lilong is extracted. Horizontally compare and analyze the differences in architectural configuration factors and the differences in indoor and outdoor space wind, light, and thermal environment performance, and explore the scale interval of architectural configuration factors that can achieve the best thermal comfort in indoor and outdoor environments. In addition, the special approach at the structural level of typical samples, through field research, extracts the relationship between typical structures and climate regulation, and serves as the main content of the space-climate construction samples at the structural level, supplementing and perfecting the deficiencies in the shape and enclosure levels.

Table 1 Building configuration factors and definitions [9]

Building configuration	Definition

[7] Zhang Wei , Gao Zhi , Ding Wowo. Outdoor thermal comfort indices: a review of recent studies [J]. Journal of Environment and Health,2015,32(09):836-841.

[8] Xiao Wei, Zhang Tong. Performance Mechanism of Building Formation and Key Strategies of Adaptive Formation Design [J]. Architect, 2019, No.202(06):16-24.

[9] The optimal building configuration factor scale values in the table are from references [59] and [61]

Body shape factor	Thermal azimuth	The angle between the direction of the main heating surface axis of the building and the geographical east direction
	Thermal tilt angle	The angle between the roof of the sunny building and the horizontal direction
	Wind azimuth	The plane angle between the main opening surface of the building and the local prevailing wind direction throughout the year
	Wind inclination angle	The angle between the wind direction and the normal direction of the building surface (roof). When the wind inclination angle is 0, the wind direction is consistent with the normal direction of the building surface, the wind flow speed is the largest, and the heat exchange intensity of the building surface is the largest.
	Void body aspect Ratio	The ratio of the vertical height of the void body to the north-south width
	Void body mouth-to-floor ratio	The ratio of the top perimeter to the bottom perimeter of a void body shape
Epidermal factor	Openable area ratio	The ratio of the total area of all openable surfaces facing a certain direction in the same space of a building to the total area of walls facing that direction
	Direction Angle of Wind Guide Surface	The acute angle between the opening surface and the wind direction
	Window to wall area ratio	The ratio of the total area of external windows facing a certain direction to the total area of walls facing the same direction
	Comprehensive shading coefficient	The ratio of the radiant heat that enters the room through the glass when the building has sunshade facilities to the radiant heat that enters the room through the standard windows of the same area without sunshade facilities under the same conditions
Construction factor	Construction that enhance or inhibit conduction, radiation, convection, and evaporation	

2.5 Correlation Analysis of Environmental Performance Factors and Building Configuration Factors

Shikumen Lilong are mostly closely arranged in a determinant layout, and each residential unit is closely related to the architectural configuration factors of the surrounding units. From the perspective of form and energy, the energy flow among the individual elements in Shikumen Lilong also affects each other. Discussion on the space-climate regulation of a single residential unit should also analyze the space-climate mechanism of Shikumen Lilong from the perspective of correlation. In short, from the perspective of form-energy, there is no single shikumen lilong house. In this research, the research field of view on the space-climate mechanism of Shikumen Lilong is expanded to the neighborhood level.

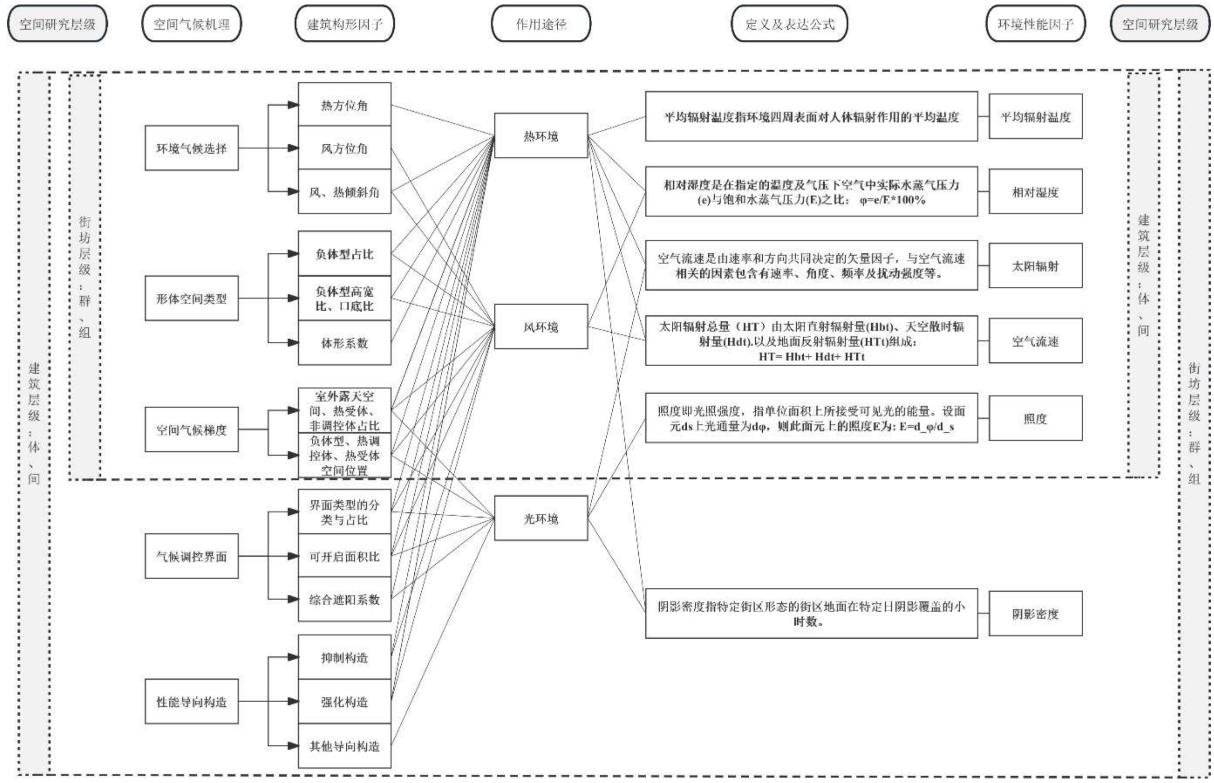


Figure 4 Correlation diagram between environmental performance factors and building configuration factors   Source: self-drawn

2.6 Space-climate construction sample data collection, simulation and interactive verification path

2.6.1 Sample data collection and simulation method

The meteorological data collection work for four typical samples is divided into two seasons, winter and summer, which are respectively scheduled on the typical weather days in winter and summer. Summer is scheduled around July 23 (great heat day), and winter is scheduled around January 20 (great cold day). The summer research work was basically completed within four days from August 12th to August 16th, but due to some special reasons, the winter research work could not be completed as scheduled. Therefore, based on the existing measured data, computer meteorological simulation software is used to simulate the thermal performance of buildings in four typical samples in winter and summer, so as to make up for the lack of data that cannot be measured in winter.

The main content of the data collection work is to collect the meteorological data of the representative space of four typical samples on a typical weather day: dry bulb temperature, black bulb temperature, relative humidity, air velocity, solar radiation, and illuminance. The measurement of indoor and outdoor thermal environment parameters is basically the same. Site layout points are used, and measuring instruments are placed to record the environmental performance factor data in half a heat flow cycle from 8:00 to 20:00. The measurement parameters and corresponding measuring instruments are shown in Table 2.

Table 2 Environmental performance factor collection equipment

Location	Type	Factor	Sensor	Note
Indoor	Thermal environment	Air temperature	Black bulb temperature tester	Automatic recording
		Relative humidity		
		Black bulb temperature		
		Dry bulb temperature	Portable temperature and humidity meter	
		Relative humidity		
		Sun radiation	Solar radiation meter	Manual record
		Radiation temperature	Infrared imager	Manual record
	Wind environment	Air velocity	Wind speed tester	Manual record
	Light environment	Illumination	Illuminometer	Manual record
Outdoor	Thermal enviroment	Radiation temperature	Infrared imager	A combination of analog atlas and manual recording. (Only the different measurement parameters between outdoor and indoor are marked here)

Considering that the sample buildings selected in this research still have some space for living or other functions, and the research period is the hottest period in Shanghai, the operation of active control facilities such as air conditioners in some residential buildings is inevitable. Such uncontrollable environmental factors have a significant impact on the measured survey data. After the data collection is completed, such data should be selectively eliminated to avoid its impact on the analysis results. Input the collected effective data of wind, light and thermal environment into EXCLE, Paraview and other software for data sorting and visual chart drawing.

The space climate simulation is mainly aimed at the building space adjustment ability of the four typical samples under the conditions of typical meteorological days in the whole year or in winter and summer. The simulation parameters are basically consistent with the survey, including simulating the wind, light, and thermal environmental performance of Shikumen residential buildings. The main simulation parameters include average radiation temperature, UTCI index, solar radiation, net benefit radiation, shadow density, illuminance and air velocity.

The relevant simulation parameters and corresponding simulation software are shown in the following Table 3.

Table 3 Space-climate Simulation Parameters and Platforms

Location	Type	factor	Platform	备注
Indoor	Thermal environment	Mean radiant temperature	Ladybug+Honeybee+Openstudio	
		Sun radiation	Ladybug	
	Wind environment	Air velocity	Ladybug+CFD	
	Light environment	Illumination	Ladybug+Honeybee	
Outdoor	Thermal environment	Shadow density	Ladybug	(Only the different measurement parameters between outdoor and indoor are marked here)
		UTCI	Ladybug+Honeybee+Openstudio	

2.6.2 Simulation-measurement interactive verification method

By sorting out the above-mentioned measured data, this research compares the advantages and disadvantages of the architectural environmental control performance of the four samples, and analyzes the superior samples of environmental control and their architectural environmental adaptability characteristics. Then simulate the performance of the four samples in typical meteorological daily wind, light, and heat environments, and compare the performance of the samples horizontally. On the basis of the superior samples, the configuration parameters of the building environment are changed to simulate, and the simulation results are compared to determine the climate suitability range of the configuration factors of the sample buildings. After that, compare the measured parameters with the performance simulation parameters, interactively verify the interaction between the spatial configuration elements and environmental performance of Shikumen obtained from the field measurement and performance simulation, and analyze the reasons for the similarities and differences between the results of the actual measurement and investigation. Sort out the climate adaptability performance of Shikumen that both corroborate with each other. Finally, the rediscovery of the space-climate mechanism of Shikumen is completed.

2.7 Summary

This chapter first analyzes the related theories of space-climate construction. On the basis of Vitruvius' ternary model of architectural environment, a ternary model of "climate environment, city-building, and human body" is established to provide a theoretical basis for the study of Shikumen's environmental regulation theory from a single building to a neighborhood scale. Based on the existing thermal comfort evaluation index, select the suitable indoor and outdoor thermal comfort evaluation index, determine the comfort range of the evaluation index, and construct the evaluation basis for the quality of the building environment regulation effect from the perspective of climate-space-energy. Starting from the theory of bioclimate design and human thermal comfort, combined with the space characteristics of Shikumen Lilong and the difference of thermal comfort factors between indoor and outdoor spaces, In this chapter, air temperature, average radiant temperature, relative humidity, and air velocity are determined as the main environmental performance factors affecting indoor thermal comfort, while solar radiation, shadow density, and air velocity are determined as influencing factors affecting outdoor thermal comfort. Combining with the field investigation, the construction factor system of Shikumen building is established from the three levels of body shape factor, skin factor and structural factor. The analysis of the interaction characteristics of Shikumen architectural configuration factors and environmental performance factors provides a theoretical and data basis for the study of Shikumen space climate mechanism. Considering the needs of sample performance simulation parameters, select and construct a reasonable platform and method for space climate simulation, and propose a method path for interactive verification between actual measurement and simulation.

Chapter3. The Shanghai Shikumen Residential Houses as Research Samples

3.1 3.1 Overview of Shikumen Lilong Development

3.1.1 The origin of Shikumen Lilong

Shikumen dwellings were born in Shanghai, which was only a fishing village before the 13th century. It was established as a town in the Southern Song Dynasty and later promoted to a county. Until Shanghai was officially opened in 1843, imperialist powers such as Britain, France, and the United States successively seized control of Shanghai's land and established concessions in Shanghai, making it the first city to be colonized in China. During World War I and World War II, due to its distance from conflict areas, Shanghai became a destination for international immigrants. At its peak, Shanghai accepted 150,000 immigrants a year. At the same time as the foreign immigrants, Chinese people from the surrounding areas of Shanghai also flooded into Shanghai. During the Shanghai "Small Knife Society" uprising and revolution, the social turmoil inside and outside Shanghai forced the wealthy businessmen and nobles from the surrounding cities to move their families to the foreign concessions for stability. As a result, the demand of the market prompted British real estate developers to build houses for rent to Chinese people. The limitations of urban land use and the preferences of users and other market demands promoted the birth of "Lilong". During the Taiping Heavenly Kingdom Movement, the social turmoil again caused the gentry in Shanghai and surrounding cities to flock to the concession, and the population increased again. A large number of row houses formed by simple board houses were built, which also became the embryonic form of Shanghai Lane Neighborhoods. The rapid development of world capitalism and the population growth brought about by urban development have made housing a necessity. Due to the need for fire protection, the management department of the concession banned the old-fashioned wooden houses. The post-post structure with good fire resistance can better meet the needs of the society. So far, the Shikumen Lilong dwellings have appeared.

Figure 5 Typical Shikumen neighborhoods and monomers Source: Self-photographed

Shikumen architecture was born out of the traditional folk houses in the south of the Yangtze River. It is a residential model formed by the innovation of the interior space of the houses and the innovation of the combination of living units against the background of modern urbanization in Shanghai. Therefore, while it is inextricably linked with geoclimate, traditional culture and society, it also has the typical characteristics of modern built urban environment(Figure 5).

（1）Jiangnan dwelling

The geographical scope of Jiangnan dwellings is limited to the plains in the middle and lower reaches of the Yangtze River. During the Ming and Qing Dynasties, the Jiangnan area was limited to the rich land of "eight prefectures and one state", that is, today's Suzhou, Changzhou, Hangzhou, Huzhou, Jiaxing, Songjiang and Zhenjiang. The location selection of Jiangnan dwellings at the settlement level pays attention to site selection, advocates the organic combination of settlements and nature, and the unity of nature and man. The layout of the settlements pays more attention to the relationship with the surrounding natural environment elements such as mountains, rivers, forests and fields. Hills and plains coexist in the Jiangnan area and the water network is densely distributed. Therefore, most residential settlements in the south of the Yangtze River conform to the terrain and are built with the mountains on their backs and the water. The plane of a single Jiangnan dwelling has typical typological characteristics. On the one hand, the Jiangnan dwelling forms an introverted courtyard centered on the patio, and the surrounding indoor functional spaces are all open to the patio. Through the transition of the gray space under the corridor around the patio, the patio is surrounded by high walls, and only the upper part is open. The patio becomes the core space connecting the interior and exterior of the dwelling. At the same time, due to the tight arrangement of the residential buildings in the south of the Yangtze River, and for the sake of defense, the windows on the facade of the residential buildings are small, so the patio is not only the core of the space, but also the main body of the residential ventilation, lighting and other climate adjustment functions.

On the other hand, the plane mostly adopts a symmetrical layout. The plane space is mainly composed of three elements: hall, living room and patio. The main entrance-patio-hall is located on the north-south central axis. The model units of three rooms and hatchbacks are topologically changed horizontally or vertically according to the space requirements of users. Most of them have one or two floors, and the space layout of the second floor is similar to that of the first floor.（Figure 6）

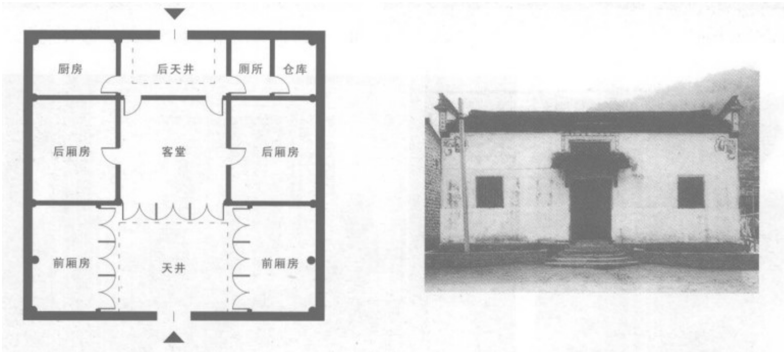


Figure 6 Plans and facades of traditional residential buildings in the south of the Yangtze River Source: " Shanghai housing after its opening to foreigners "

（2）UK Townhouses

Townhouses are an indispensable housing type in the history of European urban development. During the Middle Ages, the main structural forms of British residences were box-framing and cruck-framing, and the main residential types were hall houses and long houses born on the basis of these two types of structures (Figure 7). As the name implies, the hall house refers to the type of residence with the hall as the main space. For the purpose of ventilation, it is generally based on the owner’s financial resources as high as possible, and the indoor temperature in winter is increased by setting a brazier in the core space of the hall. Longhouses are often found in more remote areas, with living space on one side and barns on the other. The hall or long house are planar features with long sides, wide sides and short depths to ensure indoor lighting. With the popularization of openable iron windows and glass, two-deep houses in Britain gradually became popular at the end of the 16th century, and its internal spatial pattern was used until the 20th century (Figure 8).

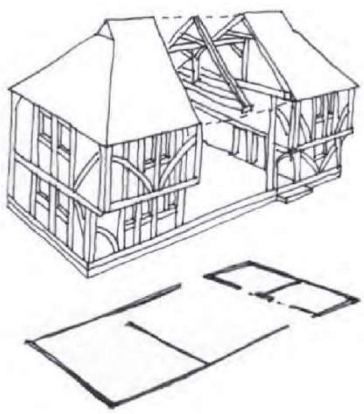
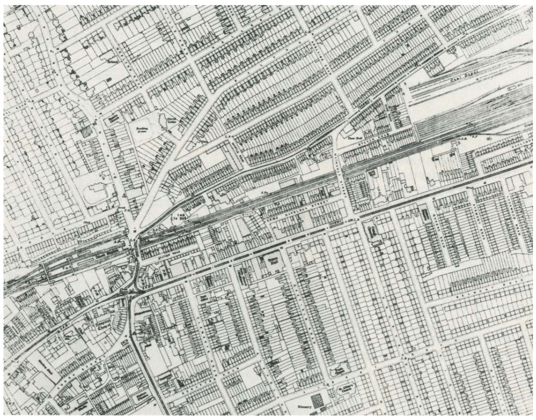



Figure 7 Medieval Hall House　Source :”Vernacular Architecture in the United Kingdom” and “The English Terraced House”

Figure 8 Typical British townhouse texture Source: The English Terraced House

In the Great Fire of London in 1666, due to the need for fire protection, the main materials of Georgian residential buildings changed from wood to masonry. During this period, British urban residences could be built with different grades of townhouses according to the needs. Higher grade residences all had basements and met the lighting needs through the "patio". The townhouses in George are arranged horizontally in rows, and the gable walls are shared between adjacent houses. The narrow side is wide and the length is deep. There are private gardens and courtyards in front of and behind the houses （Figure 9）.

Figure 9 Light Area for basement of house built in Georgian period Source: Google

During the Victorian period, Britain experienced the first industrial revolution, which led to rapid urbanization and industrialization. Great changes have taken place in the types of housing construction in British cities. As Marx said in "The Conditions of the British Working Class": "Workers' small houses are almost no longer built..." The process of rapid industrialization and urbanization of the society has created serious problems for the working class to live in. The working-class residential units are neatly arranged horizontally along the city roads, without basements, and directly enter the front room from the street through the main entrance. Then there is the back room, the middle part is the vertical traffic space, and the second floor is the bedroom. There is a small courtyard and a single-storey toilet at the back of the house, and the backyard is connected to the mews. It is convenient to transport out domestic garbage. The slightly better residential type has a slightly larger backyard and front yard on the basis of the above, and the front window along the street forms a bay window. The first floor is higher than the street to ensure indoor privacy, while the gap between the first floor and the ground optimizes the indoor temperature and humidity environment.

From the end of the 19th century to the beginning of the 20th century, the implementation of public health laws greatly improved the poor living quality of Victorian houses. Housing by-law was formed under the requirements of the public health law for the width of the street and the width of the backyard corresponding to the building. Residential units with a width of 4-5m are arranged horizontally to complete the further efficient use of land. At the same time, the spacious streets and courtyards ensure the ventilation and lighting of the indoor space, but the monotonous and boring street environment has also been criticized（Figure 10）.

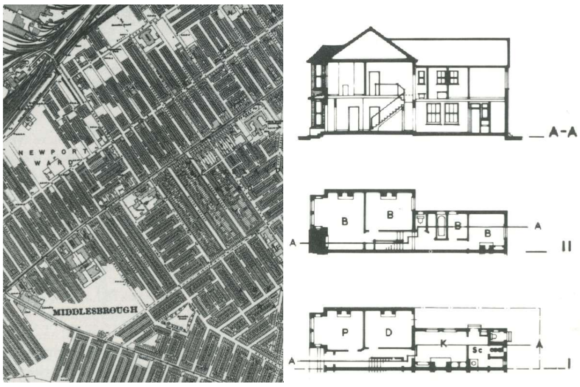
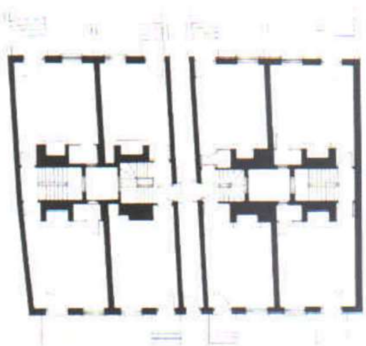


Figure 10 Victorian Housing by-law Source : “The English Terraced House”

In the process of urbanization in modern Shanghai, the rapid development of the city and the commercialization of land under the influence of land finance are the main characteristics of the development of Shanghai's urban space. From the block plan of Zundli built in the 19th century, it can be seen that the organization of the plan of the Shikumen Lilong houses is similar to that of western townhouses. At the microscopic level, each Shikumen residential unit has the same spatial composition as the traditional residential buildings in the Jiangnan area.（Figure 11Figure 12）.



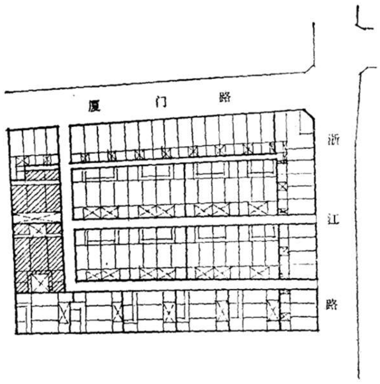


Figure 11 Residential floor plan of No. 52-55-Newington Green, London (Source: " THE ORIGINS AND DEVELOPMENTS OF TOWN HOUSES")
Figure 12 General Plan of Shanghai Zundri Source:”Lilong Architecture”

3.1.2 The Development and Decline of Shikumen Residential

The development of Shikumen Lilong houses is a microcosm of the development of Shanghai's modern society. The rise and fall of Shikumen Lilong houses basically coincides with the development and decline of Shanghai's modern construction industry. For the convenience of discussion here, the classification method of dividing Shikumen Lilongs into early Shikumen Lilongs and later Shikumen Lilongs is adopted. The specific classification of Lilongs will be discussed in 3.2.2 of this article.

In the initial stage of Shanghai’s urbanization since the opening of the port in 1843, the main body of residential construction in Shanghai is still scattered and small individuals. Land developers have both ownership and use rights of the land, and land development for self-use and partial lease and sale.

The Taiping Rebellion in 1860 and the signing of the Treaty of Shimonoseki in 1862 all contributed to the concentration of urban population in Shanghai. In 1870, the old-fashioned Shikumen began to appear. The nearly 40 years from 1910 was the prosperous period of construction of early Shikumen Lilongs. Most of them were three-room hatchback layouts, retaining more of the shape and structure of traditional Jiangnan houses. The old-style Shikumen first appeared in the British Concession, and later expanded to Nanshi and the French Concession. Representatives of typical early Shikumen Lilong houses include Hongdeli and Jianyeli.

Shanghai's modern city was initially formed from the opening of the port to 1899, and the modern construction industry also developed rapidly from 1890 to 1919. This stage is the peak time for a large number of residential buildings in Shikumen Lilong. With the development of the urban economy, the poor spatial quality of the old-style Shikumen could not meet the market demand. In the later period, Shikumen and new-style Lilong and other residential forms that are more in line with modern social life appeared one after another. Later Shikumen Lilong and new-style Lilong were built in the early 20th century and 1930s, while early Shikumen Lilong basically stopped construction in the 1920s.

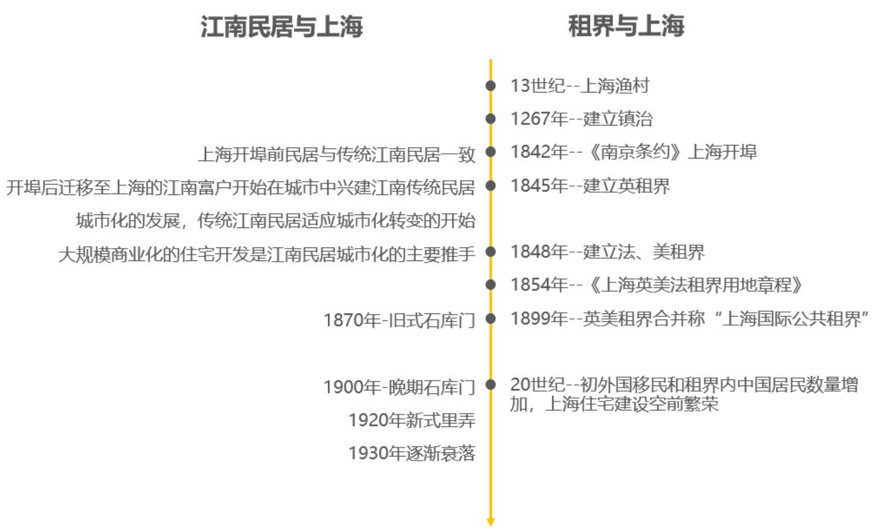


Figure 13 Shikumen Lilong Development and Historical Background Source: Self-painted

In 1990, the commercial value of Shikumen Lilong as urban fringe spaces attracted the attention of capital. The low-rise Shikumen could no longer meet the needs of Shanghai’s urban development, and high-rise buildings gradually replaced traditional lanes under the operation of capital. Although the methods of protection and revitalization of Shikumen have been continuously iterated since the 1990s, most of the Shikumen are now facing the dilemma of spatial quality decline due to the limitations of the residential space. By the time the author wrote this article, the residential buildings near Wangyun Road in the Old Town and along Jianguo Road in Huangpu District, two of the research samples of this article, had been expropriated and were about to be demolished.（Figure 14）.

Figure 14 The Shanghai Shikumen being demolished Source: Self-photographed

3.1.3 Two Chinese and British houses alternate

Shikumen Lilong is the product of the combination of Chinese and British housing. From the perspective of traditional folk houses in the south of the Yangtze River, the evolution process of the house shape of Shikumen Lilong can be seen as the urbanization process of traditional folk houses in the south of the Yangtze River under the influence of western architecture; From the perspective of British style townhouses, it is the local evolution of Townhouse after its introduction to China under the influence of Shanghai's natural and cultural background, as well as traditional Jiangnan residences. This section discusses the two main alternating processes between Chinese and English residential forms, and attempts to establish an evolutionary lineage from Townhouse to Lilong dwellings. From the perspective of the development process of Shikumen Lilong, the result of the two house type alternations between China and Britain was the emergence of Shikumen Lilong houses in the early 1872 and Shikumen Lilong houses in the late 1920.

The transition from simple wooden houses to "row style Jiangnan dwellings" was the main change in the first Sino British alternation of residential forms. In 1854, for the purpose of short-term efficiency, the British Concession authorities constructed a large number of row wooden houses with wood. There is limited image data describing the initial construction of the wooden house, but it can be basically judged that its architectural style may be traditional Chinese architectural style, and its arrangement and combination are more similar to the simple brick concrete structure of the George and Victorian era in the 19th century.

The early Shikumen Lilong, which replaced the plank house, continued to be arranged in tandem. Its main customers were mostly the gentry and nobles around Shanghai. The horizontal residential units were complete traditional houses in the south of the Yangtze River. This method of combining Chinese style residential units with Western style architectural clusters, although slightly stiff, better meets the needs of concession authorities, land developers, and residents, and also caters to the current situation of tight urban land use. At this point, the first alternating fusion of Chinese and English homesteads was completed.

The late Shikumen Lilong gradually replaced the early Shikumen Lilong to represent the beginning of the second Chinese British house shape alternation. After 1875, under the influence of public health laws, a large number of poorly built townhouses during the Victorian period in England were replaced by "regulated residences" with spacious streets and courtyards. Subsequently, health laws were enacted to promote the formation of standard styles of townhouses in the 19th and 20th centuries in England. The later Shikumen Lilong, which appeared in 1920 in Shanghai, was affected by the brick and wood structure of townhouses improved at the beginning of the 20th century: the number of bays was reduced, the architectural style was westernized, the alleys were more orderly, and the quality of residential construction and living were improved.

The evolution of Chinese and British housing at home and abroad is independent of each other, but the unique nature of the Shanghai concession has led to mutual influence between the two. According to the type of construction technology, modern residential buildings in Shanghai can be divided into Chinese houses and Foreign houses, both of which have relatively independent and interrelated evolutionary pathways. In the process of the alternation of Chinese and British residential forms, George and Victorian simple brick and wood row houses, traditional houses in Jiangnan, and upgraded brick and wood structure row houses in the early 20th century in England all had an impact on the development of the lane. Based on the correlation between the distribution of these types of houses in time and space and the types of architectural forms, this paper attempts to construct an evolutionary genealogy relationship from Townhouse to lane houses（Figure 15）。

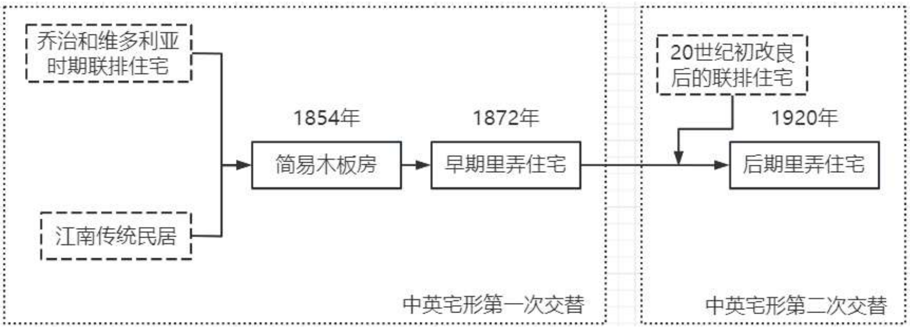


Figure 15 The genealogy of the evolution of Chinese and English house shapes from Townhouse to Lilong　Source: Self-drawing

3.2 Classification of Shikumen Types and Their Typical Features

3.2.1 Basis and method for division of Shikumen morphological type

Traditional residential settlements are gradually formed under the long-term interaction of natural selection of geo-climate and kinship reciprocity within the settlement. Jiangnan traditional residential buildings, one of the predecessors of Shikumen, are one of the typical representatives. However, the environment faced by Shikumen Lilong dwellings is completely different from that of traditional folk houses. The huge urban space in Shanghai is one of the factors that cause Shikumen Lilong dwellings to be alienated in terms of form and type. As the most complex creation in human history, the city affects every part of it with its extremely high density and efficiency. The Shikumen residential settlements with this background have more complex levels and relationships.

Aside from the complexity of the internal organization logic and element relationship, but only from the perspective of spatial form, the main elements of the Shikumen Lilong dwellings are the houses and the alleys in between. The two are the basis for each other's existence. The boundary of the houses, and the arrangement of the houses defines the shape of the alleys （Figure 16）. The alleys in Shikumen are the main media for the relationship between architecture and the city, and they are elements that cannot be ignored. Compared with traditional settlements, the importance of alleys formed between residential groups arranged in rows has increased in terms of space, function, and form. Streets and alleys, as urban public spaces close to the private spaces of buildings, have a great influence on indoor physics. The direct impact of the space environment is self-evident. The purpose of classifying and discussing Shikumen Lilong dwellings from the perspective of spatial form is also for the follow-up research on the space-climate mechanism of Shikumen. Therefore, the differences in the shape of alleys are also included in the classification basis of different Shikumen Lilong types.

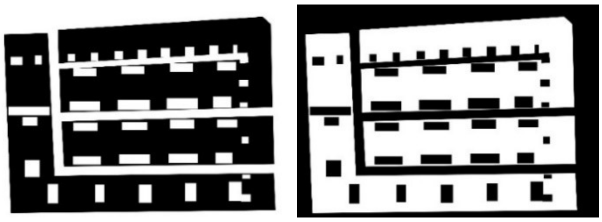


Figure 16 Shanghai Zundli Texture　Source: Self-painted

The purpose of this study to classify the morphological types of Shikumen dwellings is to select typical samples of Shikumen dwellings for the study of space-climate mechanism. Frankly speaking, the establishment of a complete pedigree of Shikumen dwellings from the three levels of neighborhood, plot, and individual requires more complex and systematic investigation and research, which is far beyond the core research of space-climate configuration that this research focuses on. scope. Based on this, the method for classifying the morphological types of Shikumen dwellings in this study is: based on the preliminary classification of Shikumen dwellings in the existing literature, based on which, the similarities and differences of Shikumen dwellings in different periods at the level of morphological types are extracted, combined with the specific social background, Determine a reasonable classification method to facilitate the research on the space-climate mechanism of Shikumen Lilong dwellings.

3.2.2 Types of Shikumen dwellings from the perspective of environmental regulation

3.2.2.1 Classification of Shikumen Lilong Types

There are two existing mainstream classification methods (Figure 17). The differences in the classification methods are mainly due to the fact that in the first method, the old-fashioned Shikumen Lilongs are divided into two categories based on the construction time, whether the general plan is regular, and whether the building orientation is elegant or not. In the second method, it is summarized into a discussion . From the perspective of theoretical research on environmental regulation, changes in architectural form and the surrounding physical space environment directly affect the space-climate mechanism of individual dwellings, and the early old Shikumen Lilong dwellings mentioned in Classification Method 1 are hard to find. Considering that this study has a dual perspective of space and energy, the classification of Shikumen pays more attention to the typological differences of their shapes, such as the obvious differences in factors such as bays and alley scales. Therefore, this research chooses to divide Shikumen Lilong houses into early Shikumen Lilong houses (about 1870-1920) and later Shikumen Lilong houses (about 1900-1930).

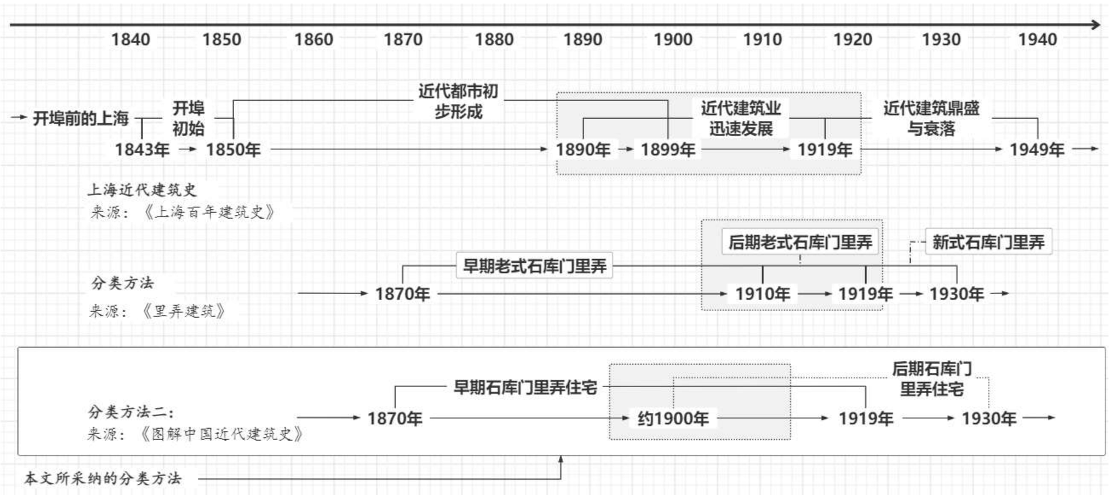


Figure 17 Classification of Shikumen Lilong, Shanghai   Source: Self-painted

3.2.2.2 Types of Lilong Closely Related to Shikumen Lilong

（1）Cantonese Lane Residence

Cantonese-style alley houses were born in Shanghai around 1910-1919. It is mainly distributed in areas such as Wusong Road in Hongkou District. The construction period of a large number of this type of housing coincides with the construction climax of Shikumen Lilong housing, and its users are mostly Guangdong residents or Japanese expatriates. Because the appearance style is similar to the bamboo tube houses in the old city of Guangzhou, it is named Cantonese-style Lane Residence.

According to the article "A Preliminary Exploration of the Architectural Form Sources of Cantonese-style Lilongs", the Cantonese-style Lilongs do not have much similarities with the old houses in Guangdong. Instead, during the urban construction process, the local Shikumen Lilongs in Shanghai were used as the main source of genes. Combining the characteristics of other traditional dwellings, it is one of the results of evolution to meet the living needs of the middle and lower classes in the city. The characteristics of the spatial form of Cantonese lanes are the result of the further modernization of Shikumen dwellings, and the determination of its name is determined by the workers from Guangdong who live there.

Cantonese-style alley houses were born out of Shikumen Lilong houses. Most of its houses are single-room horizontally connected, the main house is two-story, and the attached house is a single-story draped kitchen. A series of adaptive changes have also taken place in the Cantonese-style lane houses in the later period. For example, Shanghai Xinchang Workshop was built in 1932. The single building increased the annex to two floors and connected it with the main house. From the changes of the early construction samples to the later construction samples, it is not difficult to see that the trend of its spatial form change is consistent with the Shikumen Lilong houses. It can be guessed that its evolution process is more or less influenced by the "local architecture" Shikumen Lilong houses. It is the product of the combination of the "gene" of Shikumen Lilong and the early Cantonese-style residences.（Figure 18）

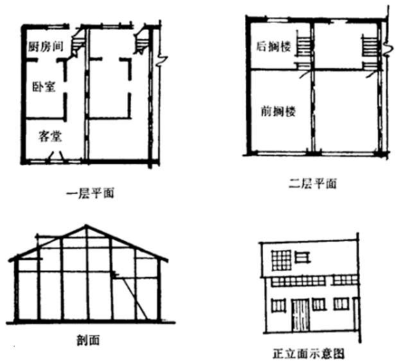


Figure 18 Cantonese-style Lane-Shanghai Xinchang Workshop Source: "Lilong Architecture"

（2）New-style Lilong

The new-style lanes gradually replaced Shikumen Lilong houses in 1920 and became the main body of new houses. If the early and late Shikumen Lilong houses are different stages of Jiangnan dwellings gradually adapting to urban life and urban space environment, then the new style of lanes can be regarded as a new stage of Shikumen Lilong houses adapting to urbanization.

The general layout of the new-style alleys is still a determinant layout, which is similar to the residences in the later Shikumen Lilongs, but the size of the alleys is larger than that of the Shikumen Lilongs. For example, the main alley in Jinghua New Village is 7.6 meters wide, which can meet the two-way vehicles passing through at the same time. . The second alley can also meet the requirements of vehicle entry and exit. The layout types of its single unit include double-room, single-room and half-way between the two, among which the single-room mode accounts for the vast majority. Most of the new-style lane buildings have three floors, the ground floor is the living room and kitchen, the second and third floors are bedrooms and terraces, and there are balconies facing south. The rear patio is retained, while the front courtyard is simplified into a garden surrounded by transparent interfaces, accompanying the transformation from the front patio to the garden. The main entrance and hall entrance are no longer on the central axis, the front and rear parts of the house are still arranged in split floors, and the floor height of the attached room is still lower than that of the main house. Divide areas with different floor heights by patios and stairwells. The floor height of the main house is lower than that of the later Shikumen Lilong, and the ground floor is about 3.6m.（图 3-11）

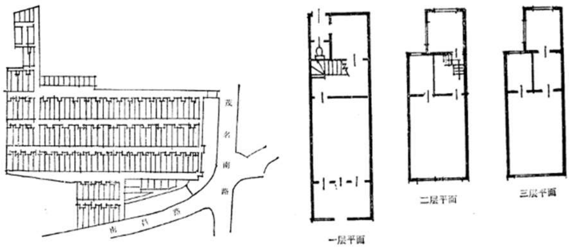


Figure 19 New-style Lilong Shanghai Huaihaifang Source: "Lilong Architecture"

3.2.2.3 Adjustments of division of type from the perspective of environmental regulation

The Cantonese-style Lilong houses built in 1922 and the Shanghai Model Village built in 1938 are typical Cantonese-style Lilong and New-style Lilong. Compare the two with Siming Village which is later Shikumen Lilong. There is a certain degree of correlation in terms of the general layout, the spatial sequence of the layout and the division of vertical space. On the one hand, all three adopt the general plan arrangement method of horizontal parallelism, and divide the Lilong as public transportation space in a homogeneous arrangement method. On the other hand, the interior is divided into two main functional spaces, the main room and the attached room, through the vertical traffic space, and a split-level arrangement is adopted in the vertical direction（Figure 20）.

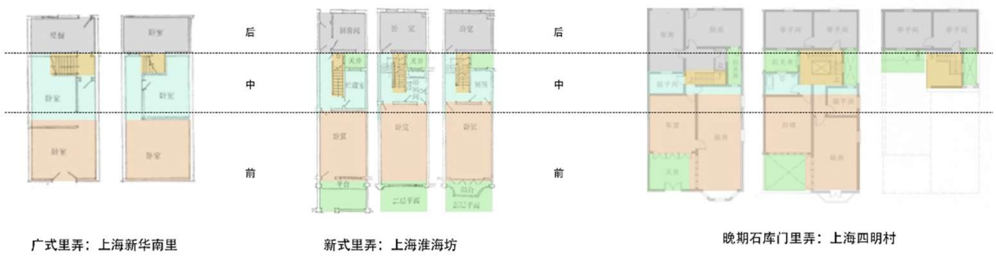


Figure 20 Horizontal comparison of the spatial layout of Cantonese-style Lilong, New-style Lilong and Later Shikumen Lilongs Source: Self-painted

Returning to the core issue of this study: the sample study of Shikumen residential space-climate construction, the difference of spatial form characteristics is one of the main variables to study the space-climate mechanism. There is an obvious correlation in form and type. Cantonese-style Lilong and new-style Lilong serve as a strong reference for Shikumen Lilong houses. From the perspective of time, the Cantonese-style alley houses appeared in the late period of the massive construction of Shikumen in the early stage, and the Shikumen Lilong began to appear gradually in the later period of this stage, which has a certain relationship with both. From the perspective of the quality of the built space environment, it is more inclined to the early Shikumen Lilong The construction period of the new-style lanes overlaps with the construction period of the Shikumen Lilong houses in the later period, and its research on the environmental regulation performance of Shikumen Lilong in the later period is more meaningful.

The changing trend of Shikumen dwelling types is the process of constantly adapting to urban life. Cantonese-style alleys and new-style Lilong are attempts in different directions in the process of residential urbanization of Shikumen Lilong. The Cantonese-style Lilong are the reappearance of the early houses in the Lingnan area that were transferred to the hot summer and cold winter climate zone, combined with the characteristics of the local Shikumen Lilong; while the new-style Lilong are closely related to the Shikumen Lilong in terms of spatial form, and the spatial form is more Prefer to adapt to the urban lifestyle. Therefore, the research on the space-climate mechanism of Cantonese-style and new-style Lilong can improve the limitations of the field of vision limited to research on Shikumen Lilong, and better summarize and refine Shikumen Lilong in the process of urbanization. The changing trend of the space-climate mechanism, summarizing and refining the more representative space-climate mechanism model of Shikumen Lilong.

From a macro point of view, although the overall construction history of Shikumen Lilong in Shanghai is only a few decades, and the four types of Lilong dwellings are all short-term and efficient construction, the essence is the action of real estate developers to respond to market demand . The social way of life is rapidly inherited and iterated along with urban development, so there are obvious differences in the residential spaces of the four construction periods. Although human living and lifestyles have changed, it is difficult to quickly change the pursuit of comfort, safety, and higher living space quality, as well as certain living habits that have been solidified. Therefore, the morphological characteristics of the four Lilong are related to each other. However, it is undeniable that slight differences in the shape and scale of local architectural space and urban space can lead to differences in meteorological and physical data of the built space environment (including architectural space environment and urban space environment), thus directly pointing to the comfort of the human body.

To sum up, Shikumen Lilongs can be roughly divided into early Shikumen Lilongs and later Shikumen Lilongs according to different construction periods. In addition, due to the systematic and complete research on the space-climate mechanism of Shikumen Lilongs. Incorporating Cantonese-style and new-style alleys into the research on the space-climate mechanism of Shikumen Lilongs. Four typical samples were selected from the four main types as the objects of the actual measurement and the simulation of building environmental performance control, and on this basis, a sample of the space-climate construction of Shikumen Lilong dwellings was established（Figure 21）.

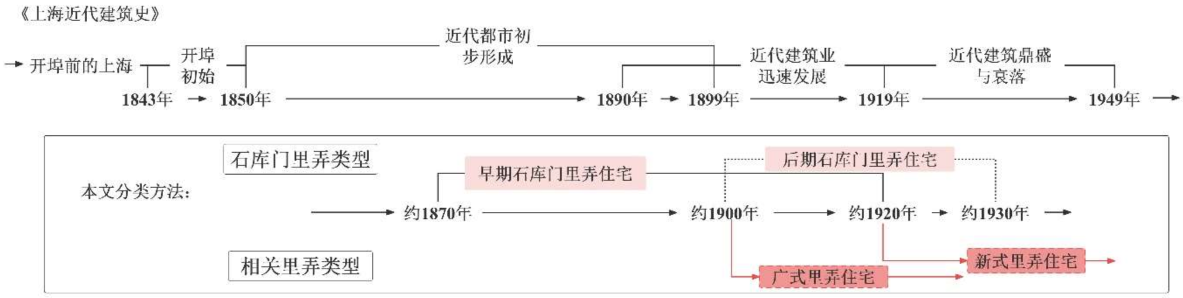


Figure 21 Four types of Lilong timelines Source: self-drawn

3.2.3 Typical morphological characteristics of Shikumen

The forms of the two types of Shikumen Lilongs and the two related types of houses in the lanes mentioned above have some common features: First, the four types of alleys are residential models mainly used for renting, which were built efficiently and completed in a short period of time under the promotion of land venture capital investment, and all of them have relatively high building density and high-density roads inside. Second, the urban texture is more homogeneous and decentralized. Except for streets, the density of other types of urban public spaces is extremely low. Third, there is a spatial sequence of "main alley-secondary alley-courtyard-living room-patio-attached room" or its simple variants in the four types of alleys. This section will briefly describe the characteristics of the two types of Shikumen Lilongs discussed in this paper and the two related types of houses in the alleys from the three main aspects of general layout, plane layout and section, and space functions.

3.2.3.1 Early Shikumen

General layout: Shikumen was the pioneer of the urbanization of traditional residential buildings in the south of the Yangtze River in the early days. Due to the limitations of its individual development model and social status, traditional residential buildings appeared on the urban land with clearly marked prices as an element of land commercialization for the first time. In order to maximize profits, build as many residential units as possible within the unit area, resulting in a tight overall layout. From the city street to the entrance of the alley, cross-street buildings are set up to distinguish the inside and outside. Most of the inner alleys are traditional Jiangnan dwellings horizontally connected to form the layout of the alleys. The width of alleys is about 2.5-3 meters, and the walking experience is poor. The scale of alleys in a single plot is relatively uniform, and there is no obvious primary and secondary structure.

Plane and section: In the early days, there were many types of Shikumen plans, but in general, three rooms or two rooms accounted for the largest proportion. As far as the overall development direction is concerned, the number of shikumen bays showed a decreasing trend. The main entrance is set on the central axis. Inside the main entrance is a nearly square patio. The living room is facing the patio. The size of the living room is about 4 meters, and the depth of the single building is about 15 meters. The wing rooms are arranged on both sides of the front patio, and the back patio connects the main house and the attached room. The wing rooms are open to the patio, with windows facing the outside if possible. The wall on the south side of the front courtyard is slightly lower than the eaves of the wing house, about 5 meters above, and does not open windows towards the secondary alley; the Shikumen Lilong at this time has not yet gotten rid of the introverted characteristics of the courtyard of the Chinese courtyard building. Later, with the reduction of the number of bays , there were double-story cases where a pavilion was built above the attached room. The top of the attached room was equipped with a balcony.

Spatial function: The functional layout of the internal space of the residence is the embodiment of the lifestyle of urban residents, and is closely related to the social environment during the construction period. From the opening of the port to about 1900, the main users of Shikumen Lilong houses in Shanghai were wealthy gentry households in the Jiangnan area, whose families were larger in size, and more wing rooms were set up to adapt to the current situation of multiple people living together. For example, in Gongshun Li, built in 1876, there are six wing rooms at the front, middle and rear on both sides of the living room on the first floor. The back part is the attached room and balcony used by the servants.（Figure 22）

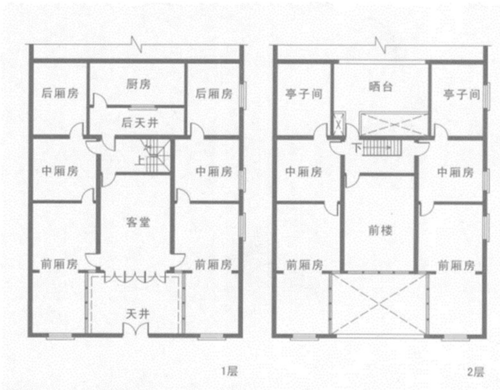


Figure 22 The floor plan of Gongshunli Source: Shanghai housing after its opening to foreigners

3.2.3.2 Cantonese Lilong

General layout: The inheritance and connection between Cantonese-style Lilong and Shikumen Lilongs are clearly reflected in the general plan. Residential units also adopt a determinant combination, three to four households share a building. Most of the residences strive for a south-facing layout. There is a cross-street building at the entrance of the lane, and water and sewage facilities for public use are set up in the lane. The second alley is very narrow, with a width of less than 3 meters, which is narrower than the early Shikumen.

Plane layout and section: Cantonese-style Lilong mostly use single bays, with a bay size of about 4 meters, which is shortened to about 3.5 meters in the later stage, and a depth of about 14 meters, which is reduced to about 6.5 meters in the later stage. The first floor is about 3.3

meters high, and the second floor is about 3 meters high. The main entrance of the residential unit is generally arranged in the center facing south, directly entering the living room from the secondary alley. The old Cantonese-style Lilong retains the back patio (Badaitou Cantonese-style Lilong), while the new Cantonese-style Lilong directly cancels the courtyard. The rear of the living room is the bedroom, and the bedrooms on the first floor are nested in the interior space of the main house, most of which have no direct connection with the outdoor space. The rear of the bedroom is the vertical circulation space and the kitchen in the attached room. The second floor of the main house is slightly overhanging, and there are two bedrooms in the north and south, with windows facing the outdoor space in the north and south respectively.

Space function: From the perspective of space function, the Cantonese-style alley is similar to the single-room early Shikumen Lilong. The living room-bedroom-kitchen is connected in series in the north-south direction, and the second floor is all bedrooms. From the perspective of functional streamlines and intensive use of space, the spatial function layout of Cantonese-style lanes is similar to that of Shikumen in the later period. It can be regarded as a "simplified version of Shikumen dwellings", which meets the needs of the middle and lower classes for short-term rental (Figure 18).

3.2.3.3 Later Shikumen

General layout: With the development of the economy, urban residents have higher demand for higher space quality, and pay more attention to issues such as building ventilation and lighting. In the later period, the layout of the general plan of Shikumen Lilong all strives to face south, but the layout of residential groups formed by horizontal parallel layout still continues. In consideration of the fire safety inside the inner alley, the scales of the main alley and the secondary alley are clearly differentiated at this time. The main alley is mostly about 5 meters wide, while the width of the secondary alley is mostly about 3 meters. As a result, the internal public space in the alleys has a clear hierarchy, and the structure presents a clear fishbone arrangement, which is obviously different from the homogeneous state of alleys in the early Shikumen.(Figure 23)

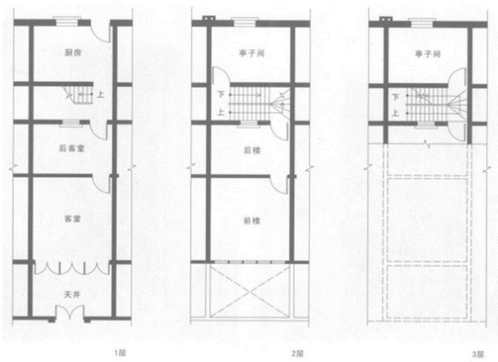


Figure 23 Floor plan of Jianyeli　Source: Shanghai housing after its opening to foreigners

Plane and section: In the late Shikumen Lilong houses, most of them were two rooms, single-room or room-and-a-half. In the two-room house, the main entrance is located in the middle of the front patio wall, which is shorter than the early Shikumen, and is located on the second floor window sill to reduce the shading of the living room lighting. The opening of the living room is about 4.5 meters. Compared with the early Shikumen Lilong, it tends to have a wider opening and a shallower entrance to achieve better lighting and ventilation effects. The rear of the living room is the traffic space and the reduced vertical back patio, and the north side of the back patio is the attached room. The second floor is all bedrooms, and the south-facing bedrooms are equipped with south-facing balconies. In single-room houses, functional spaces such as patio, living room, staircase and kitchen are connected in series in the north-south direction, and there is basically no back patio.The main house is mostly two-storey, with a storey height of about 3.3 meters, and the storey height of the attached room is relatively low, mostly three-storey.

Spatial function: The spatial function is not significantly different from that of the early Shikumen. Regardless of the shape of the bays, compared with the early Shikumen Lilongs, the late Shikumen Lilongs showed an obvious trend of miniaturization.

3.2.3.4 New-style Lilong

General layout: The new-style alleys evolved from the later Shikumen Lilongs. The general layout is the same as the new-style alleys in a determinant layout. The individual buildings are arranged southward. The scale of the alleys is significantly larger than that of the later Shikumen Lilongs. The length of main alley reaches 5-14 meters, which can better meet the needs of automobile traffic. The expansion of the scale of the main alley makes the hierarchy of the main and secondary alleys more obvious. Most of the secondary alleys are dead-end roads, which are connected to urban roads through the main alley. On the basis of convenient transportation, the tranquility of the secondary alleys can be guaranteed to the maximum extent, while improving the quality of the indoor living environment.

Plane layout and section: The main entrance of the single-room new-style lane is set on the side of the courtyard, opposite to the main entrance of the building. The interior is the living room (living room), followed by stairs and toilets, and then the back patio, kitchen and car room. The second and third floors are bedrooms. The two-bay new-style lane is arranged horizontally on the first floor with the living room and dining room, followed by the kitchen, servant's bedroom, traffic space and bathroom, and the second and third floors are still bedrooms. The inter-half type is to increase the stairwell on the basis of the single bay. The depth of the main space in the early new-style lanes was greater than the width of the face, while in the later period the width of the face was greater than the depth. The change trend of the overall shape is similar to the change trend of the early Shikumen to the later Shikumen. Consider the morphological changes produced by the needs of physical environmental factors such as ventilation and lighting. The fence of the front patio is made of iron, and the height is further reduced to only 2-3 meters. The front and rear parts of the building are still divided into two floors, separated by the traffic space and the back patio, and most of the front and back are three floors. The bottom layer is about 3.6 meters high, and the rest are about 3 meters high.

Spatial function: The interior space of single-family houses in the new-style alleys is more carefully divided, and there are small foyers, dining rooms, study rooms, small closets, sunrooms, and car rooms, which are functional spaces that adapt to the new way of social life. The semi-outdoor spaces such as patios and courtyards also gradually lose their original spatial characteristics with the reduction of the height of the wall and the opening of the enclosure, and gradually become appendages of the interior space.

3.2.3.5 Summary

Different types of Shikumen Lilong dwellings meet different market needs, and the evolution of their forms is a reflection of the social status. The development of Shikumen dwellings was originally developed to meet the housing needs arising from the influx of low-level population under the social status of urban development. It was based on the efficiency of space utilization and the control of costs and profits, and large quantities of traditional Jiangnan The product of the high-density aggregation of residential buildings into the urban environment. With the development of social economy and the gradual improvement of social policies and regulations, Shikumen Lilong naturally undergoes the above-mentioned morphological changes, resulting in two main types of Shikumen Lilong dwellings and two derivative types of Li Lane. According to the different construction times, the changes in the four types of dwellings generally present the following characteristics. The spatial orientation is more sophisticated, and the main orientation is to strive for the south. Due to the implementation and landing of policies and regulations, the arrangement of individual buildings has changed from relatively free to more regular. The squeeze of private space on urban public space is reduced, and the space of alleys gradually becomes regular. The size of the alleys is gradually decreasing. The hierarchy of alleys becomes obvious, and the scale of alleys shows a trend of increasing overall. The number of bays in a single building gradually decreases, the height of the storey increases, and the height of the enclosure wall gradually increases, and at the same time it becomes more transparent and outward-looking.

3.3 Sample selection of typical Shikumen

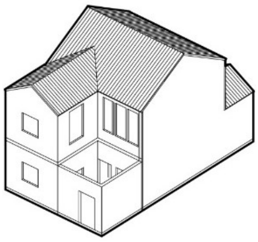
Judging from the aspect of social relationship and architectural features, Lilong is an obviously introverted residential complex. Most of the daily needs of the residents living in it can be solved within Lilong, and the social relationship between residents is also obviously introverted. The same is true for the physical space. The inner space and environment of the lanes are closely connected. From the perspective of form-energy: the close relationship of spatial form is reflected in the physical environment and energy flow of space. Although the sample of typical Shikumen dwellings in this study is a single residential building in a certain Shikumen Lilong, the research field of view is expanded from a single residential building to a group of dwellings in a lane or even the entire neighborhood. In order to be able to explore the space-climate mechanism of traditional dwellings in the urban background from a more macro perspective.

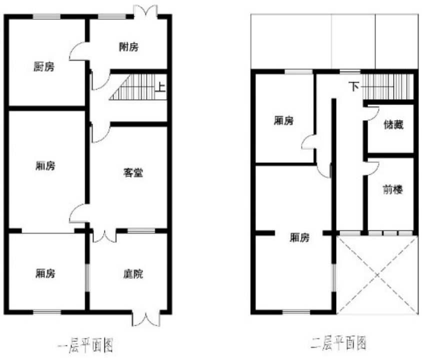
According to the two types of Shikumen Lilong dwellings and the two derived types mentioned above, the following four typical samples were selected for follow-up field survey and space-climate simulation (Table 4).

Table 4　Representative Types and Samples

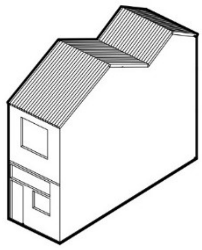
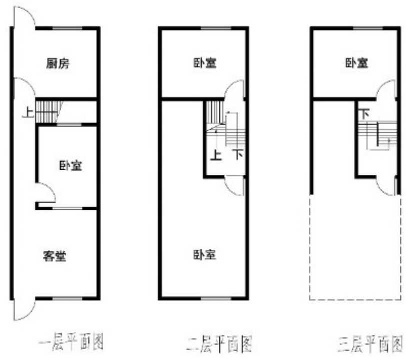
Typical sample information				
Type	Typical sample	Construction time	Address	Note
Early Shikumen（about 1870s-1920s）	Wangyun road 146 Long	About 1920	Lane 146, Laochengxiang, Huangpu District	The construction period is relatively coincident, and the two earlier types of Lilong dwellings
Cantonese-style Lilong（about after 1900）	Shunchang Road 504 Long	1926	Lane 504, Shunchang Road, Huangpu District	
Later Shikumen（about 1900s-1930s）	Siming Village	1932	Lane 913, Yan'an Middle Road, Jing'an District	Two types of Lilong dwellings whose construction periods overlap relatively and are relatively late
New style Lilong（about after 1920s）	Jinghua new village	1937	Between Changshu Road and Fumin Road, Jing'an District	

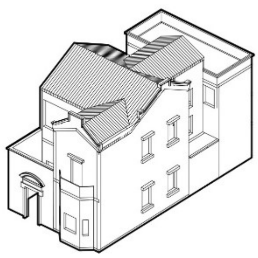
Table 5 Sample Information Sheet

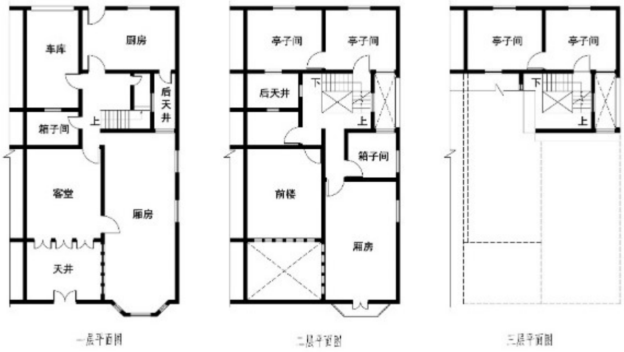
Sample No.		SKM-01	**Location**	121.5°E		**Photo**
Name		Wangyun Road 146 Long		31.2°N		
Function		Residential	**Type**	Early Shikumen		
Location	**City**	Shanghai	**Plane**	**Room**	2	
	District	Huangpu		**Depth**	1	
	Street	Wangyun Road 146 Long	**Storey**		2	**Simplified model**
Orientation	14° East by South		**Roof form**		Hard gable roof	
Construction time		About 1920	**Area/㎡**		About 93 ㎡	
Preservation status		Good	**Building Area/㎡**		About 157 ㎡	
Current use		Idle to be demolished	**Protection level**		NO	
Sample Plane						

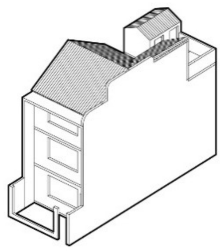


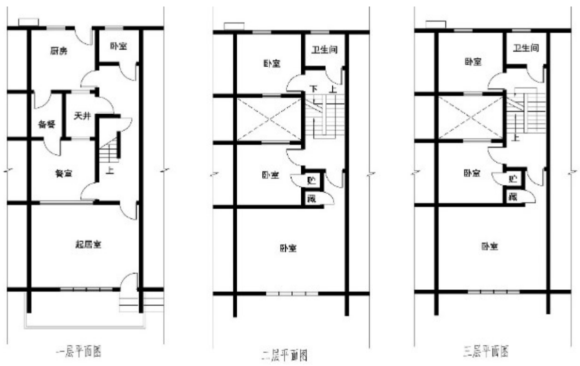
Sample No.		SKM-02	**Location**	121.5°E		**Photo**
Name		Shunchang Road 504 Long		31.2°N		
Function		Residential	**Type**	Cantonese-style Lilong		
Location	**City**	Shanghai	**Plane**	**Room**	1	
	District	Huangpu		**Depth**	1	

<table>
<tr><td></td><td>Street</td><td>Lane 504, Shunchang Road</td><td>Storey</td><td>Front:2
Back:3</td><td>Simplified model</td></tr>
<tr><td>Orientation</td><td colspan="2">20° south by east</td><td>Storey</td><td>Hard gable roof</td><td rowspan="4"></td></tr>
<tr><td colspan="2">Construction time</td><td>1926</td><td>Roof form</td><td>About 32 m²</td></tr>
<tr><td colspan="2">Preservation status</td><td>Good</td><td>Area/m²</td><td>About 74 m²</td></tr>
<tr><td colspan="2">Current use</td><td>Idle to be demolished</td><td>Building Area/m²</td><td>NO</td></tr>
<tr><td colspan="6">Sample Plane</td></tr>
<tr><td colspan="6">
</td></tr>
</table>

<table>
<tr><td colspan="2">Sample No.</td><td>SKM-03</td><td rowspan="2">Location</td><td colspan="2">121.5°E</td><td>Photo</td></tr>
<tr><td colspan="2">Name</td><td>Siming village</td><td colspan="2">31.2°N</td><td rowspan="5"></td></tr>
<tr><td colspan="2">Function</td><td>Residential</td><td>Type</td><td colspan="2">Later Shikumen Lilong</td></tr>
<tr><td rowspan="3">Location</td><td>City</td><td>Shanghai</td><td rowspan="2">Plane</td><td>Room</td><td>2</td></tr>
<tr><td>District</td><td>Jing'an</td><td>Depth</td><td>1</td></tr>
<tr><td>Street</td><td>Lane 913, Yan'an Middle Road</td><td colspan="2">Storey</td><td>Front:2
Back:3</td></tr>
<tr><td>Orientation</td><td colspan="2">19° south by east</td><td colspan="2">Roof form</td><td>Hard gable roof</td><td rowspan="4"></td></tr>
<tr><td colspan="2">Construction time</td><td>1932</td><td colspan="2">Area/m²</td><td>About 132 m²</td></tr>
<tr><td colspan="2">Preservation status</td><td>Good</td><td colspan="2">Building Area/m²</td><td>About 260 m²</td></tr>
<tr><td colspan="2">Current use</td><td>Residential</td><td colspan="2">Protection Level</td><td>Municipal</td></tr>
<tr><td colspan="7">Sample Plane</td></tr>
</table>



Sample No.		SKM-04	**Location**	121.5°E		**Photo**
Name		Jinghua new village		31.2°N		
Function		Residential	**Type**	New style Lilong		
Location	**City**	Shanghai	**Plane**	**Room**	1	
	District	Jing'an		**Depth**	1	
	Street	Lane 820,Julu Road	**Storey**		Front:2 Back:3	**Simplified model**
Orientation		28° south by east	**Roof form**		Hard gable roof	
Construction time		1937	**Area/㎡**		About 93 ㎡	
Preservation status		Good	**Building Area/㎡**		About 252 ㎡	
Current use		Residential	**Protection Level**		Municipal	
Sample plane						



3.4 Research scope of typical samples

Clear hierarchy and close connection are the spatial features of Shikumen Lilong dwellings. This study limits the research scope and research objects of four typical samples as shown in

Figure 24. The research scope includes the main, secondary alley space and architectural space, which is an effective way to fully present the hierarchical relationship of "main alley-secondary alley-courtyard-interior space". It is also the main area for collecting environmental performance factors of typical samples. Expanding the scope of sample research to the level of building complexes is a necessary condition for exploring the real space-climate mechanism of Shikumen. The building complex formed by main alleys, secondary alleys and typical single building spaces within the research scope is taken as the research object. Try to ensure that the research object is placed in the real neighborhood form, and explore the space-climate mechanism of Shikumen in a holistic, continuous, and associated feedback space collection.

The rationality of space division logic facilitates the establishment of a synergistic perspective of "climate-space-energy". The above-mentioned limited method puts the individual residential buildings in Shikumen Lilong in a specific space environment to conduct research on the mechanism of space climate. Reasonable coupling of the five space-climate mechanisms and the spatial hierarchy of Shikumen Lilong . Explore the extension of energy construction from the scale of residential units to the scale of neighborhoods.

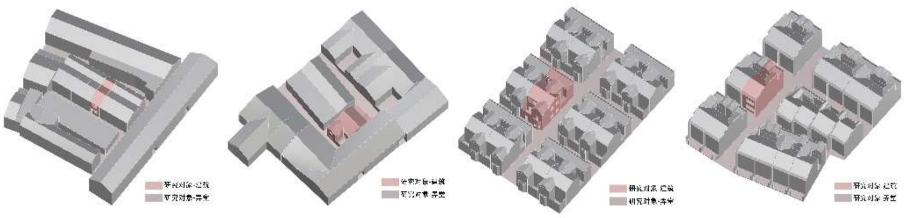


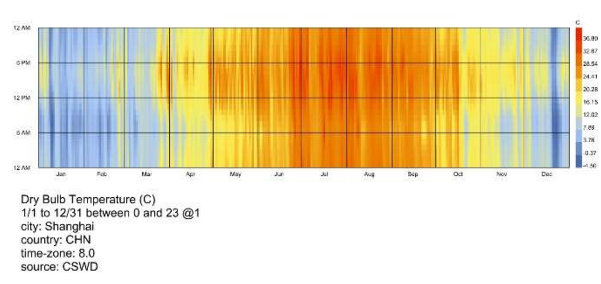
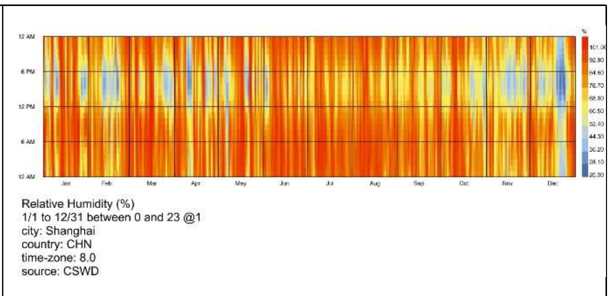
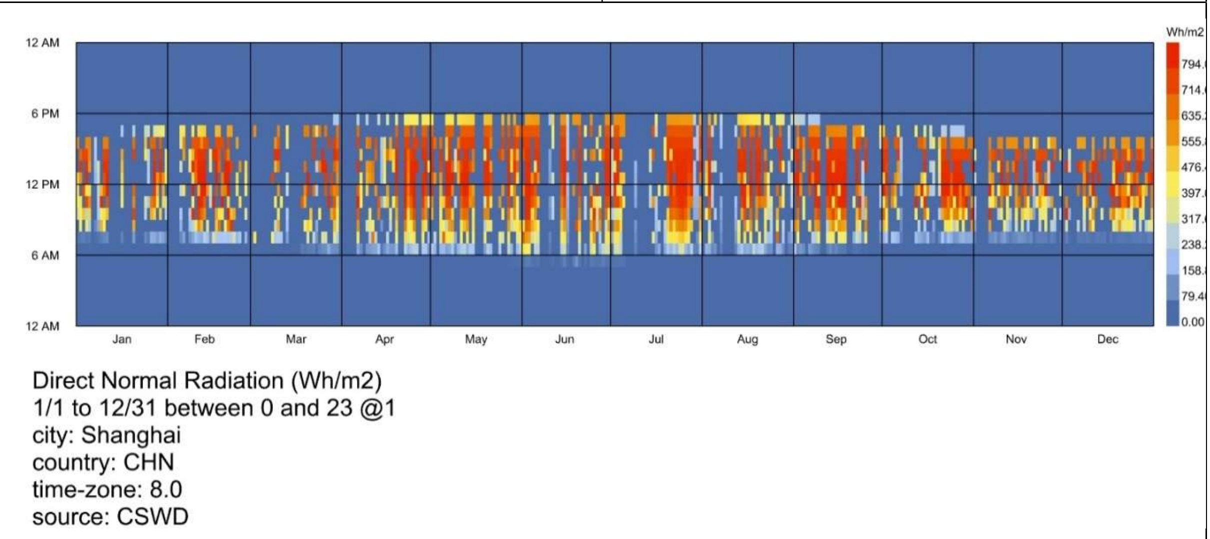
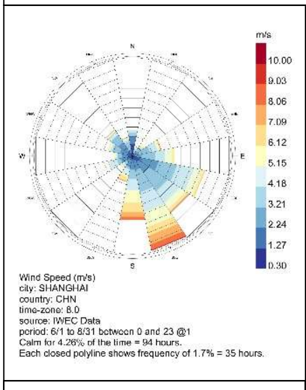
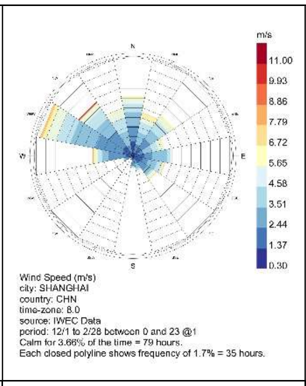
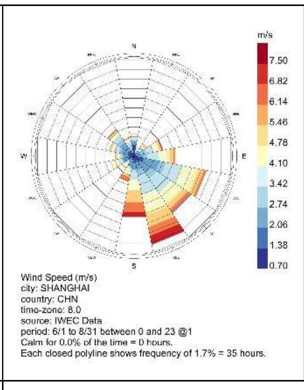
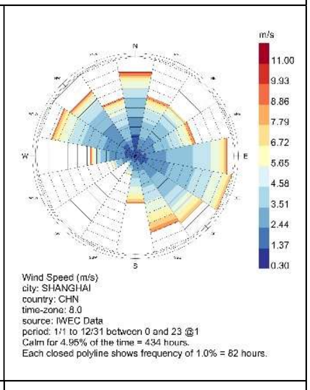
Figure 24 Sample research scope and research objects Source: self-drawn

3.5 Sample meteorological data analysis and on-site measurement points

3.5.1 Sample location and climate

Shanghai is located at the frontier of the Yangtze River Delta, with flat terrain and the Huangpu River passing through it. It is one of the cities with the most rapid urbanization in modern China. Shanghai has a subtropical monsoon climate. The city's annual average temperature is 17.6°C, with a maximum temperature of 40°C in summer and a minimum temperature of minus 4.5°C in winter. The climate in Shanghai is relatively humid. According to the annual relative humidity chart of Shanghai, the relative air humidity in Shanghai exceeds 60% for 80% of the time throughout the year. The Shanghai area enjoys sufficient sunshine, with an average annual sunshine duration of over 5 hours. According to the visual analysis of meteorological data, the prevailing wind direction in Shanghai is southeast wind throughout the year, and the wind direction in this area varies significantly in seasons. Generally speaking, the prevailing wind direction is mainly southeast and northwest wind. The northwest wind prevails in January in winter, and the maximum wind speed can exceed 6m/s. In July in summer, the northeasterly and southeasterly winds are the dominant wind directions, and most of the time it is a breeze, with only a few periods exceeding 5 m/s.(Table 6)

Table 6 Shanghai typical climate data table

<table>
<tr><td colspan="2">
</td><td colspan="2">
</td></tr>
<tr><td colspan="2">Annual dry bulb temperature</td><td colspan="2">Annual relative humidity</td></tr>
<tr><td colspan="4">
</td></tr>
<tr><td colspan="4">Annual solar radiation</td></tr>
<tr><td>
</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Summer wind rose</td><td>Winter wind rose</td><td>Summer comfort wind rose</td><td>Annual wind rose</td></tr>
</table>

According to the UTCI (Universal Thermal Climate Index) in Shanghai, the spring and autumn seasons in Shanghai are relatively comfortable, while the comfort index is low in winter and summer. In summer, there is an extremely hot state from June to August, while in winter, from December to February, there is less extreme cold weather. Considering the wind environment and sunshine environment, the thermal comfort state of the outdoor space is about 44%, According to the UTCI, the key to the climate regulation of urban outdoor spaces in the

Shanghai area is ventilation and heat dissipation, which increases the thermal comfort of space in extremely hot weather from June to August (Figure 25)

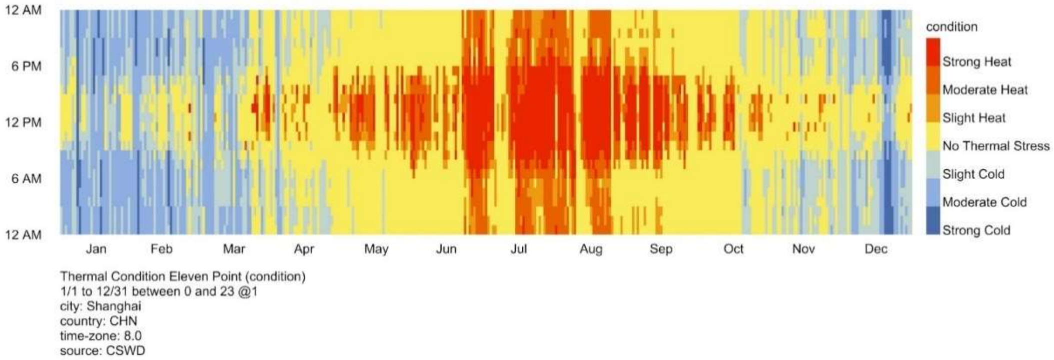


Figure 25 UTCI in Shanghai Source: self-painted

The indoor comfort analysis chart of PMV in Shanghai area clearly presents: In the natural state, only 15.47% of indoor areas in Shanghai are in a thermal comfort state throughout the year. Under the conditions of adding passive solar auxiliary heating, thermal insulation wall, sunshade + night ventilation and evaporative cooling, 55.57% of the whole year is in thermal comfort state. It is not difficult to see from further analysis that Shanghai is a typical city with a hot summer and cold winter climate, and the climate conditions in indoor spaces in winter and summer cannot meet the thermal comfort needs of the human body most of the time. In winter, the use of thermal insulation walls and passive solar heating system can significantly improve the thermal comfort of indoor space in cold seasons. However, shading + night ventilation and evaporative cooling are not effective in alleviating the climate environment in hot seasons, especially under extreme high temperature conditions, it is difficult to maintain the thermal comfort state of the indoor space environment through the simple passive strategies mentioned above. Therefore, "heat insulation in summer and heat storage in winter" has become the main goal of building environment regulation in Shanghai. (Figure 26)

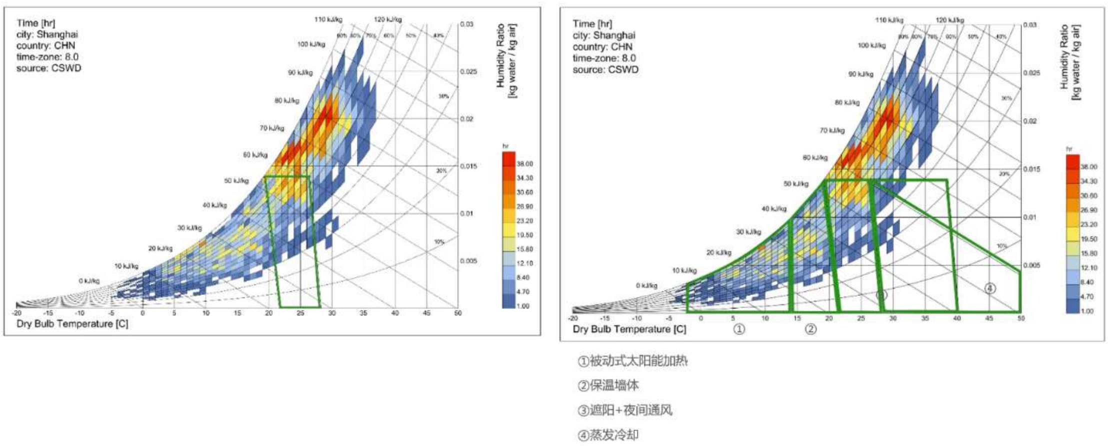


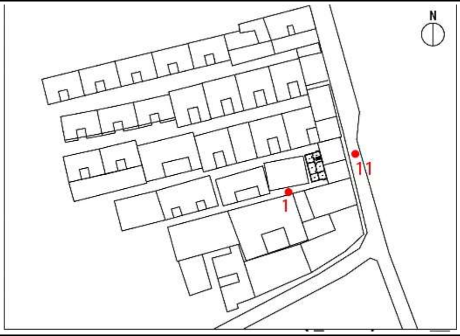
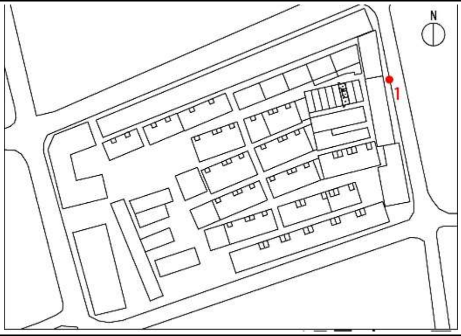
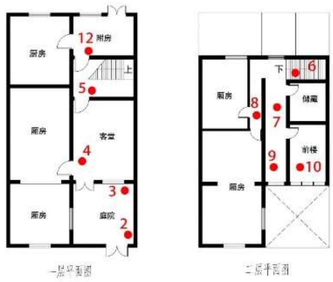
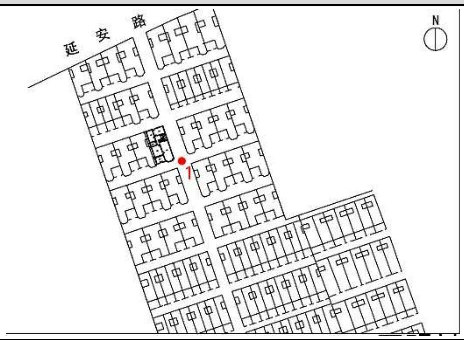
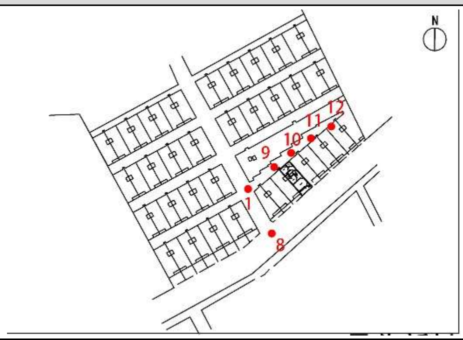
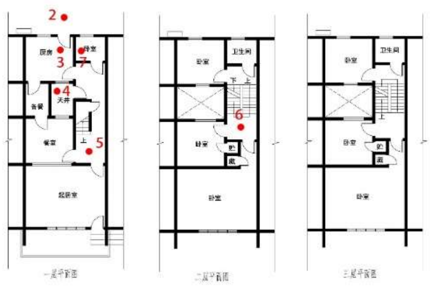
Figure 26 Shanghai PMV indoor comfort analysis map Source: self-drawn

3.5.2 Distribution of on-site measurement points

There are two layout logics and overall goals for on-site measured data collection:

Firstly, collect the main space weather data inside the typical sample. The second is the collection of gradient changes in the urban space-main alley-secondary alley-courtyard-indoor space sequence environmental meteorological data. The special urban environment in which the Shikumen Lilong dwellings are located, the main alley and the secondary alley are the buffer spaces between the Shikumen Lilong dwellings and the urban space, so they are included in the discussion. The site layout diagram is shown in Table 7:

Table 7 On-site measurement points

SKM-01	SKM-02
	
	
1: secondary alley, 2, 3: courtyard, 4: living room, 5, 6: staircase, 7, 8, 9: corridor on the second floor, 1 0: wing room on the second floor, 11: main alley, 12: attached room	1: main alley, 2, 3: secondary alley, 4: living room, 5: wing room on the second floor, 6: attached room
SKM-03	**SKM-04**
	
	
1: main Alley, 2: courtyard, 3: living room, 4: box room, 5:staircase	1: main alley, 2, 9, 10, 11, 12: secondary alley, 3: courtyard, 4: patio, 5: staircase, 6: second-floor staircase, 7: attached room

3.6 Chapter summary

This chapter summarizes the process of its origin, development and decline, and the historical reasons behind it by sorting out the development history of Shikumen Lilong dwellings and the closely related Lilong dwellings. Summarize the mainstream classification methods of Shikumen Lilong dwellings, and adjust the classification method from the perspective of space-climate regulation to form a classification method that meets the needs of studying the space-climate mechanism of Shikumen Lilong residential areas and facilitates the extraction of the space-energy interaction law of Shikumen Lilong.

According to the social and historical background and the typological characteristics of the development of Shikumen Lilong dwellings, the Shikumen Lilong dwellings are divided into early Shikumen Lilongs and later Shikumen Lilongs. Considering the trend of morphological evolution during the development of Shikumen Lilong dwellings, the Cantonese-style Lilong and the new-style Lilong are brought into the research field of vision. From the perspective of spatial form, a relatively complete set of classification and evolution of Shikumen Lilongs is formed, and the spatial morphological characteristics of the four types of lanes are briefly analyzed. Then select a typical sample from each of the four types. Limit and divide the sample research scope, levels and objects as the basis for exploring the multi-level continuous space-climate mechanism of Shikumen Lilong dwellings in neighborhoods, alleys and residential units. Finally, this chapter sorts out the macro-climate characteristics of the Shanghai area, which are hot and rainy in summer and cold and humid in winter. Through the analysis of the annual outdoor UTCI and indoor PMV thermal comfort evaluation index in Shanghai area. It is clear that the main goal of space-climate regulation in Shanghai is "heat insulation in summer and heat storage in winter". Based on the spatial sequence of "main alley-secondary alley-courtyard-living room-back patio-attached room", the points for collecting environmental performance factors of four typical samples were determined according to local conditions, so as to facilitate the subsequent on-site measurement.

Chapter4. The Space-Climate Mechanism of Shanghai Shikumen Residential Houses

From the perspective of "climate-space-energy" synergistic association, there is a space-climate mechanism in residential buildings that effectively responds to natural climate and rationally organizes energy flow. The space-climate mechanism refers to the mechanism by which buildings realize the reasonable flow and transformation of internal and external energy in the climate environment through the shaping and organization of space, revealing the translation structure between energy flow and configuration adjustment. The space-climate mechanism includes five aspects: space climate selection, physical space type, space climate gradient, climate control interface, and performance-oriented structure.

The traditional houses in the south of the Yangtze River have typical climate adaptability characteristics. The evolution of the morphological types of the Shikumen Lilongs is a process of adapting to urban life. The difference between the space and energy of Shikumen Lilong dwellings brought about by the difference of these configuration elements has become one of the core issues of this research. This chapter mainly explores the space-climate mechanism of Shikumen dwellings through the simulation of sample wind, light and thermal environment and the analysis and interactive verification of measured data.

4.1 Space climate selection

4.1.1 Climate selection mechanism

The construction process of residential buildings, through the control of elements such as site selection, settlement combination, and building orientation, responds architecturally to the climate environment in which the building is located at a macro level. Reasonably regulate and utilize climate factors such as solar radiation and air flow in the environment, and use the ingenuity of spatial form to avoid disadvantages. Selectively adjust the flow of indoor and outdoor matter and energy to maintain a comfortable and stable state in the room. The basic principles of site selection for villages and walled cities, such as "backing the mountain and facing the water" and "embracing the yang" as the ancients said, are the concentrated expression of the climate selection mechanism. Many existing traditional residential villages such as Hongcun and Xidi embody the above-mentioned space-climate selection mechanism.

4.1.2 On-site measurement and analysis

Shikumen Lilong dwellings at the group-group-body-interlevel level can reflect the consistency of their site selection and orientation measures based on the selection of favorable climatic elements and the weakening or avoiding of unfavorable climatic elements. The macro sites of the four typical samples are all located in the alluvial plain of the Yangtze River Delta, with an average elevation of about 2.19 meters. Although the site selection of Shikumen is more affected by the effect of urban accumulation, it is undeniable that the orientation of Shikumen Lilong is chosen. On the one hand, it is deeply influenced by the concept of space-climate regulation. In this study, the difference in environmental climate selection is mainly represented by the difference of three building configuration factors of typical cases, wind, thermal azimuth and inclination angle.

The wind azimuth angle is defined as the angle between the main ventilation interface of the building and the prevailing wind direction, which represents the ability of the building to use the prevailing wind to promote indoor ventilation under different orientations. From the perspective of the whole year, the prevailing wind direction in the Shanghai area is 22.5° from east to south, and the wind direction lasts for about 820 hours, and the wind from the due east lasts for 779 hours. The prevailing wind direction in winter is west-north 22.5° and the duration is about 656 hours. The annual wind direction in Shanghai is mainly from the southeast and northwest. The duration of the prevailing wind in the two directions is relatively close, and the difference is within dozens of hours. Considering that the main goal of space regulation in Shikumen dwellings is ventilation and dehumidification in summer and heat storage and heat preservation in winter, the requirement for ventilation efficiency is more significant in summer. In this study, 22.5° east by south is taken as the local prevailing wind direction. The wind azimuth angles of the four samples can be obtained through on-site measurement, as shown in Table 8.

The difference in the wind and thermal inclination angles of the façade enclosure structure and the roof system of residential buildings is the performance of the environmental climate selection. The building controls the rate of flow and interaction between natural climate factors such as light, radiation, and airflow and the indoor space through the change of the inclination angle of the facade and the roof, and regulates the climate environment of the indoor space. Generally speaking, the wind and thermal inclination angles of residential buildings include the inclination angles of the windward side of the facade enclosure structure and the inclination angles of the windward side of the roof. The vertical enclosure structures of the four typical samples are all vertical walls, so the wind and thermal inclination angles of the façades are not discussed. In this study, the inclination angle refers to the wind and thermal inclination angle of the roof. According to the definition, the roof wind and thermal inclination angle can be uniformly defined by the roof inclination angle. According to the actual survey and investigation, the roof inclination angles of the four typical samples are concentrated around 28° (Table 9).

The measured wind speed data shows that the instantaneous wind speed of the main and secondary alleys of the sample can reach 2m/s. The wind environment in the alleys of Samples 3 and 4 is better than that of Samples 1 and 2, especially in the secondary alleys. According to the measured wall surface temperature data, in summer, the south-facing facade of Shikumen residences is the main heating surface, followed by west-facing and east-facing surfaces.

Table 8 Sample residential wind azimuth

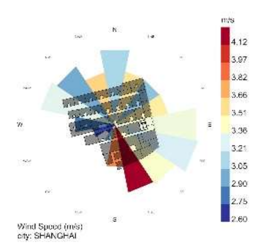
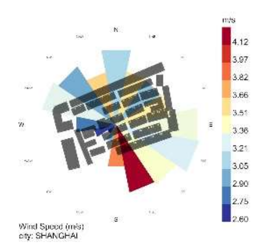
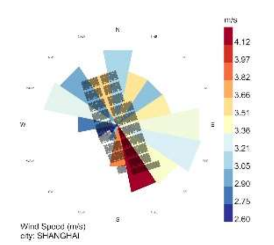
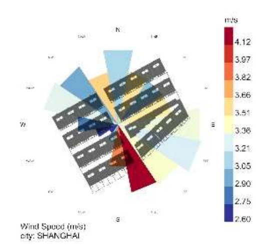
SKM-01	SKM-02	SKM-03	SKM-04
			
Building Wind Azimuth:37°	Building Wind Azimuth:45°	Building Wind Azimuth:41°	Building Wind Azimuth:51°

Table 9 Sample roof slope angle

Sample	SKM-01	SKM-02	SKM-03	SKM-04
Roof slope angle	30°	26°	29°	30°

4.1.3 Environmental performance simulation

4.1.3.1 Wind azimuth selection

According to the heat map of the wind environment simulation under the prevailing wind conditions of four typical samples throughout the year, it can be known that:

The building wind azimuth angle of Lane 146 on Wangyun Road is 37°, the average wind speed in the alley is about 1m/s, the area of the alley facing the city street is the tuyere area, and the wind speed at the bottom of the building crossing the street exceeds 2.5m/s. The wind speed distribution in the alleys is uneven. The air velocity in most alleys is lower than 2m/s. Except for some areas, it cannot meet the indoor ventilation requirements. The spatial distribution of wind speed in alleys decreases gradually with the distance from urban streets. The wind speed in the depths of the alley is much lower than the average value, and the air flow in the courtyard is slow, with the wind speed basically lower than 1m/s.

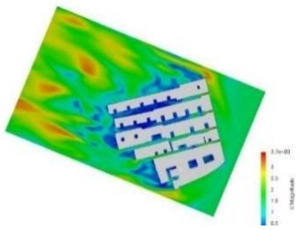
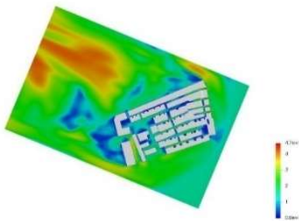
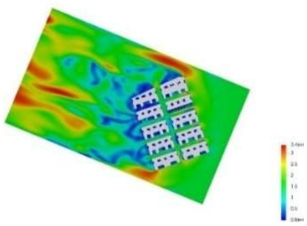
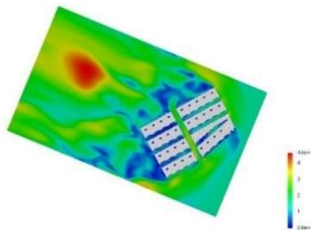
The wind azimuth angle of Shunchang Road 504 is 45°, and the wind speed inside the alley is relatively uniform, with an average wind speed of about 1.5m/s. The wind speed at the junction of alleys and urban streets can reach up to 4m/s, and the wind speed in relatively closed alleys in neighborhoods is less than 0.5m/s. The overall average wind speed of the north-south alleys is higher than that of the east-west alleys.

The azimuth angle of the wind in Siming Village is 41°, and the wind speed in the primary and secondary alleys is relatively uniform, with an average wind speed exceeding 2m/s, which can meet the indoor ventilation needs. High wind speed nodes with wind speed exceeding 3.5m/s appear in the junction area between the alleys on the windward side and the urban streets. The air flow inside the courtyard is also significantly improved compared with the previous two samples, and the wind speed in the back patio area is basically 0 at a height of 2 meters.

The azimuth angle of the wind in Jinghua New Village is 51°, the angle between the direction of the main alley and the direction of the incoming wind is smaller, and the wind speed of the main alley and the secondary alley is obviously hierarchical. The average wind speed of the main alley is higher than 3m/s, and the average wind speed of the secondary alley is 2m/s, which is equal to the average wind speed of the secondary alleys of Siming Village. The value basically meets the ventilation requirements of the indoor space, but the large wind azimuth causes the front row of buildings to have a more obvious shielding effect on the rear row of buildings. From the wind environment simulation, the air velocity of the secondary alley shows a trend of gradually decreasing from south to north (Table 10).

Table 10 Simulation of wind environment at a height of 2m under prevailing wind direction

Source: self-drawn

SKM-01	SKM-02
	
SKM-03	SKM-04
	

Simulation of air velocity under different wind azimuth angles by Siming Village sample with the best overall ventilation effect in the sample (Table 11): When the wind azimuth angle of the buildings arranged in determinant is 0°, the direction of the secondary alley is parallel to the prevailing wind direction. At this time, the average wind speed of the main alley is about 1.5m/s, and the ventilation effect of the secondary alley is the best, and the air velocity can reach more than 2m/s , The wind speed in some areas is as high as 2.5m/s. The air flow takes away the dirty air, and all of them are in the range of comfortable wind speed outside the human body. The alleys adopt a criss-cross layout, and the sub-alleys are parallel to each other. Ideally, the difference in wind speed between the front and back sides of a group of buildings is relatively small, resulting in a wind pressure difference of only about 1Pa between the front and back sides of the building, which is not conducive to the formation of drafts.

When the building wind azimuth gradually increases to about 40°, the wind speed of the sub-lane street decreases, but can still reach 1.5-1.8m/s, and the wind speed of the main alley rises, with an average wind speed of 2m/s. The appearance at the end of local alleys can meet the ventilation requirements of streets and alleys without negatively affecting human comfort. More importantly, under the condition of the wind azimuth angle, the secondary alley forms a certain angle with the prevailing wind direction, and the secondary alley on the windward side of the building and the secondary alley on the leeward side form an air pressure difference as high as 2 Pa, which is conducive to indoor wind pressure ventilation.

When the wind azimuth angle increases to 90°, the main ventilation interface and secondary alleys of the building are perpendicular to the prevailing wind direction, and the wind speed of the main aisle increases significantly, with an average wind speed of more than 2m/s. Buildings with determinant layout in the wind direction have the highest face-on wind pressure, which can reach 3Pa, and the air velocity is also the maximum value of 2.5m/s. Due to the uniform height of residential buildings in Shikumen Lilong, the main ventilation interface of the buildings at the rear of the determinant layout has relatively low wind pressure, and the wind pressure difference between the north and south sides is small, less than 1Pa, which is not conducive to indoor wind pressure ventilation. The air velocity in the secondary alley at the rear of the residence is very slow, with an average value of less than 0.5m/s, which is far from meeting the ventilation requirements of the secondary alley (Table 12). The wind azimuth angles of the four typical samples are all around 40°. From the simulation results, it is inferred that this angle range is the best wind azimuth range that can better take into account the ventilation effect of the sub-alley and the interior space of the building.

Table 11 Simulation of Air Velocity at Different Wind Azimuth Angles in Siming Village

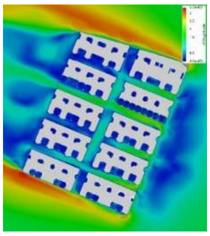
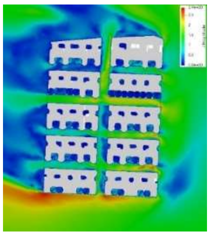
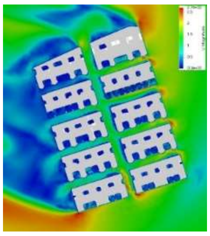
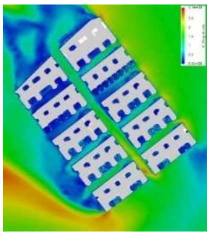
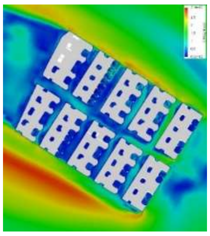
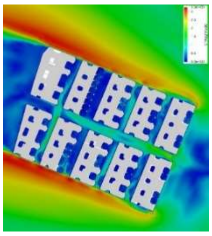
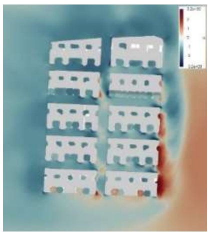
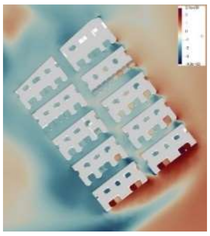
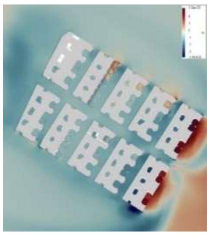
Wind Azimuth:0°	Wind Azimuth:20°	Wind Azimuth:40°
		
Wind Azimuth:60°	Wind Azimuth:80°	Wind Azimuth:90°
		

Table 12 Simulation of wind pressure at different wind azimuth angles in Siming Village

Wind Azimuth:0°	Wind Azimuth:20°	Wind Azimuth:40°
		
Wind Azimuth:60°	Wind Azimuth:80°	Wind Azimuth:90°
		

To sum up, when the building wind azimuth angle is close to 0°, the ventilation and heat dissipation of the residential units in the central area is poor, and when the wind azimuth angle is close to 90°, the air flow state in the secondary alley is the best. A relatively uniform low-pressure area is formed in the secondary alley, and the wind pressure difference between the front and rear interfaces of the building is small, making it difficult to form drafts. When the wind azimuth angle is about 40-60°, the air flow of the sub-lane and the air pressure difference at the main ventilation interface of the building show better performance, and the air flow of the sub-lane-building interior-sub-lane is better formed. It plays a better role in indoor heat dissipation and dehumidification in summer (Table 13). This kind of high-density urban traditional settlement adopts the low-pressure ventilation method of alleys, which is relatively common. For example, the entrance streets of the "liyuan folk houses" in Qingdao are facing south to east, and the streets should be in the direction of the ocean monsoon to ensure the air flow of the urban streets to meet the indoor ventilation needs. The summer ventilation patterns of the four typical samples are also roughly consistent with this.

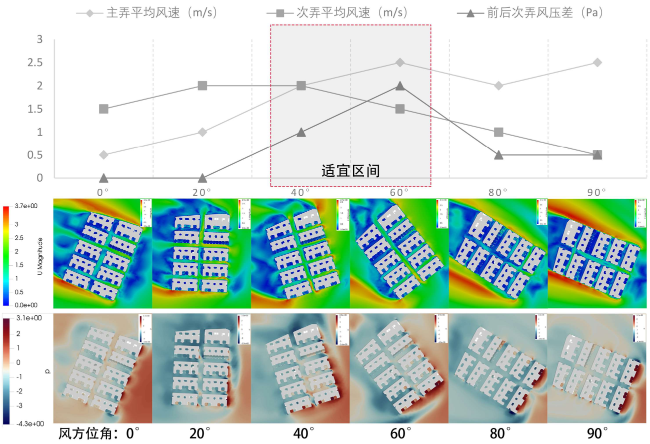


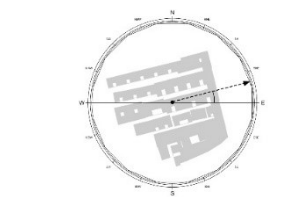
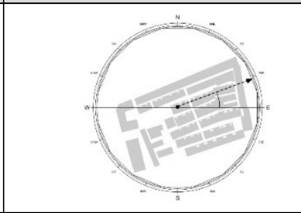
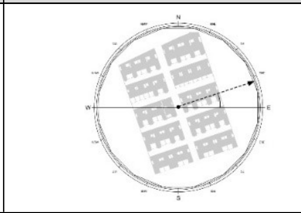
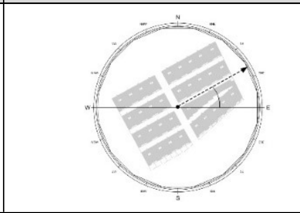
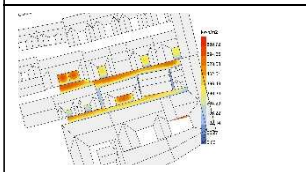
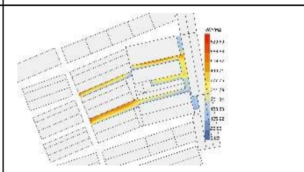
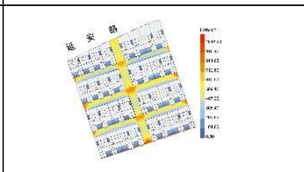
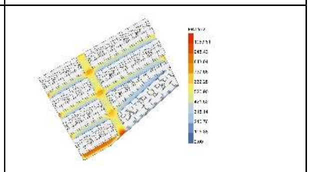
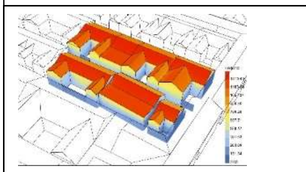
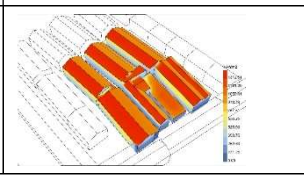
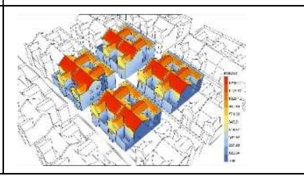
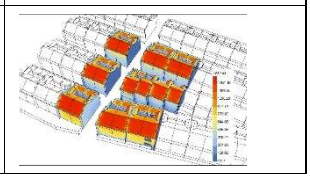
Table 13　Wind azimuth selection source: self-drawing

4.1.3.2 Thermal Azimuth Selection

The thermal azimuth is defined as the angle between the direction of the main heating surface of the building and the geographic east direction, which represents the ability of the building to absorb solar radiation energy at different orientation angles [10]. It can be obtained by calculation that the thermal azimuth angle values of the four typical samples are relatively concentrated, all of which are about 20°, that is, the orientation of the building is about 20° south by east. Through the annual solar radiation simulation of four typical samples, it can be known that the alley radiation levels of samples No. 1 and No. 2 are relatively low, with peak values lower than 700 KW·h/㎡, and the street radiation peaks of No. 3 and No. 4 samples are both at 1000 KW·h/㎡ above. Among them, the main and secondary alleys present a relatively obvious hierarchy, and the peak values of the secondary alleys are all lower than 700 KW·h/㎡. Here, the wind azimuth angles of the two groups of samples are similar, and the obvious difference in the radiation level of the alleys is mainly due to the differences in their scales, which will be discussed in Section 4.2 of this paper. The north-south radiation of the east-west alleys is quite different, and the lowest value is only about 200 KW·h/㎡ in the building area near the south side. In the exposed enclosure interface of the sample, the solar radiation index is the highest on the roof, the three facades of south-west-east decrease in order, and the north facade is the lowest, that is, the main heating surface is the south-facing interface. The highest radiation peak value of the south-facing heating surface is the south-facing facade in sample 1, and the lowest peak value is 644 KW·h/㎡ of sample 4 (the area not affected by horizontal sunshade), and samples 2 and 3 rank third and fourth respectively (Table 14).

[10] 肖葳. 适应性体形绿色建筑设计空间调节的体形策略研究[D].东南大学,2018.

Table 14 Thermal azimuth angle of sample dwellings and simulation of heat radiation in hot summer days

SKM-01 ： Thermal Azimuth: 14°	SKM-02： Thermal azimuth: 20°	SKM-03： Thermal Azimuth: 19°	SKM-04： Thermal azimuth: 28°
			
			
			

Taking Siming Village as a representative sample, the thermal radiation level can be known by simulating its thermal radiation level under different thermal azimuth angles. When the front eave wall is used as the main heating surface, as the solar azimuth increases, the heat radiation level of the north-south alley gradually decreases, the heat radiation level of the east-west alley gradually increases, and the heat radiation peak value of the main heating surface gradually decreases. The simulation results show that when the thermal azimuth of the sample is 0°, the average solar radiation value inside the sub-lane is less than 300 KW·h/㎡. When the overall orientation of the sample building is 10°-30° south by east, the main and secondary alleys in this interval receive relatively uniform solar radiation throughout the year（Table 15）; When the building is facing the due south direction, the peak value of heat radiation on the front eaves wall reaches 1283 KW·h/㎡, and the peak value of solar radiation on the south-facing facade is above 700 KW·h/㎡, which is concentrated in the cornice area. When the thermal azimuth is at 20°-30°, the peak thermal radiation of the façade in the direction of the south bay gradually drops to about 600 KW·h/㎡. When the thermal azimuth of the building is above 50°, the gable surface replaces the front eaves wall as the main heat radiation surface. Therefore, it can be basically judged that when the building thermal azimuth angle is 20°-30°, the heat radiation in the two main heating directions of south and west is relatively uniform（Table 16）。

During the investigation of building solar radiation simulations at different thermal azimuths in Siming Village on great heat, it was found that the alley, as an urban public space, not only undertakes the transportation function, but also serves as an important space for residents to communicate and gather inside the alley. Therefore, ensuring uniform and appropriate solar radiation inside the alley is a necessary factor to improve the comfort and sanitation of the space. Through the simulation, it can be seen that the optimal thermal orientation range of residential buildings in Shikumen Lilong is about 20°-30°, which is determined on the basis of reasonable utilization of solar radiation and comprehensive consideration of thermal comfort in winter and summer.

The thermal azimuth angles of the four typical samples are all about 20°. According to the simulation results of solar radiation in different orientations of sample 3, it can be seen that when the thermal azimuth angle of the building is 20°-30°, the heat radiation in the two main heating directions of south and west is relatively uniform At the same time, both the main and secondary alleys can get a certain amount of solar radiation to ensure the quality of urban public space (Figure 27).

To sum up, through the simulation of the wind environment, the best orientation of the building is 20°-40° east of south, and the simulation of solar radiation shows that the best orientation of the building is between 20°-30° east of south. Considering the wind and heat factors comprehensively, the optimal building azimuth range of Shikumen Lilong residential buildings is 20°-30° south by east.

Table 15 Simulation of solar radiation in alleys of different thermal azimuths in Siming Village on great heat

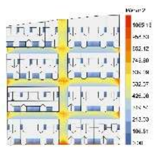
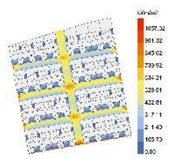
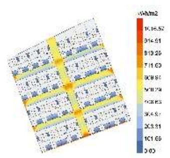
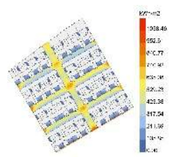
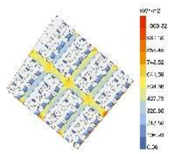
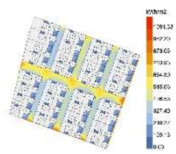
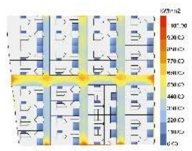
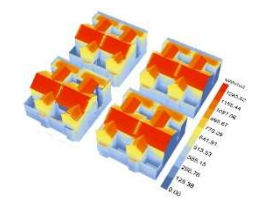
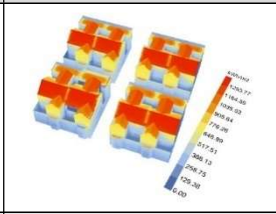
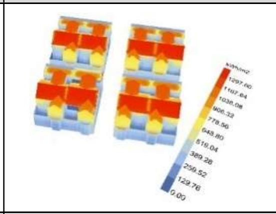
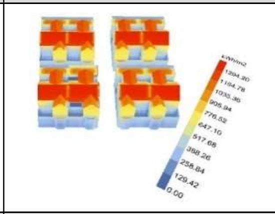
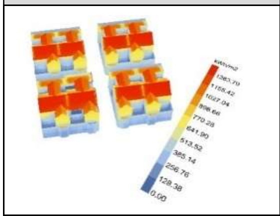
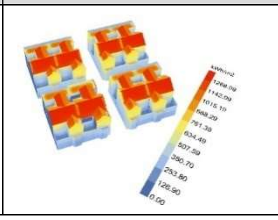
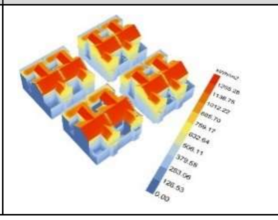
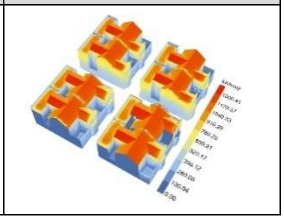
0°	10°	20°	30°
			
40°	50°	70°	90°
			

Table 16 Sun radiation simulation of buildings with different thermal azimuths in Siming

Village on great heat

0°	10°	20°	30°
			
40°	50°	70°	90°
			

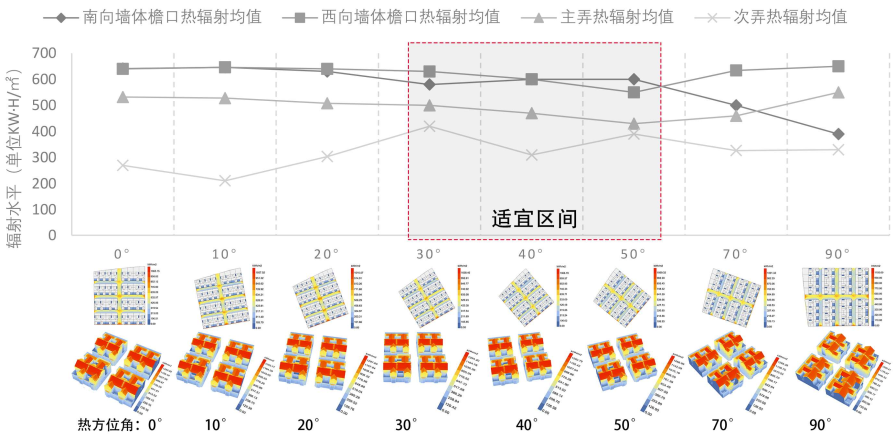
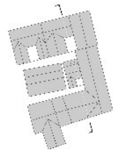
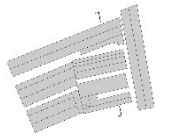
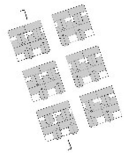
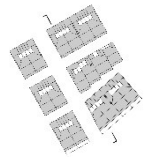
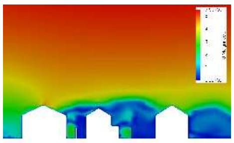
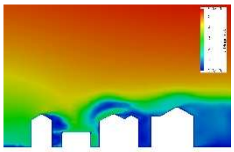
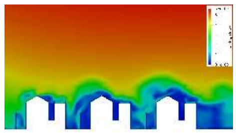
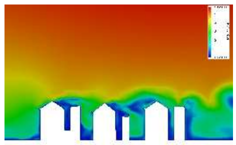


Figure 27 Thermal azimuth selection Source: self-drawn

4.1.3.3 Selection of roof inclination angle

According to the wind environment simulation, the wind speeds of the four sample alleys are all 1.5-2m/s. Except for sample 4, the wind speed in the roof area is above 3m/s, and the wind speed in the leeward roof is lower than 1m/s, forming a negative pressure area from the roof to the sky above the alley, and the wind pressure on the leeward roof is about -3Pa. Due to the larger wind azimuth angle and higher roof wind speed of sample 4, the wind pressure on the leeward roof is above -4Pa, which is more conducive to the wind pressure ventilation of the back patio and the secondary alley (Table 17). It can be judged from the air flow state of the four samples that the roof inclination angle of about 30° can better ensure the ventilation requirements of the back patio and the secondary alley.

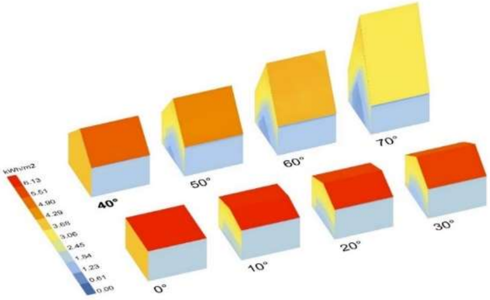
Table 17 Sample wind environment simulation

Cutting position				
Wind speed distribution				
Wind pressure distribution				

According to the annual solar radiation simulation, among the four samples, the maximum peak of roof solar radiation occurs at Lane 146 of Wangyun Road, and the peak value of the south-facing roof can reach 1315 KW·h/㎡. The smallest peak is Siming Village, whose south-facing roof peak is 1286 KW·h/㎡. The radiation peaks of the south-facing roofs of the four samples are relatively close, and the difference is only 30 KW·h/㎡(Table 14)

Through the simulation of the degree of solar radiation received by different roof inclination angles, it can be seen that on the day of great heat, as the value of the thermal inclination angle decreases, the higher the intensity of solar radiation received by the roof of residential buildings in Shanghai. When the roof thermal inclination angle is 0°, the sun-facing roof receives the highest solar radiation intensity, which is about 6.13KW·h/㎡. When the roof thermal inclination angle reaches 70°, the value is reduced to 3 KW·h/㎡. The thermal inclination angles of the four typical samples selected are all around 28°, and the solar radiation absorption on great heat is about 5 KW·h/㎡. The difference between the average thermal inclination angle of the roof of four typical samples and the local best thermal inclination angle is only 3°.(Figure 28 (Left) Relationship between roof thermal inclination angle and solar radiation in Shanghai area Source: Self-painted)

The annual variation range of the solar altitude angle where the sample belongs is from 35°23′ on a big cold day to 82°15′ on a big hot day (Figure 29). Different roof inclination angles have different projected areas in the direction of solar radiation, resulting in different energy absorption efficiencies. According to existing research, when the latitude is between 25°-30°, the optimal roof thermal inclination angle is generally the local latitude minus 5°. The calculation shows that the optimum thermal inclination angle in Shanghai area is 25°. Based on the simulation results and the existing research conclusions, considering the relationship between the roof, radiation and wind speed, the optimal roof inclination angle of the residential buildings in Li Lane, Shikumen, Shanghai is 25-30°.



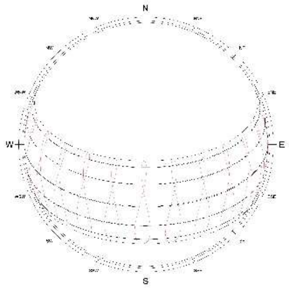


Figure 28 (Left) Relationship between roof thermal inclination angle and solar radiation in Shanghai area Source: Self-painted

Figure 29（Right）Annual sun trajectory map in Shanghai area Source: Grasshopper platform export

4.1.4 Measured-Simulated Interactive Verification

The building wind and thermal azimuth are determined by the building orientation and the wind and thermal environment. Comparing the wind and thermal environment data of the sample on-site measurement and performance simulation at similar points can be obtained: the actual measurement and simulation results are basically consistent. The wind, thermal azimuth, and roof inclination angle of the samples are all within a suitable range, and the thermal environment of the samples is basically the same. The wind environment of the two groups of samples is different under the similar building azimuth angle. It is speculated that the difference in the spatial form of the alley is one of the reasons for this phenomenon. This issue will be discussed in Section 4.2 of this paper.(Figure 30)

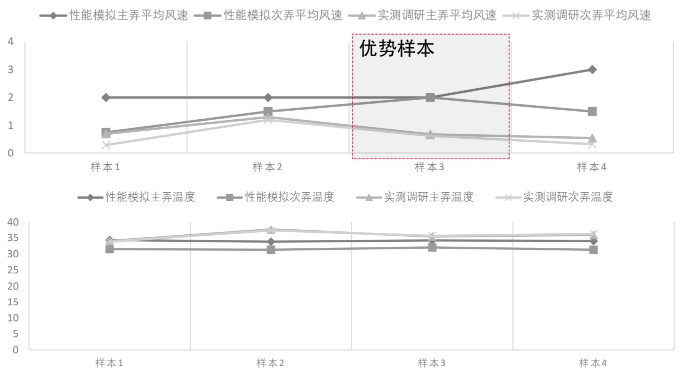


Figure 30 Interactive verification of wind and thermal environment simulation Source: self-painted

4.2 Physical space type

4.2.1 Physical space adaptive mechanism

The physical space adaptive mechanism is for the building to reasonably regulate the indoor and outdoor environment through the morphological characteristics of climate adaptability. At the beginning of this century, on the basis of the research of Rainer Banham and others, Randall Thomas proposed the "building type" for the regulation of the built environment. The space-climate control types of vernacular buildings are divided into isolation type, acquisition type, and adjustment type. Among them, the climate control space occupies an important position in the adjustable dwellings. For example, the courtyard and hall space of Huizhou courtyard-style dwellings, the patio and corridors of Shoujinliao dwellings, etc. According to the degree of openness and the different spatial positions, these spaces that undertake the main climate regulation function are divided into negative shape and regulation space. The negative shape bears the brunt in the process of regulating the external environment, and it is the first-level control space for residential buildings to buffer the harsh climate. Therefore, the negative shape also has the most local climate adaptability characteristics. The negative shape space of Shikumen Lilong Residence is mainly composed of alleys, courtyards and patios.

4.2.2 On-site measurement and analysis

Field measurements show that the Shikumen Lilong dwellings are similar to Jiangnan dwellings. The Shikumen Lilong dwellings originally developed and constructed are typical adjustable dwellings, with negative shape spaces such as courtyards and patios. With the development of urbanization, the adaptive transformation of its physical space types has gradually formed the basic physical space types represented by the four typical samples (Figure 31). For the convenience of space climate simulation, the samples are abstracted and simplified as shown in Figure 32. The physical space types of the four typical samples are different at different spatial levels.

From the perspective of climate-space-energy, there is no single Shikumen residential building. The main and secondary alley spaces formed by the organized arrangement of residential units also have the meaning of climate regulation for Shikumen residential groups. In this study, the three architectural configuration factors of negative shape proportion, negative shape height-to-width ratio and negative shape-to-bottom ratio are used to represent the differences in shape space types of four typical samples. Table 18 shows the correlation index of body type and space type in four typical samples: at the group level, the proportion of negative body shape in the four types of residential buildings in all lanes is basically maintained at about 20%. The secondary aspect ratio is between 1.8 and 2.8, which is relatively discrete. The two groups of dwellings built later have a main-lane aspect ratio of 1.5. In the typical samples, the alley interfaces are relatively neat, with no large overhanging structures except for street-crossing buildings, and their mouth-to-floor ratios are all 1. On the single building level, the number of negative shape spaces is relatively discrete. Except that there is no patio and courtyard inside the building of sample 2, the proportion of negative body shape in other samples is about 10%

Siming Village has the highest proportion of negative body shape, reaching 10.7%, and the height-to-width ratio of negative body shape in courtyards is mostly 1 to 1.5. The aspect ratio of the patio in Siming Village is about 2, and the aspect ratio of the patio in Jinghua New Village is up to 4.3. The interface of the inner courtyard of the sample is relatively modern, and there are basically no overhanging structures with obvious climate regulation effects, so the ratio of the mouth to the bottom is 1.

The surrounding buildings of samples 1 and 3 with double rooms are mostly connected by 4 households. In contrast, samples 2 and 4 with single rooms are mostly a group of closely connected buildings composed of 8 households. Based on this calculation, the sample energy body shape coefficient can be basically located between 0.41-0.45. This coefficient still differs from the requirement in the current code that the shape coefficient of strip buildings in hot summer and cold winter regions should not be greater than 0.35. The sample body shape coefficient basically shows the law that the later the construction period, the smaller the sample body shape coefficient.

The actual measurement data of the sample shows that in terms of wind environment: the wind speed distribution of the main and secondary alleys of samples 3 and 4 with smaller alley height-to-width ratios is more uniform. In samples 1 and 3 that contain courtyards, the wind speed in the courtyard is basically lower than 0.5m/s, and the average wind speed in the courtyards of samples 3 and 4 is lower than 0.3m/s. In terms of light environment, sample 3 is the best sample for the measured courtyard and patio illumination, and the illumination can reach 200lx; the thermal environment performance of the measured sample alley area is basically the same, and the temperature of the courtyard patio area of samples 1, 3, and 4 can be 2-5°C lower than that of the main alley.

It is worth noting that the connection between the sample unit and the inner alley space environment changes at the level of physical space type, which is mainly divided into two categories. Types with courtyards represented by samples 1 and 3, and types without courtyards represented by samples 2 and 4. Whether or not the negative shape space of the courtyard is included directly distinguishes the relationship between the sample indoor space and the urban external space such as alleys. This relationship mainly has two types: direct connection and indirect buffer connection. Therefore, for the research on the shape space type, space-climate gradient and climate control interface of the four samples, it is divided into two types with courtyards and without courtyards to explore the appropriate intervals of their architectural configuration factors.

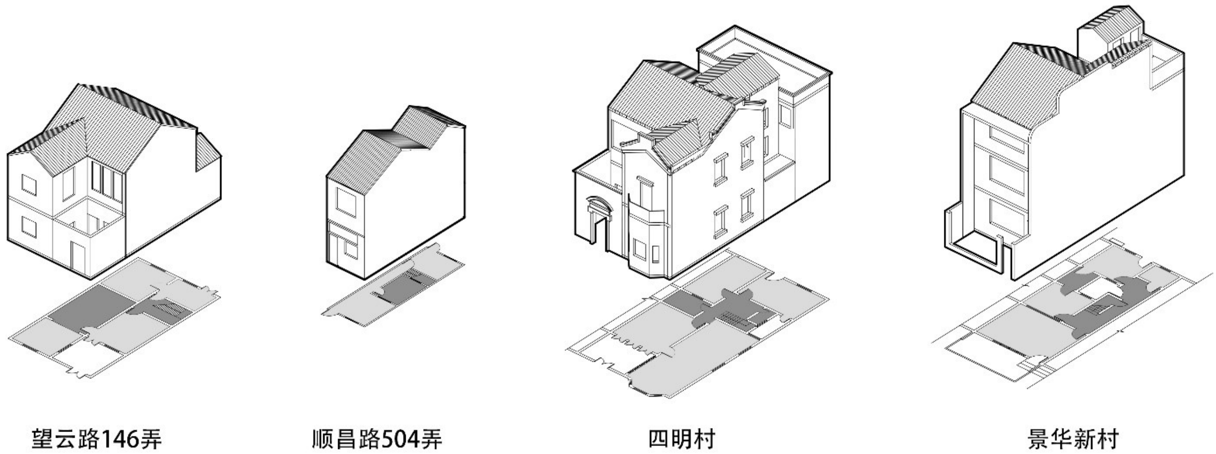


Figure 31 Sample basic shape space type Source: self-drawing

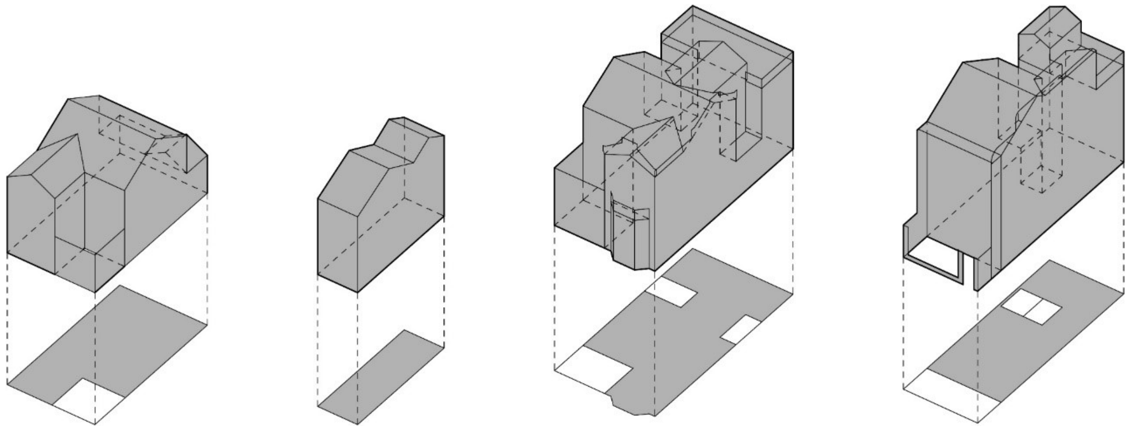
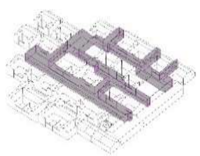
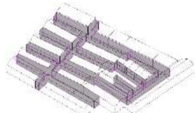
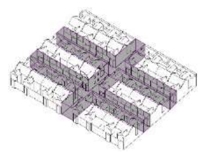
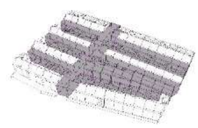
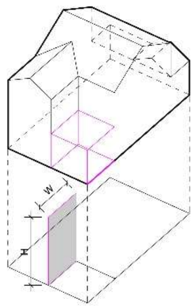
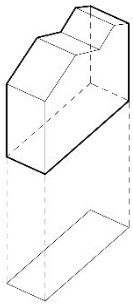
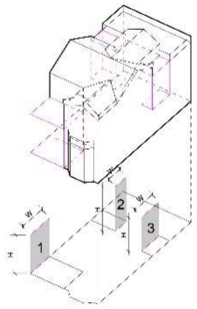
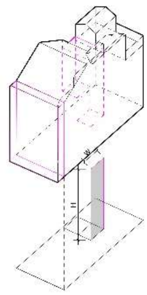
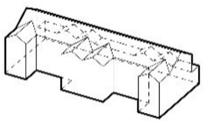
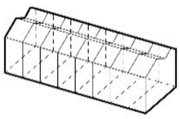
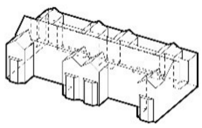
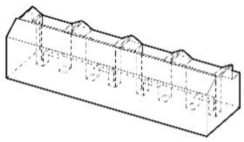


Figure 32 Sample abstract solid model Source: Self-painted

Table 18 Sample physical space type correlation index

Research level	Group level			
Sample	SKM-01 	SKM-02 	SKM-03 	SKM-04 
Void body ratio	24.2%	20.2%	20.5%	20.4%
Void body aspect Ratio	2.4：1	2.8：1	Main alley 1.5：1 Secondary alley 1.8：1	Main alley 1.5：1 Secondary alley 2.1：1
Void body mouth-to-floor ratio	1：1	1：1	About 1：1	About 1：1
Research level	Building level			

Sample	SKM-01	SKM-02	SKM-03	SKM-04
Void body ratio	6.7%	No	10.7%	12.9%
Void body aspect ratio diagram				
Void body number	1	0	3	1
Void body aspect Ratio	1：1	No	1.5：1、2.8：1、1.8：1	1：1、4.3：1
Void body mouth-to-floor ratio	1：1	No	1：1	1：1
Sample group				
Building Shape Coefficient	0.42（Four households as a group）	0.41（Eight households as a group）	0.45（Four households as a group）	0.41（Eight households as a group）

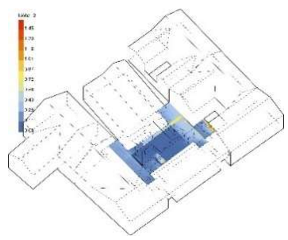
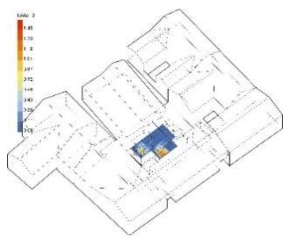
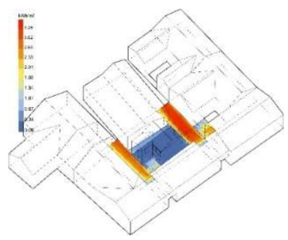
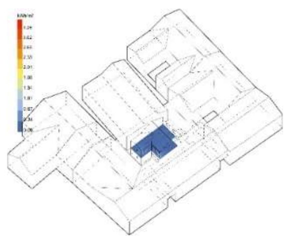
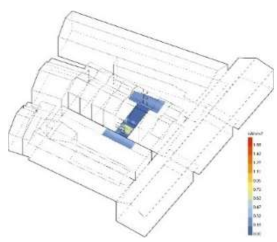
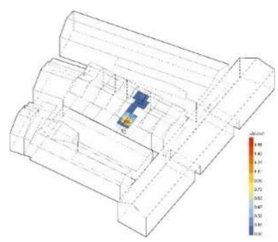
4.2.3 Environmental performance simulation

4.2.3.1 The relationship between void body and thermal environment

It can be seen from the simulation that the alley space thermal radiation level of No. 3 and No. 4 samples with smaller alley height-to-width ratios is higher than that of No. 1 and No. 2 samples on severe cold days or hot days. The average solar radiation level of the alleys on great cold is twice that of the latter, and the average solar radiation level of the former is generally 0.5 KW·h/㎡ higher than the latter. The courtyard and patio radiation level is the largest in the entrance courtyard of Sample 3, which has the largest aspect ratio, and the radiation levels are 0.1 KW·h/㎡ and 1.5 KW·h/㎡ in severe cold and severe heat, respectively. Comprehensive analysis shows that the ground solar radiation level in negative-shaped spaces such as alleys, courtyards, and patios is negatively correlated with its height-to-width ratio. The larger the height-to-width ratio, the lower the average ground radiation level, and vice versa. (Table 19)

The indoor spaces of the four samples obtain solar radiation mainly through the doors and windows of the facade walls. The openings are mainly facing the negative-shaped spaces such as alleys, courtyards, and patios. The thermal radiation of the indoor spaces is basically zero except for the south-facing window area. The solar radiation level in the window area is related to the negative aspect ratio of the window facing. After simulation analysis, the radiation level of the indoor window area shows the following rules: ① Due to the shielding of solar radiation by the front and rear buildings, the thermal radiation of the single sample indoor area near the window increases with the increase of the number of floors. ②The radiation level of the same floor is negatively correlated with the negative shape aspect ratio of the window opening direction: the maximum indoor heat radiation on a severe cold day is in the area in front of the south-facing window on the second floor of Siming Village, and the peak value is 1.8 KW·h/㎡. The minimum indoor heat radiation is Jinghua New Village on great heat. Although the horizontal and vertical shading above the window openings play a partial shading role, the alleys with a height-to-width ratio of 2.1 and the patio with a height-to-width ratio of 4.3 also play a greater role. Based on comprehensive analysis, if the windows are facing negative shapes with an aspect ratio greater than or equal to 2, the thermal radiation level in the indoor window area is low.(Table 20)

Table 19 Simulation of solar radiation of samples in severe cold and hot day

<table>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Sample 1 solar radiation simulation on great cold, 1st floor on the left, 2nd floor on the right, source: self-painted</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Sample 1 Simulation of solar radiation on great heat, 1st floor on the left, 2nd floor on the right, source: self-painted</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Sample 2 solar radiation simulation on great cold, 1st floor on the left, 2nd and 3rd floors on the right, source: self-painted</td></tr>
</table>

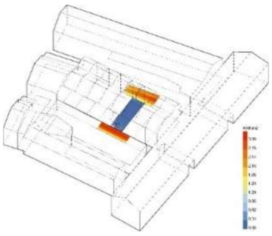
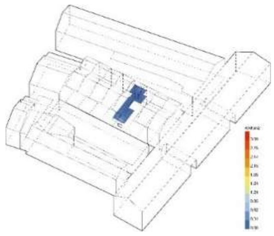
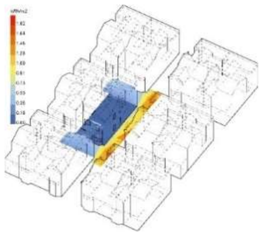
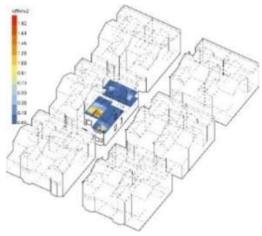
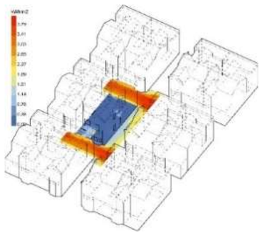
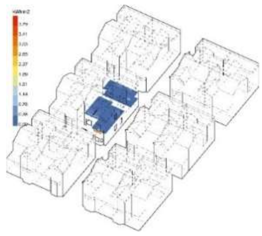
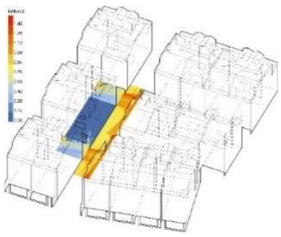
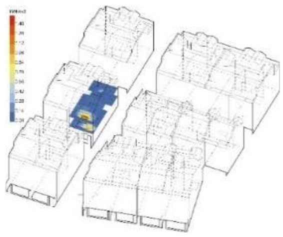
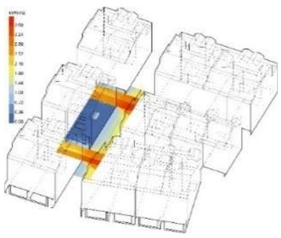
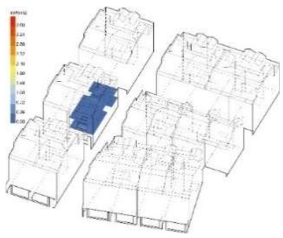
<table>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Sample 2 Simulation of solar radiation on great heat, 1st floor on the left, 2nd and 3rd floors on the right, source: self-painted</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Sample 3 Simulation of solar radiation on great cold, 1st floor on the left, 2nd and 3rd floor on the right, source: self-painted</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Sample 3 Simulation of solar radiation on great heat, 1st floor on the left, 2nd and 3rd floor on the right, source: self-painted</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Sample 4 Simulation of solar radiation on great cold, 1st floor on the left, 2nd and 3rd floor on the right, source: self-painted</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Sample 4 Simulation of solar radiation on great heat, 1st floor on the left, 2nd and 3rd floor on the right, source: self-painted</td></tr>
</table>

Table 20 Radiation level simulation at typical points of samples Unit: KW·h/㎡

Typical day	SKM-01	SKM-02	SMK-03	SKM-04

Alley Space Radiation Level				
Great cold	0.2	0.2	0.4	0.5
Great heat	3	3	3.5	3.6
Courtyard/Patio Radiant Levels				
Great cold	0.2	无	0.1/0.1/0.4	0
Great heat	1.5	无	1.3/1.5/1.4	1
Indoor space Thermal Radiation Level				
Great cold	1F：0.6 2F：1.3	1F：0.9 2F：1.5	1F：0.4 2F：1.8	1F：0.2 2F：1.4
Great heat	1F：0.5 2F：0.6	1F：0.6 2F：0.6	1F：0.4 2F：0.7	1F：0.3 2F：0.3

To sum up, during the great heat day, samples 1 and 2 are the best for alleys to isolate solar radiation, and samples 3 and 4 are the best for courtyards and patios, and their negative aspect ratios are all greater than 2.

Sample 4 has the lowest heat radiation level in the indoor window area, and its alley and patio aspect ratio is also the largest. From the perspective of isolating solar radiation in summer, the aspect ratio of the negative shape is limited to about 2:1, which can better reduce the thermal radiation level of the negative shape and the surrounding indoor window area.

Among the samples 1 and 3 with courtyards, Siming Village, which has a negative shape space and radiation level in front of the window, is selected as a sample. Select 1, 1.5, 2, and 2.5 for the aspect ratio A1 of the sub-lane, and 1, 1.5, and 2 for the courtyard aspect ratio A2 to simulate the thermal environment. The results are shown in Table 21 and Table 22 respectively.

The lowest outdoor UTCI index in the alley, courtyard and patio area of the simulation sample is 33°C on a hot day, and the body feeling belongs to the lower limit of the threshold of Strong Heat Stress (32≤UTCI<38). When the aspect ratio of the sub-lane is 1, the UTCI index in the central area of the sub-along and 1.7 meters from the ground is the highest at 36°C, and when the aspect ratio is greater than 2, the UTCI index in the same area can drop below 34°C. When the aspect ratio is 2.5, the UTCI index in the same area is close to the lowest value of 33°C. Only from the perspective of outdoor thermal comfort on a hot day, the height-to-width ratio of the secondary alley is about 2, which can make the general thermal comfort index of the alley close to the comfort zone as much as possible. Combined with the impact of the height-to-width ratio on the thermal environment of the alley in the severe cold days, the height-to-width ratio of courtyard samples can be basically limited to about 2, which can better meet the control needs of winter and summer(Figure 33).

The change of the height-to-width ratio of the courtyard space is basically the same as that of the sub-lane space, and the effective range of thermal environment regulation inside the courtyard increases with the increase of the height-to-width ratio of the courtyard. Under the sample scale of Siming Village, when the courtyard height-to-width ratio is 1, the UTCI index at 1.7 meters in the center of the courtyard is 34.2°C, and when the height-to-width ratio increases to 1.5, the index at the same location is 33.6°C, which is close to the temperature inside the courtyard. When the aspect ratio is 2, the upper boundary of the area where the UTCI index is lower than 33.6 degrees Celsius increases to the position of the second floor. From the perspective of courtyard thermal environment regulation on a hot day, the courtyard height-to-width ratio should be set between 1.5-2.

Table 21 Outdoor UTCI simulation of sample 3 with different height and aspect ratios of alley on a hot day

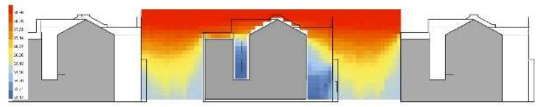
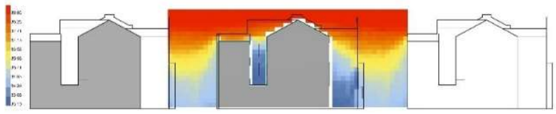
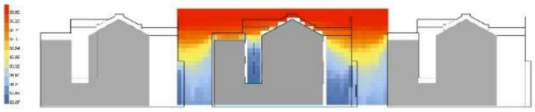
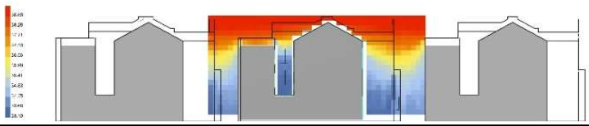
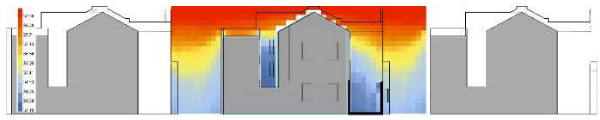
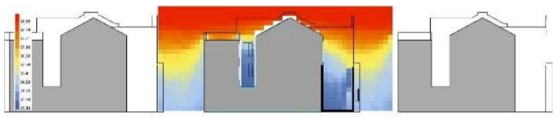
Height and aspect ratios of alley	UTCI
$A_1=1$	
$A_1=1.5$	
$A_1=2$	
$A_1=2.5$	

Table 22 Outdoor UTCI simulation of sample 3 with different height and aspect ratios of courtyard on a hot day

Height and aspect ratios of courtyard	UTCI
$A_2=1$	
$A_2=1.5$	
$A_2=2$	

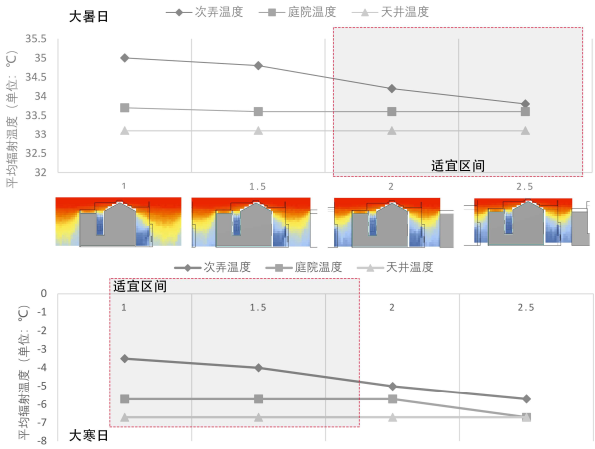
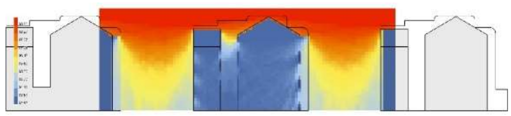
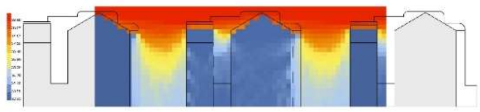
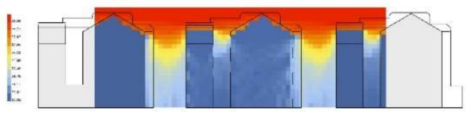
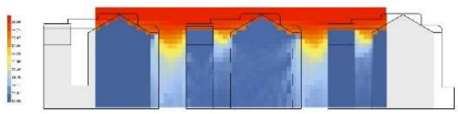


Figure 33 Effect of A1 on summer and winter thermal environment

In samples 2 and 4 without courtyards, sample 4 Jinghua New Village with better radiation levels in alleys and indoor windows was selected as a representative, and the second aspect ratio A1 was changed to 1, 1.5, 2 and 2.5 for thermal environment simulation . The results are shown in Table 23. The analysis of the simulation results shows that the UTCI of the outdoor space in the alley of sample 4 without a courtyard is negatively correlated with the height-width ratio of the secondary alley. With the goal of obtaining a lower UTCI index for alleys and patios in summer, the best sub-lane height-to-width ratio is about 1.5-2. Compared with samples with courtyards, this ratio is relatively small to ensure that the UTCI index at the interface of the indoor space directly connected with the alley is lower.

Table 23 Sample 4 Outdoor UTCI simulation with different aspect ratios

The aspect ratio of secondary alley	UTCI
A_1=1	
A_1=1.5	
A_1=2	
A_1=2.5	

4.2.3.2 Relationship between void body and wind environment

It can be seen from the simulation that at the elevation of 1.7m, the average wind speed in the secondary alleys is basically the same, about 2m/s. The wind speed of Jinghua New Village Second Lane, which has the widest alley scale, is up to 3m/s, and the local wind speed can reach up to 4.8m/s. The poor overall ventilation level in the sub-lane is sample 1. In the prevailing wind state, the wind speed distribution is uneven, the wind speed in the tuyere area is relatively high, and the air circulation in the leeward area is slow. The average wind speed in the sub-lane is about 1.5m/s.

The wind speed level in courtyards and patios is relatively lower. At an elevation of 1.7m, compared with sample 1 and sample 3 with courtyards, the internal ventilation conditions are basically the same, with an average wind speed of 1m/s. Compared with samples 3 and 4 with patios, the aspect ratio of the patios is discrete. The internal ventilation conditions are obviously different. At the elevation of 5m, the rear patio of sample 4 with the largest aspect ratio has the best ventilation condition, and the average wind speed can reach 1.5m/s. In sample 3, the wind speed of the patio at the same elevation is only 0.5 and 1m/s. (Figure 34Figure 35)

Comprehensive analysis of the difference between the sample shape space type and the wind environment, in the three main negative shape spaces:

(1) The scale of the secondary alley is about 6m, and the primary and secondary alleys of Sample 4 with a height-to-width ratio of 2:1 are in the best ventilation state, so the scale of the alley should be as large as possible on the basis of the height-to-width ratio of 2:1.

(2) There is little difference in the ventilation in the courtyards of samples 1 and 3 whose courtyard height-to-width ratios range from 1 to 1.5.

(3) The height-to-width ratio of the patio is relatively large, and its internal wind pressure and ventilation effect is poor. Consideration should be given to optimizing negative shape ventilation by using the chimney effect of the patio, and its height-to-width ratio can be limited to about 4.

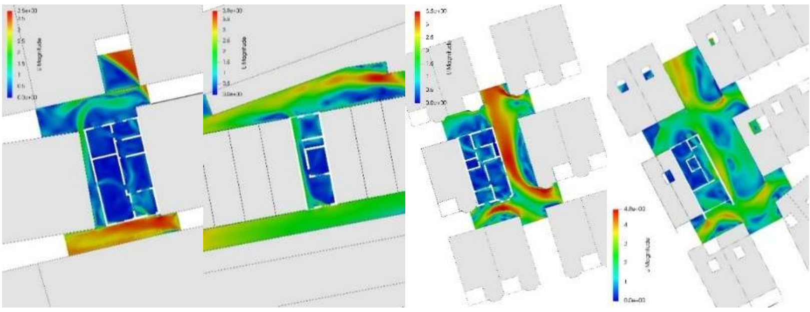


Figure 34 The plane ventilation simulation of four sample dwellings at an elevation of 1.7m under the prevailing wind Source: self-painted

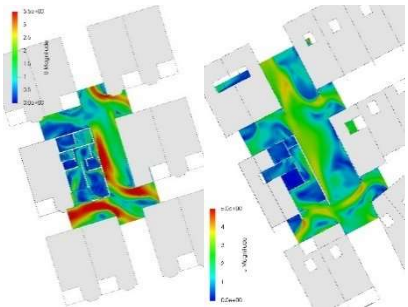


Figure 35 Ventilation simulation on the 5m elevation plane of No. 3 and No. 4 sample dwelling houses under the prevailing wind Source: Self-painted

Through the simulation of four typical samples, it can be seen that the negative body shape space aspect ratio has a particularly obvious impact on the wind environment. Among the samples including the courtyard, the sample of Siming Village with better ventilation in the negative shape space was selected, and the height-to-width ratio of the negative shape was changed to simulate the wind environment. The results are shown in Table 24and Table 25 respectively.

The simulation results show that under the conditions of different height-to-width ratios, the average wind speed of the sub-alongs on the windward side is above 2m/s, and the sub-alongs on the leeward side are divided into a wind shadow area and a separation area, and the wind speed in the partial area of the separation area is about 2m/s , it can reserve a better initial wind speed for the indoor ventilation of the rear residential unit. However, the proportion of the separation area decreases with the increase of the height-to-width ratio of the alley. The average wind speed level in the sub-alley gradually decreases with the increase of the aspect ratio of the alley. From the perspective of the air flow velocity of the secondary alley, the smaller the height-to-width ratio of the secondary alley, the better the internal ventilation effect. Samples with an aspect ratio of less than 1.5 can form a better sub-lane ventilation state, and the optimization of indoor ventilation should be the goal. The optimal sub-height-to-width ratio for samples without courtyards should be about 1.5, and for samples with courtyards, the value should be about 2 （Figure 36）。

The simulation results of the influence of courtyard height-to-width ratio on the ventilation of the courtyard and the internal space of the single building show that the wind shadow area in the courtyard is the smallest when the courtyard height-to-width ratio is 1:1, and the ventilation effect in the courtyard is the best. When the courtyard aspect ratio is 1.5 and 2, the indoor ventilation effect of the first floor is better than when the courtyard aspect ratio A2 is 1. The change of courtyard aspect ratio A2 in the interval from 1 to 2 has little effect on the indoor ventilation on the second floor, and the indoor wind speed can reach about 2m/s, which meets the indoor ventilation needs. Considering the courtyard and indoor ventilation effect comprehensively, the aspect ratio of the courtyard should be controlled between 1.5-2.

Among the samples that do not contain courtyards, sample 4 is selected to change the height-to-width ratio to simulate the wind environment respectively. The results are shown inTable 26. There is no significant relationship between the performance of the indoor wind environment without courtyard samples and the aspect ratio. When the sample 4 interface is opened, most of the indoor areas can meet the ventilation needs. From the perspective of indoor ventilation, the height and width of the sample without patio can be limited between 1-2.5.

Table 24 Simulation of wind environment with different height-to-width ratios for sample 3

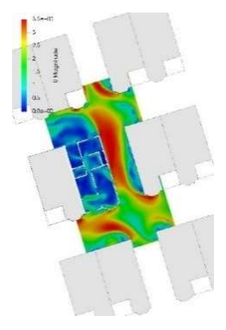
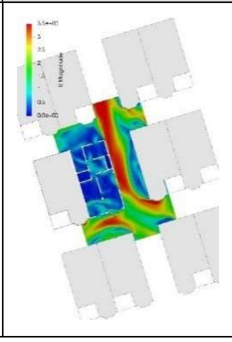
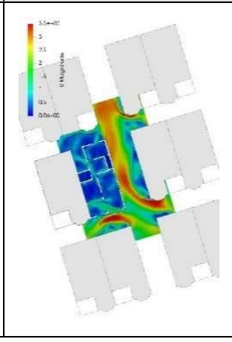
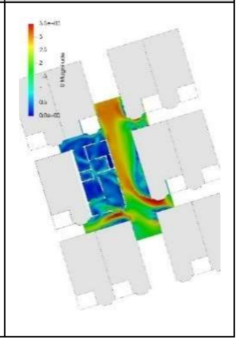
A_1=1	A_1=1.5	A_1=2	A_1=2.5
			

Table 25　Wind Environment Simulation of Sample 3 with Different Courtyard Aspect Ratio

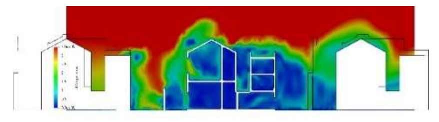
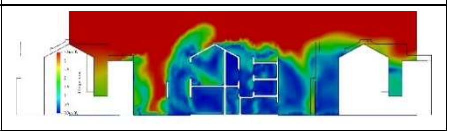
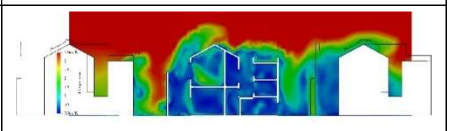
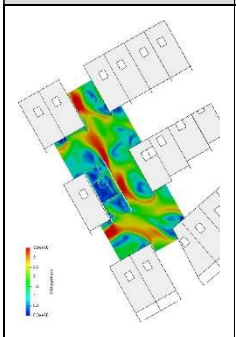
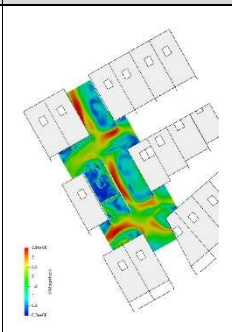
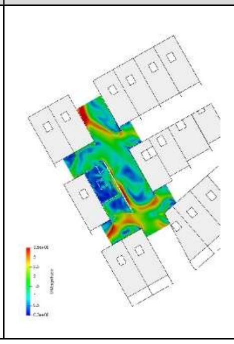
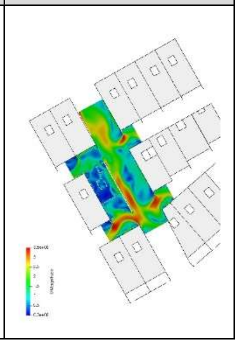
庭院高宽比 A_2	风模拟图示
A_2=1	
A_2=1.5	
A_2=2	

Table 26 Wind environment simulation of sample 4 with different height-to-width ratios of alley

A_1=1	A_1=1.5	A_1=2	A_1=2.5
			

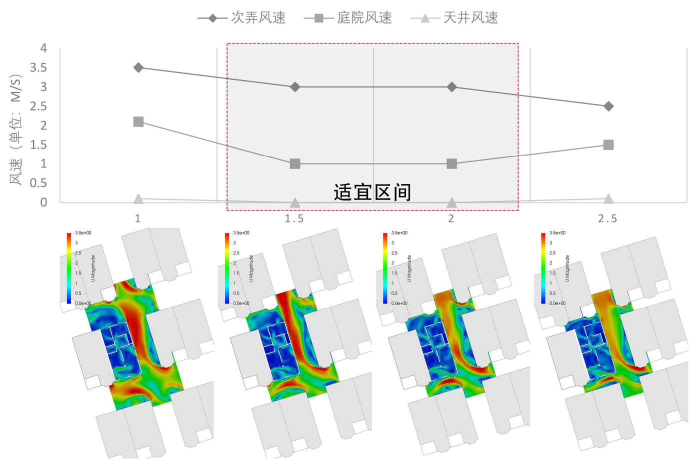
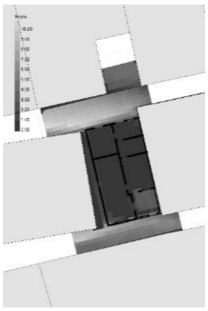
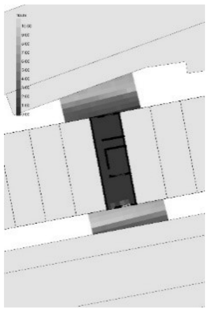
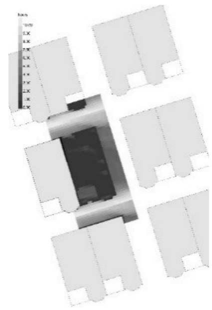
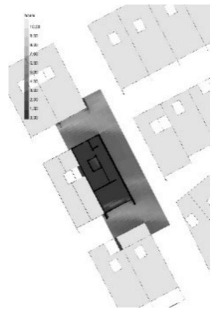


Figure 36 The influence of A1 on the wind environment Source: self-painted

4.2.3.3 The relationship between void body and light environment

The shadow density of the sub-lane refers to the time that each area of the sub-lane is in shadow during the day, which represents the level of direct sunlight on the street. After simulation, it can be obtained that the spatial shadow density of the sample alley is basically positively correlated with the aspect ratio of the alley, that is, the higher the aspect ratio, the higher the shadow density of the alley, and vice versa. The sample with the largest height-to-width ratio in the second alley has the highest shadow density on a hot day, and the shadow time of more than 50% of the alley can reach 7 hours. In samples 3 and 4 with the height-to-width ratio of the alley around 2, the shadow time of the sub-one-third area exceeds 7 hours. In order to reduce the direct sunlight of the second row on a hot day, the height-to-width ratio of the second row should be greater than 2.(Table 27)

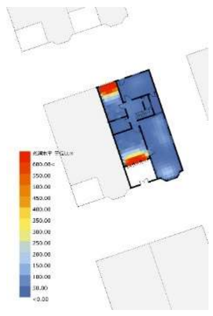
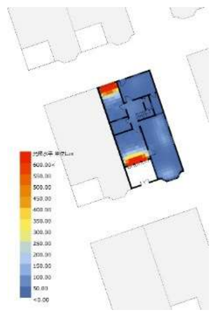
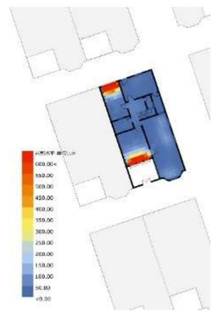
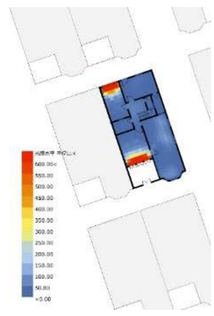
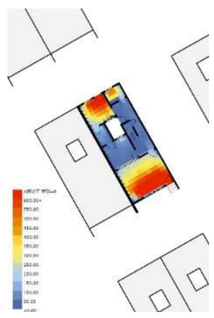
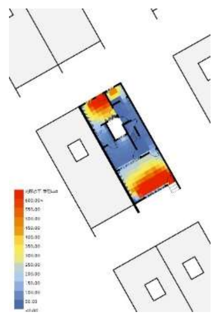
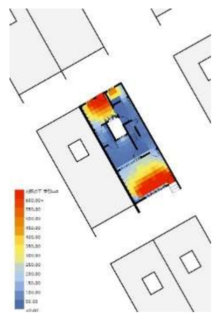
Table 27 Simulation of shadow density of samples on a hot day

SKM-01	SKM-02	SKM-03	SKM-04
			

From the simulation results of the indoor light environment (Table 37), sample 3 with a courtyard and sample 4 without a courtyard with better indoor light environment were respectively selected. Change the aspect ratio A1 of secondary alley, and simulate the indoor lighting environment separately,The results are shown in Table 28. From the perspective of meeting the indoor lighting needs as much as possible, the best indoor lighting for courtyard samples requires a height-to-width ratio of 1-1.5. However, because the openable area of sample 4 in the south direction is much larger than that of sample 3, the indoor lighting requirements can be met in the second lane with an aspect ratio less than or equal to 2.5 (Figure 37).

It is worth noting that if the ratio of height to width becomes larger, the UTCI of the negative shape space decreases, but the wind speed and indoor illuminance also decrease accordingly. According to the simulation results, it can be seen that if only the ultimate indoor thermal environment performance is pursued, it will lead to poor indoor wind and light environment performance. Therefore, this study comprehensively considers the interactive effects of changes in configuration elements on wind, light, and thermal environments, and takes the overall goal of a relatively balanced state of wind, light, and thermal environments in the sample to limit the appropriate range of architectural configuration factors. The height-to-width ratio of alleys with courtyards should be about 2; the height-to-width ratio of alleys without courtyards should be about 1.5, and the height-to-width ratio of courtyards should be about 1.5 (Figure 30Figure 33Figure 36) [11].

Table 28 Indoor light environment simulation at 0.75m elevation in hot day

$A_1=1$	$A_1=1.5$	$A_1=2$	$A_1=2.5$
样本 3			
			
样本 4			
			

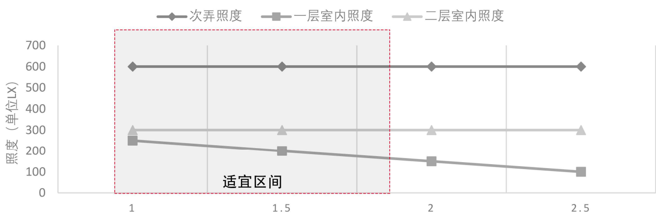


Figure 37 The influence of A1 on the light environment Source: self-painted

4.2.4 Measured-Simulated Interactive Verification

Comparing the actual measured wind speed values of sub-alleys, courtyards, and patios with the simulated values of sample performance are shown in Figure 38. The following conclusions can be corroborated mutually: samples 3 and 4, whose alley space is more regular and whose height-to-width ratio is close to the appropriate range, perform best in overall environmental regulation. Samples 1 and 2 with a secondary height-to-width ratio greater than 2 performed poorly in the wind environment. No courtyard samples 1 and 3 have the best light environment in the living room. The thermal environment performance of the four samples in summer is basically the same. In the same way, it can be verified that the impact of courtyard

[11]The reasoning process of courtyard height-to-width ratio on wind, light, and thermal environment is consistent with that of Sub Lane, and will not be repeated here.

height-to-width ratio on the environment basically follows the above rules. The samples whose negative body shape parameters in sub lanes and courtyards are within the suitable range defined above can obtain relatively better overall environmental regulation results.

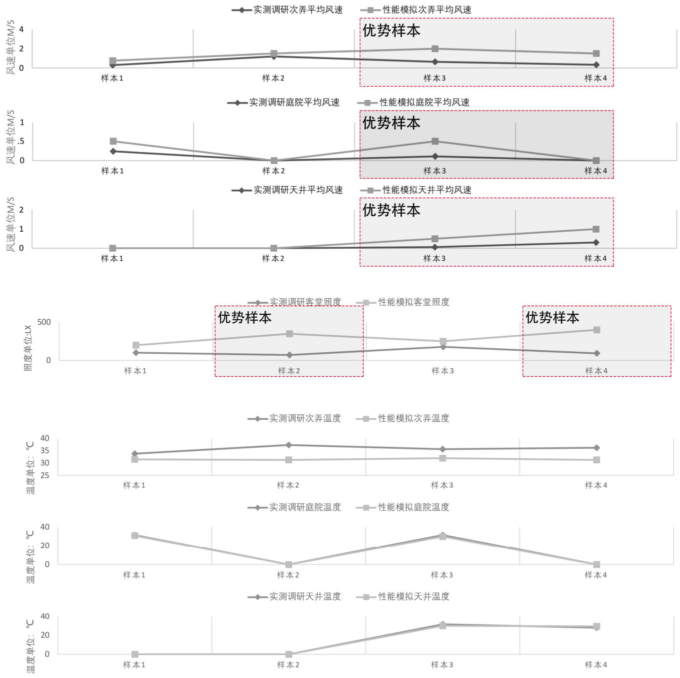


Figure 38 Wind speed, illuminance, temperature actual measurement-simulation interactive verification in void body of sample Source: self-drawing

4.3 Space climate gradient

4.3.1 Spatial Gradient Mechanism

The space-climate gradient of the traditional residential thermodynamic model in the hot summer and cold winter region is mainly divided into three levels: outdoor open space, thermal control body and thermal receptor. In the process of arranging the space in the width direction and combining in the depth direction in the traditional residential space, the multi-level space is formed, and the energy flow and the gradient of the microclimate environment are also formed.

During the process of Shikumen dwellings adapting to the urban environment, the development of intensive spatial forms and the transformation of the opening mechanism of the enclosure interface, the alleys have assumed part of the role of climate control. As a result, the space-climate gradient of "group level outdoor open space" - "body-intermediate level outdoor open space" - "heat receptor" is formed. In addition, Shikumen residences also contain some non-regulated spaces. This study defines the group-level outdoor open space in Shikumen Lilong houses to be composed of main and secondary alleys. The outdoor open space at the building level is mainly composed of patios and courtyards. The heat receptor space are the main functional spaces such as living room, kitchen and bedroom. Non-regulated spaces are mostly storage rooms and traffic spaces. According to the above classification methods, the outdoor open-air space at the group-group level, the outdoor open-air space at the body-room level, thermal receptors, and non-regulated spaces in the four samples are shown in Figure 39. The ratio of outdoor open space, heat receptor space and non-regulatory space is about 2:16:1 (Table 29).

Table 29 The proportion of each level of the sample space climate gradient

	Outdoor open space	Heat receptor space	Non-regulatory space
SKM-01	6.7%	75.1%	18.2%
SKM-02	0%	83.7%	16.3%
SKM-03	10.7%	81.5%	7.8%
SKM-04	12.9%	80.7%	6.4%

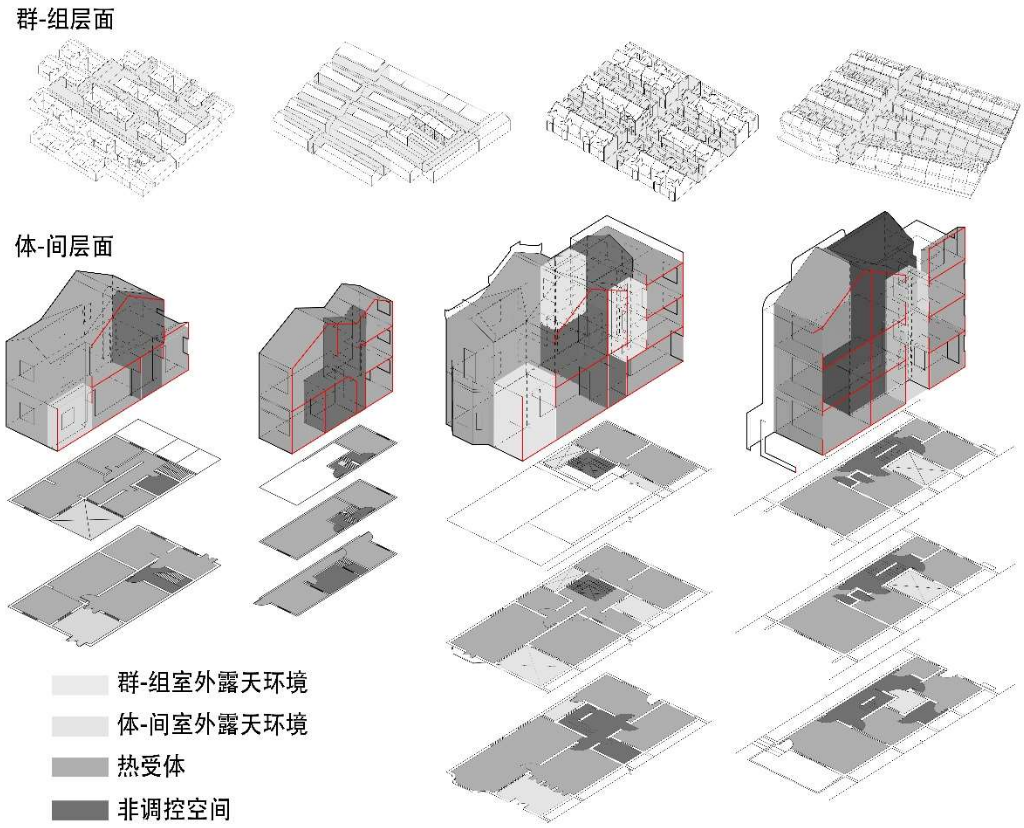


Figure 39 Sample space climate gradient diagram   Source: self-painted

4.3.2 On-site measurement and analysis

4.3.2.1 Measurement of Thermal Environment Gradient

The measured data shows that the temperature and humidity of the indoor space of Sample 1 fluctuate drastically throughout the day, and the indoor and outdoor temperature difference is about 3°C. The south-facing facade of Sample 1 is a single-layer wooden structure, which has poor insulation against radiant heat (Figure 40).The temperature difference between the corridors and stairwells in the central area and the outdoor temperature can reach up to

10°C.The indoor and outdoor temperature changes of sample 2 are relatively balanced, basically stable at 5°C. At night, the indoor and outdoor temperatures are the same. In sample 3, point 4 located between the boxes and point 5 located in the staircase are valid data (excluding the invalid data of the living room, master bedroom and courtyard in sample 3), and the temperature difference between them and the outdoors is maintained between 2-10°C. The temperature difference between indoor and outdoor of sample 4 is 3-10°C. The distribution law of effective temperature data presents a gradual decreasing trend of alley-courtyard-living room-staircase or back patio. The temperature in the core area of the indoor space is lower, and vice versa. The gradient distribution law of humidity is basically the same as that of temperature.(Table 30Table 31)

Figure 40 Material of the south-facing facade of sample 1 and thermal imaging on a hot day
Source: self-photographed

Table 30 The measured temperature data of the sample on a hot day

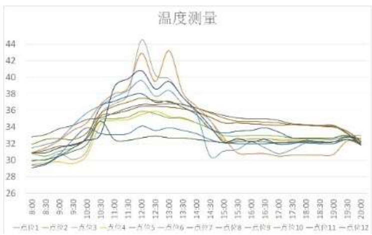
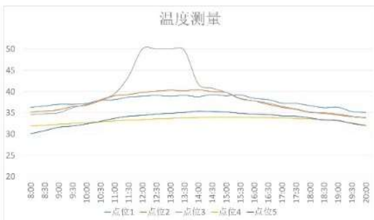
SKM-01	SKM-02
	
SKM-03	SKM-04
	

Table 31 Summary table of measured humidity in four typical sample dwellings on a hot day

SKM-01	SKM-02

	
SKM-03	SKM-04
	

The black ball WBGT index, also known as the black ball temperature index, is used to measure the thermal sensation of the human body under the combined effects of air temperature, humidity and radiant heat. Among them, the humidity factor accounts for 70%, which can be more clearly used as a hot and humid environment indicator for heat stroke prevention. During the actual measurement process, the sample 3 Siming Village had a great impact on the heat and humidity data of the courtyard measurement points because the air conditioners were turned on in the master bedroom and hall. The courtyard, living room and master bedroom data of sample 3 are not considered here. In samples 1, 2, and 4, the WBGT index in the three main spatial levels of secondary alleys, courtyards, and halls presents an obvious gradient distribution. When the outdoor WBGT index of the three samples is as high as 34°C, the hall space can still be maintained within the indoor thermal comfort threshold of about 30°C in summer. This phenomenon directly reflects the gradient of the space-climate in the sample dwellings, and it also confirms the effectiveness of spatial regulation of the sample dwellings in the extremely hot environment of the summer. (Table 32)

Table 32 The measured black ball WGBT index data of samples on a hot day

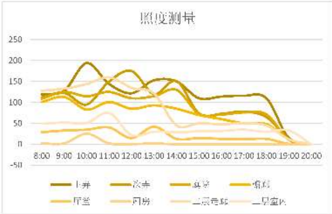
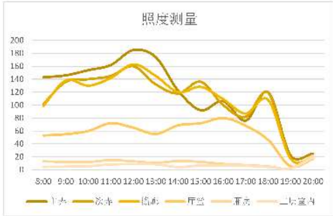
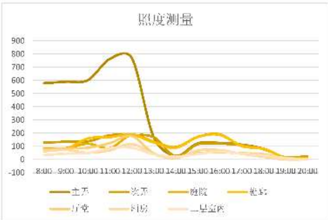
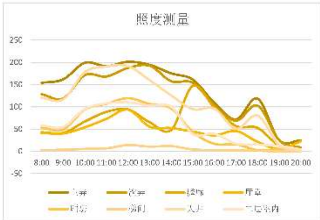
SKM-01	SKM-02
	
SKM-03	SKM-04
	

4.3.2.2 Light environment gradient measurement

As shown by the measured sample illuminance data, the conclusions obtained from the analysis are basically consistent with the simulation results. Samples 3 and 4 had better indoor lighting conditions than samples 1 and 2. The illuminance of primary and secondary alleys-courtyard-hall-room-rooms is distributed in a gradient and gradually attenuates. The second layer has better illumination data than the first layer. The illuminance level of main living spaces such as halls and wing rooms is relatively good, while the illuminance level of traffic spaces is generally poor. The actual measurement of illuminance is closely related to the sunshine level and cloud cover distribution, and there is no uniform rule in the longitudinal variation of the illuminance measured in the four samples throughout the day.（Table 33）。

The overall lighting level of the living room in the main space of the sample can be roughly ranked as sample 4> sample 3> sample 2> sample 1. It is basically consistent with the order of the ratio (F) of the space's surface width to depth. The front building and wing rooms on the first and second floors basically conform to the above rules. In addition, sample 4 and sample 2 without courtyards and walls have relatively better ventilation in the living room space. The demand for the quality of the indoor light environment makes Shikumen show a trend of decreasing wall height (early Shikumen to later Shikumen), and the interface is gradually transparent (Shikumen Lilongs to new style lanes) (Table 38) .

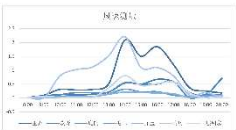
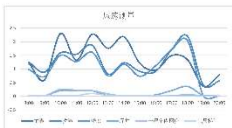
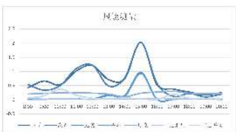
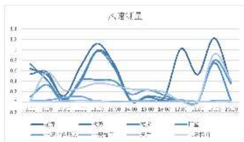
Table 33 Summary table of measured illuminance of four typical sample dwellings on a hot day

SKM-01	SKM-02
	
SKM-03	**SKM-04**
	

4.3.2.3 Wind Environment Gradient Measurement

The measured data distribution of the sample wind environment is relatively discrete. According to the simulation results of the wind environment of the sample residential buildings, under the steady-state wind direction and wind speed, the air velocity presents an obvious gradient distribution on the plane. The wind speed attenuates between the main alley-secondary alley-courtyard-hall, and the wind speed in the indoor space on the second floor is generally higher than that on the first floor.（Table 34）

Table 34 Summary table of actual measurement of air velocity in four typical sample dwellings on a hot day

SKM-01	SKM-02
	
SKM-03	**SKM-04**
	

4.3.3 Environmental performance simulation

4.3.3.1 Thermal Environment Gradient Performance Simulation

It can be seen from the simulation that samples 1 and 3 show an obvious average radiant temperature gradient from sub-alley-courtyard-indoor on a hot day. In sample 1, the average heat radiation temperature at the 1.7-meter elevation of the sub-lane is 31°C, 30.5°C in the courtyard, and only below 29°C in the living room area. Compared with the two, the alley temperature of sample 1 with narrower alleys is 1-2 degrees Celsius lower than that of sample 2, and the temperature of the courtyard space of sample 3 with higher courtyard walls is lower. In samples 3 and 4, the patio space also becomes one of the areas with lower radiation temperature. The indoor average radiant temperature gradient generally presents a gradually decreasing gradient distribution from south to north. In contrast, the setting of the courtyard makes the radiation level in the living room area of samples 1 and 3 lower. For samples No. 2 and No. 4 without courtyards, the south-facing main space is only separated from the secondary alley by a wall, and the average heat radiation level of the south-facing window area is relatively high. Due to the existence of horizontal and vertical sunshades in Sample 4, the indoor average radiant temperature of the south-facing main space near the window is lower than that of Sample 2. In general, samples 1 and 3 with courtyards have more climate gradients than samples 2 and 4, especially in the south-facing living room area on the first floor. The radiant temperature in the southern boundary area of samples 1 and 3 is lower, which is more conducive to maintaining the indoor thermal comfort state in summer.（Table 35Table 36）

Table 35 Simulation of indoor radiant temperature gradient from sample time to indoor on a hot day

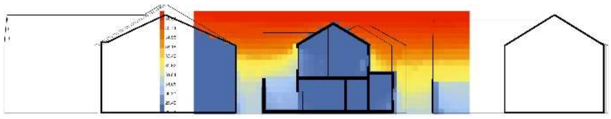
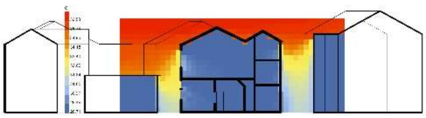
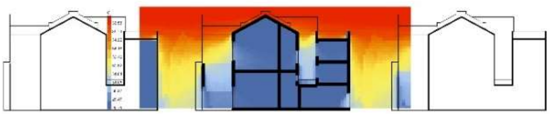
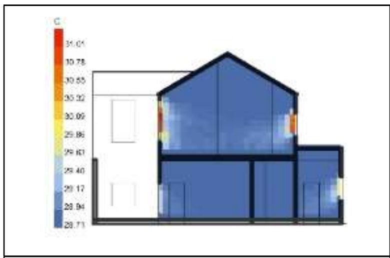
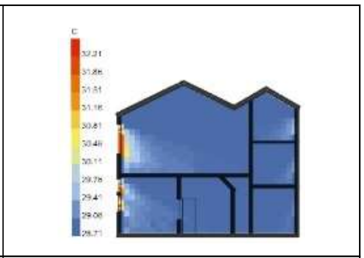
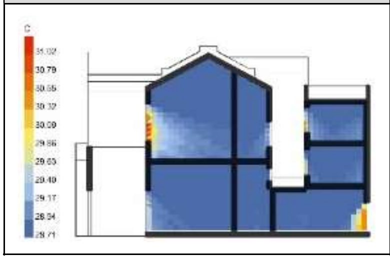
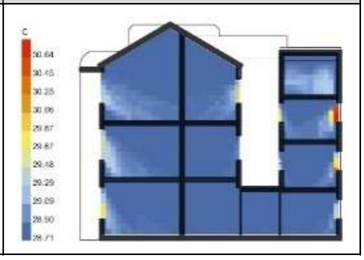
Sample	Mean Radiant Temperature Simulation Graphics
SKM-01	
SKM-02	
SKM-03	
SKM-04	

Table 36 Simulation of indoor average radiant temperature gradient in four typical sample dwellings in summer

SKM-01	SKM-02

	
SKM-03	SKM-04
	

4.3.3.2 Light environment gradient performance simulation

By simulating the light environment at a height of 0.75m above the indoor floor of the sample on a hot day, it can be obtained that from south to north, there is a gradient distribution with better lighting at both ends and poorer lighting in the central room. The lighting of the samples in the outdoor open-air space such as the patio in the middle room is better than that of the sample without the patio; The lighting on the second and third floors is better than that on the ground floor; samples with larger south-facing alleys have better lighting on the first floor; samples 1 and 3 with courtyards have slightly less daylighting than samples 2 and 4 without courtyards.

Among the four samples, the overall lighting level of the indoor space is better than samples 3 and 4. Among them, the lighting level of the south-facing room of sample 3 is higher than 300Lx within 2m of the window area on the first floor, and the lighting level of the middle and rear areas can still be maintained at around 150Lx. Due to the existence of the patio, the overall light level of the room in the middle of the first floor can be maintained at about 100Lx. The depth of the back room on the north side is relatively small, and the north-facing windows can ensure that most of the indoor areas meet the daily light requirements. The lighting of the north-south rooms on the second and third floors can reach about 300Lx.

The north-south rooms of sample 4 have better lighting levels. However, the windows in the middle rooms only open towards the back patio, and the aspect ratio of the back patio is 4.3:1. As a result, the lighting level of the middle rooms on the first and second floors is only below 100Lx, which is difficult to meet the needs of daily life. This conclusion is consistent with the information reported by the residents during the field measurement process that "the lighting in the central room is extremely poor". Since there is no patio in samples 1 and 2, the lighting level of the rooms in the middle of the first and second floors is lower than 100Lx. The bay of the living room is shorter than the depth, so that the north-south lighting level of the space is seriously attenuated, and the lighting level of the north side of some south-facing rooms is also lower than 150Lx.(Table 37Table 38)

To sum up, the specific building configuration factors presented by the sample simulation can optimize the indoor light environment gradient. The aspect ratio of the patio after setting in the middle should not be higher than 4:1. The north-south room bay and depth are close to 1:1, which can optimize the overall illumination level of the north-south room.

Table 37 Simulation of light environment at 0.75m elevation in the sample room on a hot day

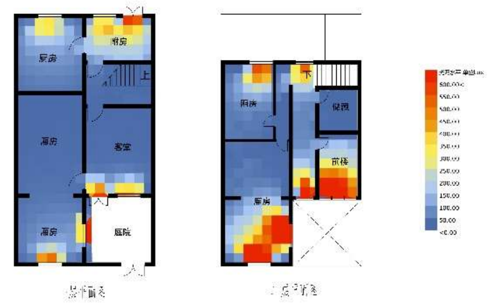
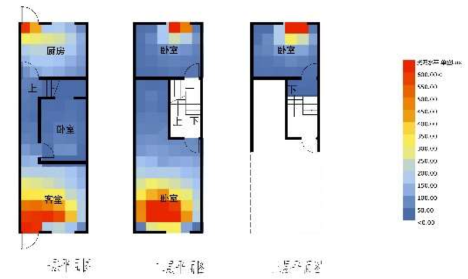
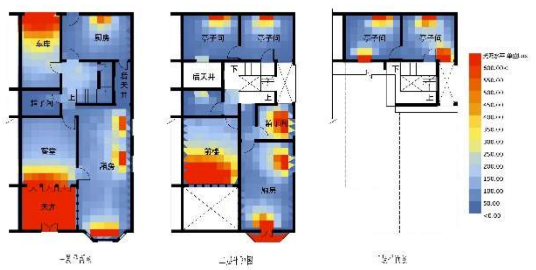
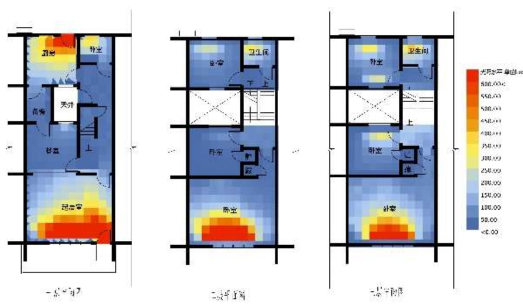
SKM-01	SKM-02
	
SKM-03	SKM-04
	

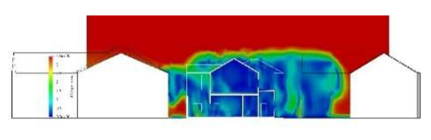
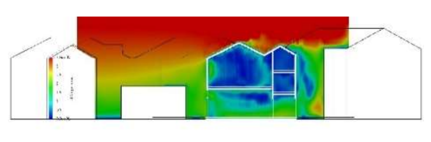
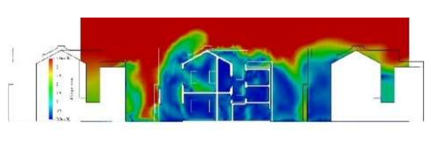
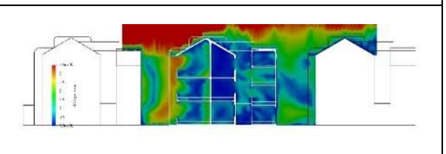
Table 38 Ratio of width to depth of the main space of the sample

Ratio of width to depth of the main space（F）	SKM-01	SKM-02	SKM-03	SKM-04
Living room	0.77：1	1：1	0.84：1	1.3：1
First floor wing room	1：1	无	0.43：1	无
Front building	0.63：1	0.45：1	0.84：1	1.3：1
Wing room on the second floor	0.4：1	无	0.6：1	无

4.3.3.3 Wind environment gradient performance simulation

The simulation results show that the air velocity of all samples presents the following characteristics: the gradient distribution of the wind speed gradually decays from the windward direction to the leeward direction, and from the upper layer to the ground layer. The central area of the building is poorly ventilated. In sample 1, the courtyard, living room and front building areas are well ventilated, and the wind speed flow is the slowest in the middle traffic space on the first floor and the back building area on the second floor. The first floor of sample 2 is conducive to the formation of drafts when the doors and windows are open. The ventilation of the corridor space on the first floor is better. There is no through air duct in the area between the back building and the front building on the second floor, so the ventilation status is poor. In sample 3, the ventilation in the front building is the best, and the ventilation between the boxes on the first and second floors in the middle is the worst, but the function is mostly storage space, and the wind speed requirement is not high. Sample 4 has the best ventilation in the south-facing living room and bedroom, followed by the attached room on the north side, and the worst in the central room. Overall, samples 3 and 4 have the best ventilation effects, followed by samples 1 and 2, and the north-south transparent space sequence in sample 2 significantly optimizes the indoor ventilation effect.（Table 39）

Table 39 Simulation of Wind Environmental Gradients in Four Samples

SKM-01	
SKM-02	
SKM-03	
SKM-04	

4.3.4 Measured-Simulated Interactive Verification

During the construction of residential buildings in hot summer and cold winter regions, the enclosure structure divides the indoor and outdoor areas in a spatial sense, and is also the boundary between indoor and outdoor hot and humid environments. The gradient distribution of heat and humidity environment maps the way residential space regulates climate stratification. Through the actual measurement-simulation interactive verification, it can be obtained that the main alley-secondary alley-(courtyard)-indoor-(patio) is a typical spatial sequence presented by the sample. Comparing the measured average wind speed and air temperature with the simulated data in the above typical spaces, it can be seen that Shikumen dwellings have a climate environment gradient attached to the above material space levels.

Samples without courtyards 2 and 4 have fewer space-climate gradient levels, mainly main alley-secondary alley-indoor-(patio). The south-facing main space is only separated from the secondary alley by a wall, and its thermal environment performance is worse than that of the courtyard samples, and the ventilation effect has been optimized. The southward horizontal and vertical shading of sample 4 has a significant effect on reducing the southward spatial thermal radiation. In courtyard samples 1 and 3, there is an obvious wind speed and temperature gradient from main alley-secondary alley-courtyard-indoor-patio (Figure 41Figure 42). In terms of light environment, the simulation results show that the overall indoor light level of sample 3 with a higher proportion of negative body shape is better, while the light on the first floor of the sample with a courtyard is slightly worse than that of the sample without a courtyard (Table 37).

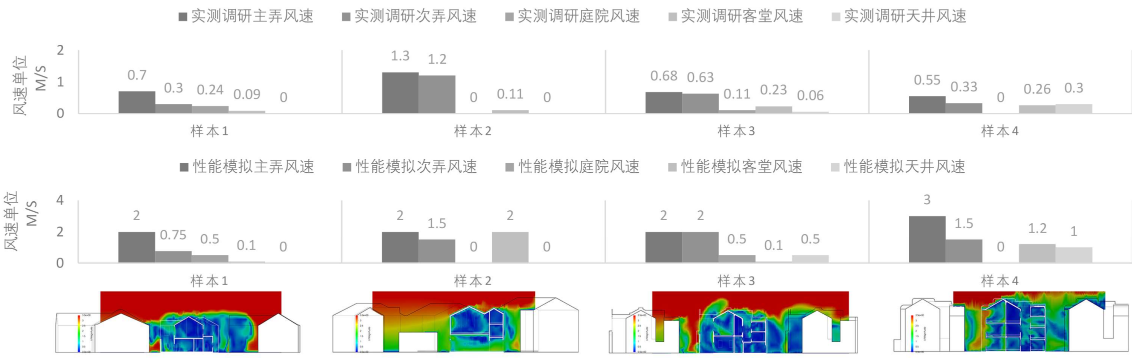


Figure 41 Interactive verification of field measurement of wind speed gradient and performance simulation Source: Self-drawing

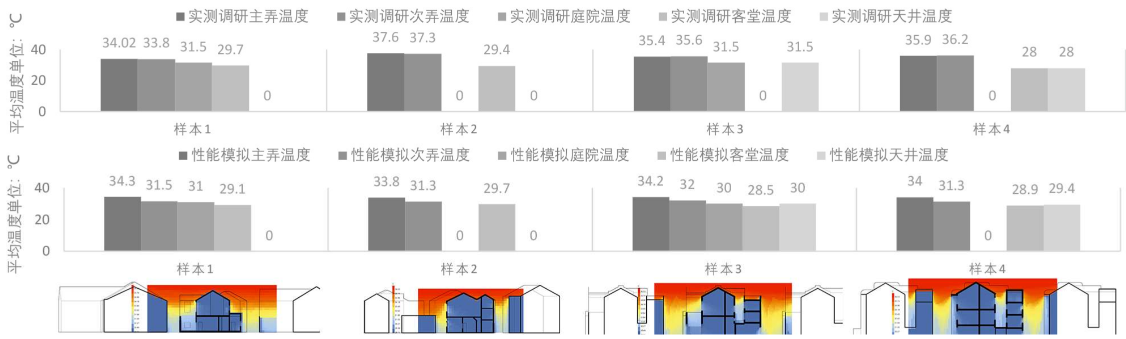


Figure 42 Interactive verification of field measurement of thermal gradient and performance simulation Source: Self-drawing

4.4 Climate control interface

4.4.1 Interface Control Mechanism

The hierarchical distribution of traditional residential space climate forms a gradient space adjustment mechanism that isolates and regulates the harsh outdoor environment and shelters the livable indoor environment. The space is limited by the enclosure interface, and changes in factors such as the openable area ratio of the enclosure interface, the direction angle of the wind guide surface, the area of the window wall, and the comprehensive shading coefficient have a direct impact on the climate environment of the space limited by it. The guiding mechanism of the climate control interface is that the enclosure interface changes the above factors to achieve reasonable guidance and utilization of energy and material flow on both sides of the limited space, thereby ensuring the comfort and stability of the indoor space's wind and heat environment.

4.4.2 On-site measurement and analysis

According to the relationship between the enclosure interface of traditional dwellings and the surrounding environment, it can be roughly divided into isolated type, selective type and open type. As the name suggests, they correspond to three ways to open the residential interface. Influenced by the land use environment, economic level, and social status, the four samples of Shikumen Lilong dwellings are mostly selective interfaces and isolated interfaces. There are few windows in the interior partition walls, and the default interface is the isolated interface. The types of enclosure interfaces and their spatial distribution are shown in Table 40. In samples 1 and 3, the selective interface and the isolated interface are about 2.5:1, and in samples 2 and 4, the ratio is about 1:2.5. Due to the difference in the position of the sample in the group and the number of individual bays in the sample, the proportion of the climate control interface is relatively discrete, but the general rule is that the north-south wall is a selective interface, and the east-west wall is an isolated interface.

The selective regulatory interface of the sample dwellings is mainly distributed on the north and south sides. From the simulation of the overall wind and heat environment, it can be seen that the main wind and heat direction of Shikumen residential buildings is southward, and the difference in the openable area ratio of the southward wall and the comprehensive shading coefficient have a great impact on the comfort of the thermal control body and thermal receptors . The opening area ratio of the north-south wall of the four samples can be obtained by combing, as shown in the table. Among them, the ratio of the openable area of the south-facing wall is the highest in Sample 2, Lane 146, Wangyun Road, accounting for 37.1%, and the lowest is in Sample 1, accounting for only 18.7%. The south-facing openable area ratios of the double-room samples are all smaller than the openable area ratios of the single-room samples. The openable area ratio of the north-facing wall is smaller than that of the south-facing wall, and the openable area ratio distribution is more concentrated, ranging from 15.9% to 22.1%.（Table 41）。

The results of the thermal imaging images in the actual measurement survey are shown. The south-facing interfaces of the four sample living rooms started from 10:00 to 18:00 during the daytime around the great heat day, and the radiation temperatures of the south-facing interfaces of the living rooms were all higher than 33 degrees Celsius (Table 42). The southward wall of sample 4 is equipped with horizontal and vertical sunshades. During the same period of time, the thermal imaging temperature of the inner wall surface affected by the sunshade components is 1-2 °C lower than that of other areas. Through the measurement of the internal and external heat radiation temperature of the south-facing solid wall, it can be concluded that the brick wall of the Shikumen Lilong residential house has good thermal insulation performance, and the temperature difference between the internal and external walls can reach more than 3 degrees Celsius. The south wall of sample 1 is made of wood, and the temperature difference between the inner and outer walls is small (Table 43). Therefore, setting up horizontal sunshade components and using masonry or concrete interfaces can better isolate solar radiation and ensure indoor thermal comfort.

Table 40 The interface distribution and proportion of the four samples

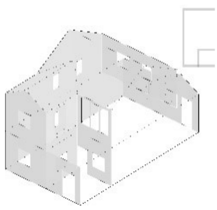
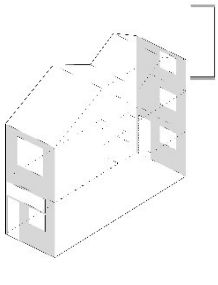
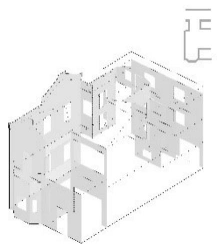
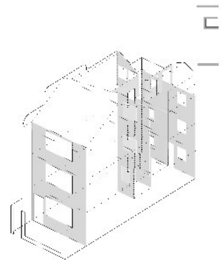
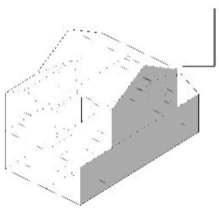
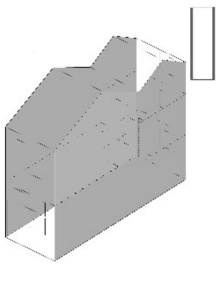
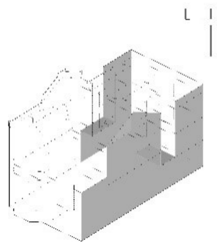
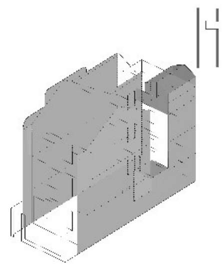
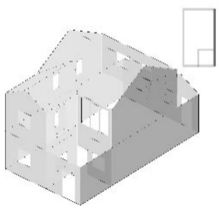
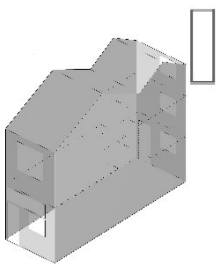
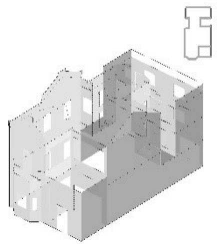
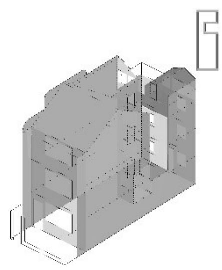
Sample	SKM-01	SKM-02	SKM-03	SKM-04
Selective interface	 74.8%	 22.7%	 67.6%	 36.4%
Isolated interface	 25.2%	 77.3%	 32.4%	 63.6%
Enclosure interface				

Table 41 The openable area ratio of the north-south wall of the sample（R）

Sample	SKM-01	SKM-02	SKM-03	SKM-04
Openable area ratio of south facing wall	18.7%	37.1%	23.9	27.9%
Openable area ratio of north facing wall	15.9%	22.1%	12.6%	18.8%

Table 42　The thermal image of the south interface of the sample

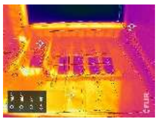
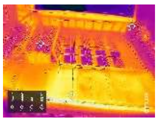
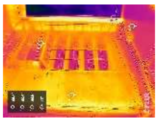
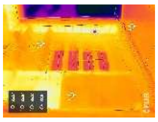
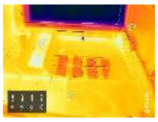
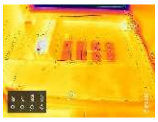
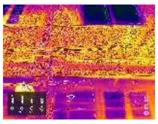
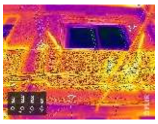
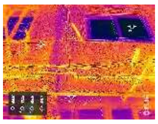
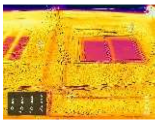
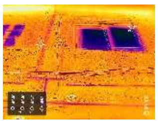
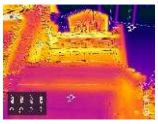
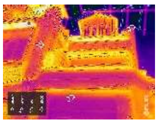
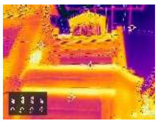
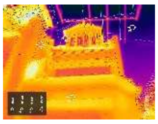
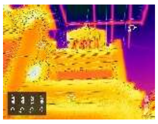
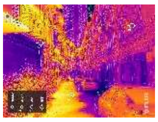
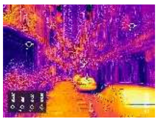
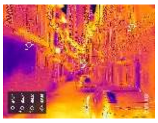
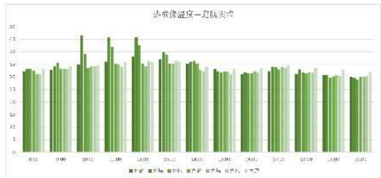
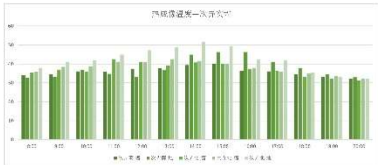
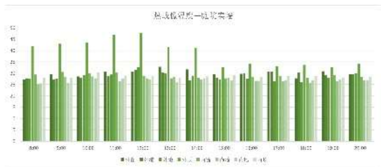
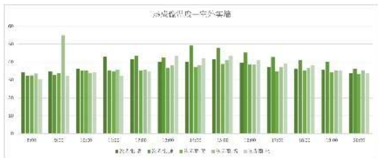
Time	10：00	12：00	13：00	14：00	16：00	18：00
SKM-01						
SKM-02						
SKM-03						
SKM-04						

Table 43 Thermal imaging temperature inside and outside of the south facing wall in the living room

SKM-01	SKM-02
	
SKM-03	SKM-04
	

4.4.3 Environmental performance simulation

4.4.3.1 Relationship between openable area ratio and wind and thermal environment

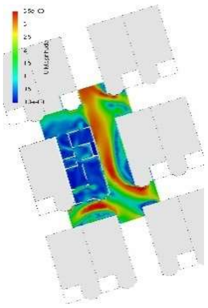
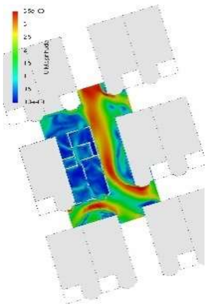
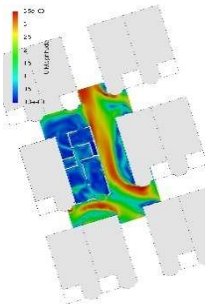
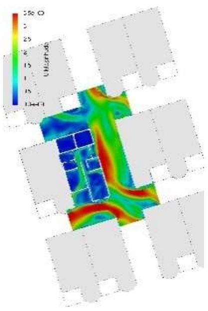
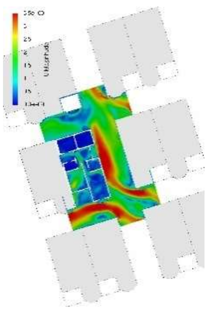
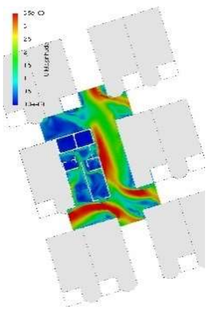
According to the typical sample wind environment simulation, the south facing wall is the windward side. The order of ventilation effects of south facing rooms from good to bad is sample 4, sample 2, sample 3 and sample 1. It is basically consistent with the order of the openable area ratio of the south-facing wall. It can be obtained that the ventilation effect of the south facing room is positively correlated with the openable area ratio of the windward wall. Single-room samples generally exist in the corridor part connecting the front, middle and rear rooms. This area forms the draft with the highest air velocity when the doors and windows are open.（Table 17）. Here, sample 3 with a courtyard and sample 4 without a courtyard are selected as representatives, and the proportion of openable area in the north-south direction is changed respectively, and the wind environment status of the internal space is analyzed, as shown in

Table 44.

Among the courtyard samples, the ventilation status of the first floor is positively correlated with the north-south window opening area. When the current window opening area is 1.2 times, smooth and stable ventilation is formed at an elevation of 1.7m indoors, and the wind speed can reach 1.5m/s. At this time, the openable area ratio of the north-south direction is about 28% and 12%, respectively. In the wind environment simulation without courtyard samples, when the openable area of window openings is greater than 0.9 times the current open area, the first floor can basically meet the ventilation needs of most indoor spaces. At this time, the openable areas in the north and south directions are 25% and 17%, respectively.

The average indoor radiant temperature is positively correlated with the south-facing openable area ratio. The first floor space is shielded by the courtyard wall, and the radiation level of the living room does not increase significantly when the openable area of the first floor space increases. Therefore, from the perspective of indoor heat dissipation, the openable area of the first floor space can be increased, and the proportion of the north-south interface on the second floor can be appropriately reduced to provide better shade and heat dissipation during the summer solstice (Table 45). In samples without courtyards, due to the existence of horizontal shading, the southward radiation temperature is maintained below 30 degrees Celsius. Therefore, it can be considered to properly set up a large area of openable areas under the condition of effective horizontal shading to ensure indoor ventilation and dehumidification.

Table 44 The north-south openable area ratio variable and wind environment simulation

SKM-03			
Openable area ratio	R*0.8 south：19% north：10%	R*1.2 south：28% north：12.6%	R*1.4 south：33% north：17%
Wind environment at 1.7m elevation			
Wind environment at an altitude of 5 meters			
SKM-04			
Openable area ratio	R*0.7	R*0.9	R*1.1

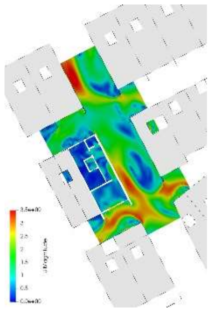
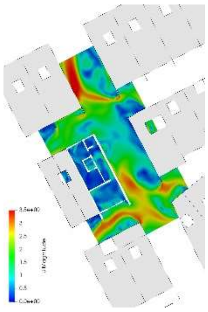
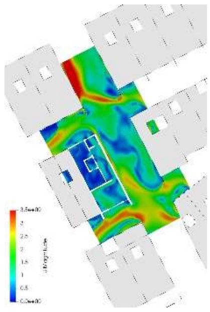
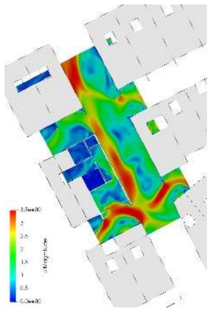
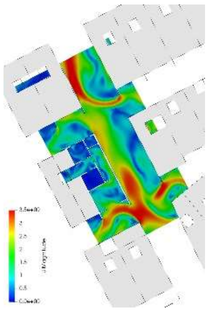
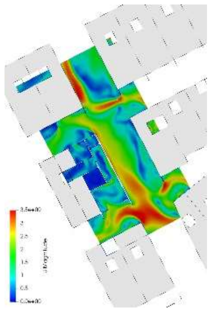
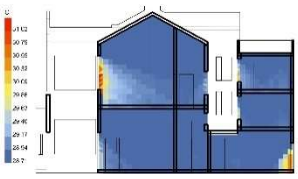
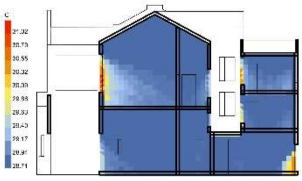
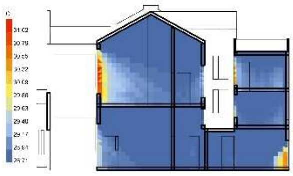
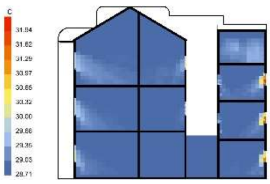
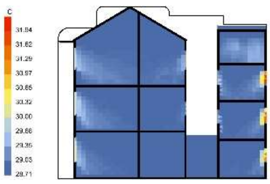
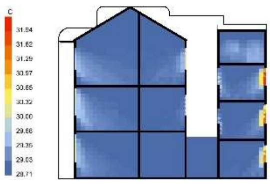
Wind environment at 1.7m elevation			
Wind environment at an altitude of 5 meters			
Note: R is the current openable area			

Table 45 The north-south openable area ratio variable and thermal environment simulation

SKM-03			
Openable area ratio	R*0.8 south：19% north：10%	R*1.2 south：28% north：12.6%	R*1.4 south：33% north：17%
Indoor thermal environment simulation			
SKM-04			
Openable area ratio	R*0.7 south：19.53% north：13.16%	R*0.9 south：25.11% north：16.92%	R*1.1 south：30.69% north：20.68%
Indoor thermal environment simulation			
Note: R is the current openable area			

4.4.3.2 The relationship between comprehensive shading factor and light and thermal environment

Select sample 4 with horizontal and vertical shading as a representative to calculate the comprehensive shading coefficient (S). The average radiation level of the south-facing master bedroom space on the second and third floors is greatly affected, but the space on the first floor has no obvious impact. The simulation shows that the total indoor incident radiation is 7.31

KW·h under the scale of the existing sunshade components, and the value is 11.27 KW·h without sunshade. The S value of the sample 4 can be calculated to be about 0.8.（Table 46）

Among samples No. 2 and No. 4 that do not include courtyards, sample 3 is selected as a representative to change the size of the horizontal sunshade components at the eaves respectively, and simulate the indoor average radiant temperature. When the width of horizontal shading components is greater than 0.8m, the average radiant temperature in the south-facing window area can be lower than 30°C, and the comprehensive shading coefficient (S) at this time is 0.86. From the perspective of reducing the indoor radiation temperature and the total solar radiation of the enclosure structure, the S value of samples without courtyards should be lower than 0.86（Table 47）。

Through the simulation of beneficial, excess and net beneficial radiation of four samples. The excess radiation of the exposed envelope of the sample building is basically less than the beneficial radiation, and the net beneficial radiation is all positive. Among them, the highest net benefit radiation value of sample 3 is 27 KW·h, the value of sample 4 is higher than 10 KW·h, the minimum value is sample 1, only 2 KW·h, Therefore, the exposed interfaces of the four samples tend to receive radiation, so as to ensure that more beneficial radiation is received when the temperature is lower than 18°C（Table 48）。

Table 46 Comprehensive shading factor (S) simulation

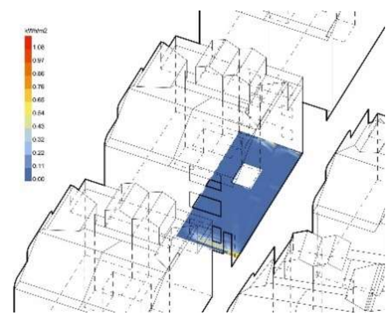
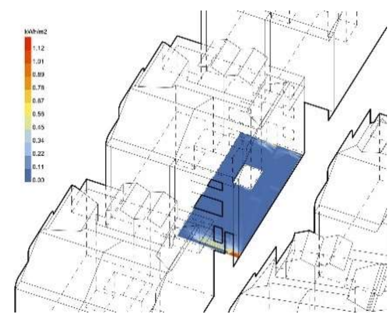
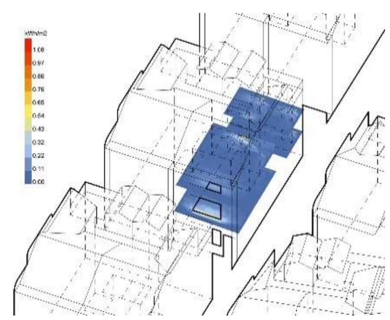
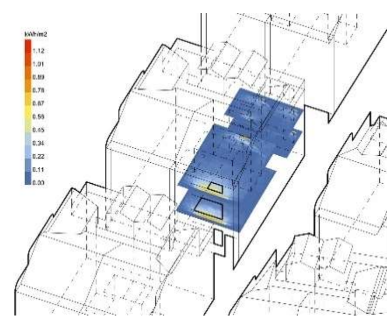
	Sample 4 with shade	Sample 4 without shade
1st floor		
2nd and 3rd floors		
Total incident radiation	9.1 KW·h	11.27 KW·h

Table 47 Indoor average radiant temperature simulation of sample 4 sunshade component size

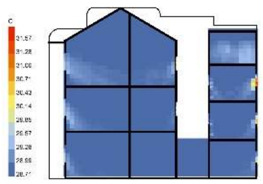
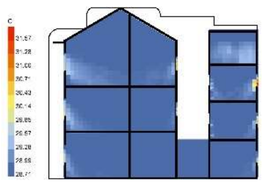
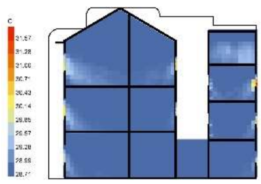
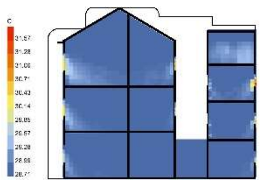
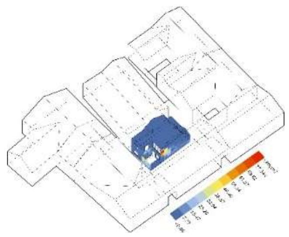
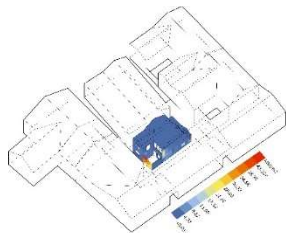
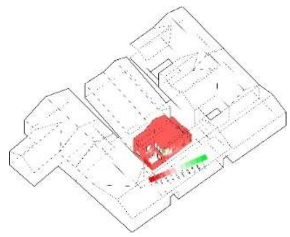
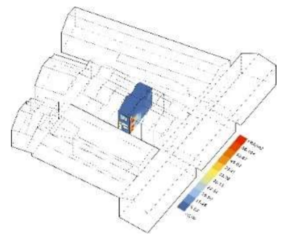
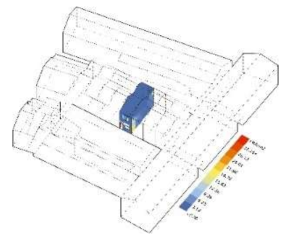
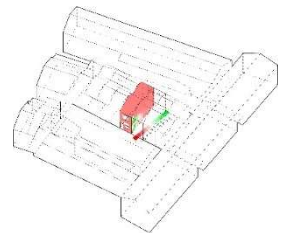
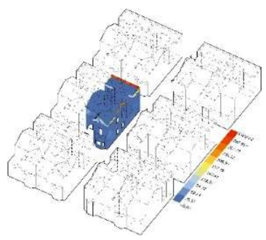
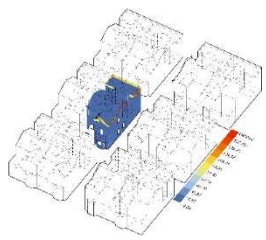
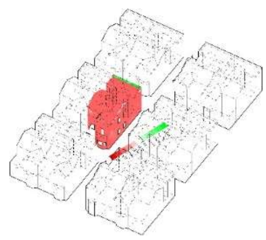
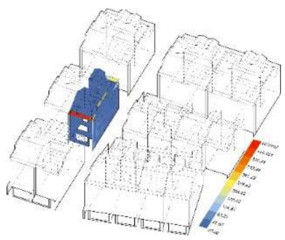
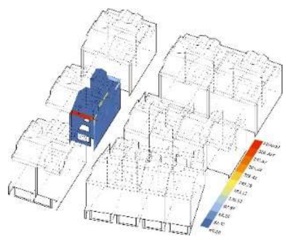
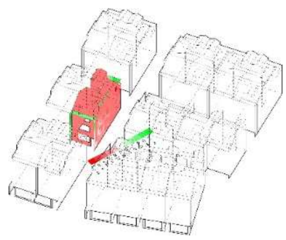
L=1.2	L=0.8	L=0.6	L=0.4
			
Radiant temperature of the area in front of the window：29℃	Radiant temperature of the area in front of the window：30℃	Radiant temperature of the area in front of the window：30.4℃	Radiant temperature of the area in front of the window：31℃
Comprehensive shading factor：0.76	Comprehensive shading factor：0.86	Comprehensive shading factor：0.9	Comprehensive shading factor：0.94

Table 48　Sample beneficial, excess, net beneficial radiation simulation

Sample	Beneficial radiation	Excess radiation	Net beneficial radiation
SMK-01			
SKM-02			
SKM-03			
SKM-04			

4.4.4 Measured-Simulated Interactive Verification

Comparing the on-site measurement data and simulated data of the wind, light, and thermal environment of the hall, attached room, and second-floor bedroom, interactive verification can be obtained: the proportion of openable area of sample 3 is closer to the appropriate range, and its indoor light and thermal environment performance is better. The indoor wind environment of Samples 2 and 4 lacking the shade of the courtyard is better than that of Samples 1 and 3 as a whole. Based on the wind, light, and thermal environment control results, the overall effect of the indoor environment control of samples 3 and 4 is more balanced (Figure 43). There are contradictions in the regulation of indoor environment in winter and summer by the changes of some building configuration factors (such as the openable area ratio of the interface and the negative shape height-to-width ratio, etc.). As reflected in the superior samples, balancing the impact on the wind, light, and thermal environment with appropriate values of structural elements is also a manifestation of the wisdom of Shikumen residential construction.

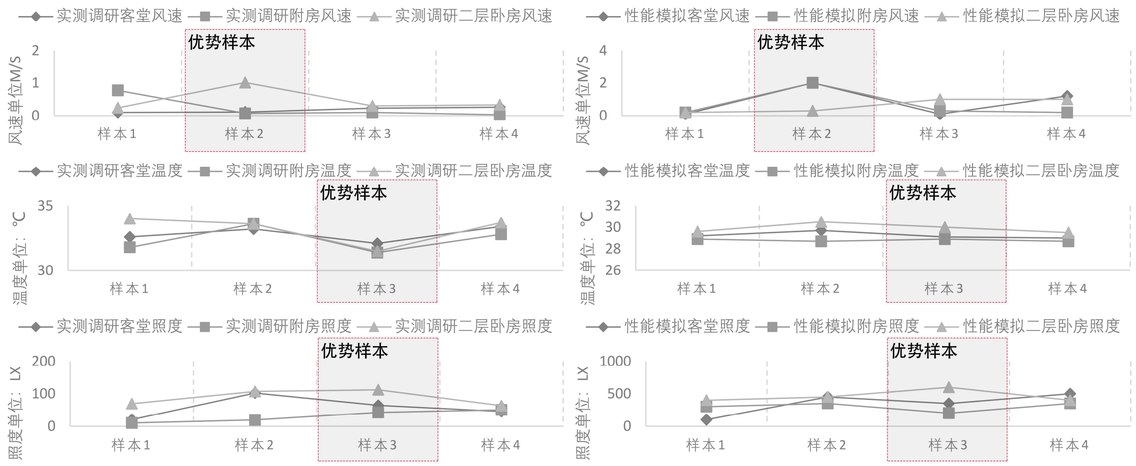


Figure 43 The interactive verification of actual measurement and simulation in the influence of the proportion of openable area Source: Self-drawing

4.5 Performance-oriented structure

4.5.1 Performance-oriented structure mechanism

Performance-oriented structure is a technical strategy to strengthen or inhibit energy flow and regulate indoor and outdoor climate environment through the form and opening and closing methods of building structures for heat transfer methods such as conduction, convection, radiation, and evaporation. According to the different effects of structure on energy flow, it can be divided into the following eight types of performance-oriented structures: enhanced conduction, enhanced radiation, enhanced convection, enhanced evaporation, suppressed conduction, suppressed radiation, suppressed convection, and suppressed evaporation. According to the field measurement and investigation, the performance-oriented structures of residential buildings in Shikumen Lilong in Shanghai are mostly four types: conduction suppression, radiation suppression, evaporation enhancement, and convection enhancement.

4.5.2 Structure-enhance convection

The reinforced convection structures of residential buildings in Shikumen Lilong in

Shanghai mainly include the following types: dormer windows that can be opened on the roof, transom windows and ventilation holes facing the secondary alley, and ventilation holes that run through the secondary alley-entrance garden-living room-back room-back patio, etc. （Figure 44Figure 45）

The four typical samples are equipped with openable dormer windows on the roof to strengthen the wind pressure and heat pressure ventilation of the indoor space. In sample 1, the southern wall of Lane 146 on Wangyun Road is provided with a transom facing the second lane. Sample 3 Siming village has round ventilation holes on the wall facing the main alley or secondary alley, mostly located at the height of 1.2m behind the house, with a diameter of about 20cm. This phenomenon is common in Siming villages. In the early days of Siming Village, casement windows were used to open windows, and the ventilation efficiency was reduced after changing to sliding windows. The residential units of Sample 4 are provided with ventilation holes at the bottom of the wall near the entrance garden, with a width of about 30 cm and a height of about 5 cm. The ventilation holes lead directly to the living room and to the north side of the back patio, forming a cross-ventilation path from the secondary alley-entrance garden-living room-back room-back patio. This measure complements the air-cooling effect of the vegetation in the entrance garden and the wind-drawing effect of the patio, and jointly ensures the ventilation effect of the main spaces such as the living room and the back room. In addition, after investigation, it was found that there is a chimney on the roof of the junction area between the living room and the back room of Jinghua New Village. In the early stage of development and construction, it was one of the main passages connecting the indoor space and the roof space. The chimney effect further enhanced the indoor and outdoor ventilation rate.

Figure 44 The dormer windows and transom windows can be opened on the roof. Source: Self-photographed

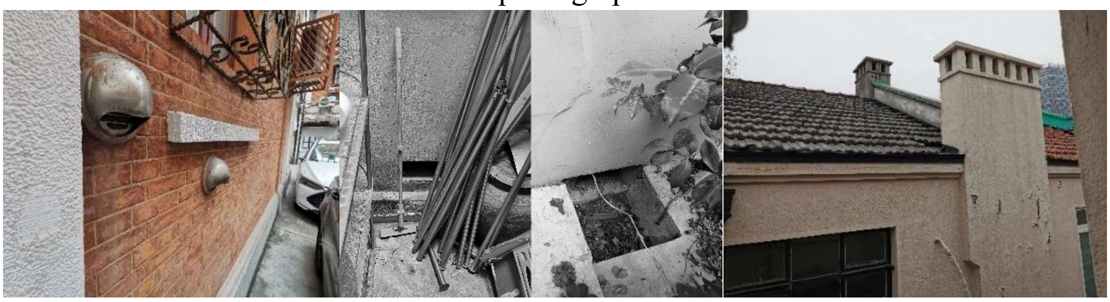


Figure 45 Ventilation holes are opened towards the secondary alley, ventilation holes and chimneys running through the secondary alley-entrance garden-living room-back room-back patio Source: self-photographed

4.5.3 Strucrture-Enhance Evaporation

The enhanced evaporation structure of residential buildings in Shikumen Lilongs mainly includes planting trees and shrubs in the main, secondary alleys and household gardens, and arranging water nodes such as washbasins in the secondary alleys and patios.（Figure 46）

In sample 1, Lane 146, Wangyun Road, green plants are planted on the south wall boundary, and the excess heat is taken away by the transpiration of plants. On the side of the main entrance to the south of the residential unit of Sample 4 Jinghua New Village, there is an entrance garden with a width of about 5 meters and a depth of about 1 meter. Many landscape shrubs are planted in it, which can reduce the temperature of the air flowing into the room. Sample 2 Shunchang Road Lane 504 arranges daily water nodes such as washbasins on the south side of secondary alley , and the evaporation of water from the open-air washbasins also plays a part in cooling. Although the establishment of public water nodes in the sub-alleys is limited by the development of urban infrastructure, the "side effect" produced by it also virtually optimizes the thermal environment of the alley space. A sink is installed inside the patio of sample 4, and the organized drainage from the roof is discharged into the ground through the patio. The evaporation of water is used to further reduce the temperature of the patio, strengthen the temperature difference between the bottom and the top of the patio, and improve the heat-pressure ventilation efficiency of the patio.

Figure 46 The vegetation in the home garden, the water nodes in the secondary alley and the patio　Source: self-photographed

4.5.4 Structure-Restrain Conduction

The conduction suppression structure of the residential buildings in Shikumen Lilong in Shanghai mainly includes brick or concrete enclosure interfaces, and the use of bricks and concrete materials can better reduce the indoor and outdoor heat conduction efficiency. The outer enclosure structures of the four sample dwellings are all made of red bricks or concrete masonry, and the wall thickness of sample 3 is about 240mm. Combined with the actual measurement and investigation of the wall surface temperature on site, this method can effectively reduce the indoor and outdoor heat transfer efficiency.（Figure 47）

Figure 47 Enclosure interface of brickwork and concrete Source: Self-photographed

4.5.5 Structure-Restrain radiation

Field surveys show that the radiation suppression structures of Shikumen dwellings mainly include body overhangs, top cornice overhangs, sun-shading green plants planted along the south-facing interface, and horizontal and vertical sun-shading components.（Figure 48Figure 49Figure 50）

Sample 1 Residential buildings in Lane 146 of Wangyun Road add horizontal sunshades to the south-facing door and window openings to block and reduce the incidence of solar radiation and ensure a more comfortable indoor radiation temperature.

The second-floor slab overhangs about 30 cm in Sample 2, providing sunshade for the long windows on the first floor, ensuring that most of the long windows are under the shadow when the sun is high. The eaves on the top protrude about 40 cm, which serves as a sunshade for the window openings on the second floor. In sample 3, the door and window openings of residential units in Siming Village are decorated with stone strips for partial sun shading, and evergreen vegetation is set on the edge of the south wall to block part of the solar radiation. Trees and shrubs are planted on the east and west sides of the main alley in Sample 4 to prevent excessive solar radiation on the gable surface of the building from direct sunlight from east to west, and reduce the radiant temperature of the gable surface of the building. At the beginning of the development and construction of Sample 4, the horizontal and vertical sunshade components were used as one of the elements of the building facade. The eaves of Jinghua New Village have overhangs of nearly 1m in size as horizontal sunshade components, and the partition walls between residential units are extended by about 1m to divide the entrance courtyard space of different residential units, and at the same time play the role of vertical sunshade.

Figure 48　Overhanging blocks and overhanging cornices Source: Self-photographed

Figure 49 Horizontal and vertical sunshade components Source: Self-photographed

Figure 50 Vegetation in the main and secondary alleys Source: Source: Self-photographed

4.5.6 Other performance-oriented structure

The four samples are made of wooden floors, and the porous nature of wood can better regulate the indoor humidity. In addition, there are various structures to improve the performance of indoor lighting. For example, the walls of the back patio near the main building in Siming Village are lowered to increase the lighting in the back rooms and pavilions; Jinghua New Village uses iron fences as the courtyard enclosure structure to optimize the lighting effect in the living room area on the first floor.

4.6 Chapter Summary

This chapter studies the space-climate mechanism of the five levels of the sample with the collaborative perspective of "climate-space-energy" by means of actual measurement-simulation cross-validation. To sort out the relationship between the characteristics of architectural configuration elements of climate adaptability and environmental performance in Shikumen dwellings. The environmental performance of the samples is compared horizontally, and based on the samples with better overall performance, the impact of changes in architectural configuration factors on the regulation of the space environment is simulated and analyzed. Consider its positive or negative impact on wind, light, and thermal environmental regulation from an associated perspective. To obtain an overall better indoor wind, light and heat environment performance as the main goal to determine the appropriate range of building configuration factors as shown in Table 49:

Table 49 Appropriate range of configuration factors in sample Shikumen residential buildings

Space-climate mechanism	**Sample building configuration factor characteristics**		**Appropriate range of building configuration factor**
Space climate selection	Wind azimuth	The wind azimuth is between 37°-51°	The wind azimuth should be between 40°-60°. At this time, the orientation of the building is about 20°-40° south by east. The included angles between the main alley, the secondary alley and the prevailing wind direction are all about 45°, which can better meet the needs of the secondary alley and indoor ventilation. Furthermore, reducing the formation of the wind shadow area on the leeward side of the building and the vortex area on the windward side is conducive to increasing the wind pressure difference between the front and back of the building and optimizing indoor ventilation.
	Thermal azimuth	The thermal azimuth is between 14°-28°	The thermal azimuth should be between 20°-30°. At this time, the orientation of the building is 20°-30° south by east, which can make reasonable use of solar radiation and meet the uniform solar radiation level of the main and secondary alleys. Ensure the quality of urban public spaces. Under this orientation, the radiation on the south and west sides of the main heating surface of the building is relatively uniform, avoiding the unfavorable situation of excessive solar radiation on a single enclosure interface.
	Wind-heat inclination angle	The wind-heat inclination angle is between 26-30°	The wind-heat inclination angle should be located in the range of 25°-30°, and the roof inclination angle should be within this range to minimize the absorption of solar radiation on the roof and at the same time facilitate the ventilation of the rear patio and rear alley.

Physical space type	Void body aspect ratio	The aspect ratio of the main and secondary alleys of the sample is between 1.5-2.8, the courtyard is between 1-1.5; the back patio is between 1.8-4.3	With a courtyard: The negative shape aspect ratio of the sub-lane should be about 2. At this time, the comprehensive quality of internal radiation, ventilation and lighting of the sub-lane is better. Under the limitation of indoor lighting requirements, the negative shape of the courtyard should be between 1.5 and 2. At this time, the wind pulling effect of the courtyard is weak. The height-to-width ratio of the patio should be less than 4:1 as far as possible to ensure the draft effect while ensuring the illumination level of the central room. No courtyard: The aspect ratio of the negative shape of the secondary alley should be between 1.5 and 2. This value is slightly smaller than the sample with courtyard, which is similar to the sample with courtyard.
	Void body mouth-to-floor ratio	The sample negative body shape mouth-to-floor ratio is about 1	Shikumen is influenced by Western modernist architecture, without large overhanging eaves and negative shape changes.
	Proportion of void body	The proportion of negative body shape at the group-group level is about 20%, and the proportion of negative body shape at the body-interlayer level is between 6.7-11.5%.	The proportion of negative body shape at the group level should be about 20%, the negative body shape at the interbody level should be about 10%, and the overall negative body shape of the neighborhood should be 30%.
Space climate gradient	Ratio of opening and depth in main space	Between 0.4 and 1.3	The bay depth ratio is positively correlated with the indoor lighting environment. According to the indoor lighting simulation results of four samples, this value should be set between 0.8 and 1.3.
	The ratio of outdoor open space, heat receptors, non-regulatory space	The ratio of the three types of space at the building level is about 2:16:1	Samples with courtyards have more climatic gradient levels, and the indoor thermal environment on the first floor is better. Samples without courtyards have fewer climatic gradient levels, and the wind and light environment on the first floor are better.
Climate control interface	The proportion of openable area	The openable area ratio of the north-south wall is between 18%-37% and 12%-22% respectively	There are courtyard samples: the openable area of the north-south direction should be increased appropriately on the first floor, and the second floor can be appropriately reduced. The overall openable area of the north-south direction should be about 28% and 12% respectively. Samples without courtyards: The north-south openable area should be about 25% and 17%.
	Comprehensive shading coefficient	The comprehensive shading coefficient of	There is no obvious horizontal shading for samples with courtyards; the comprehensive shading

		sample 4 is 0.8	coefficient for samples without courtyards should be less than or equal to 0.86
	Interface type	The proportion of sample selection interface is between 22.7-74.8%	The net beneficial radiation of the exposed interface of the building is positive, and it is advisable to use selective interface to increase the introduction of beneficial radiation.
Performance-oriented structure	Structure-enhance convection	The dormer window can be opened on the roof, the transom and ventilation holes can be opened toward the second alley, and the ventilation holes that run through the second alley-entrance garden-living room-back room-back patio, etc.	It should be reasonably selected, combined and utilized according to the actual situation.
	Strucrture-Enhance Evaporation	Plant trees and shrubs in the main, secondary alleys and home gardens, and arrange water nodes such as washbasins in the secondary alleys and patios, etc.	
	Structure-Restrain Conduction	Brick or concrete enclosure interface.	
	Structure-Restrain radiation	The overhang of the block, the overhang of the top eaves, the sun-shading green plants planted along the south-facing interface, horizontal and vertical sun-shading components, etc.	
	Other performance-oriented structure	Wooden floor, lowered courtyard patio fence, iron light-transmitting fence.	

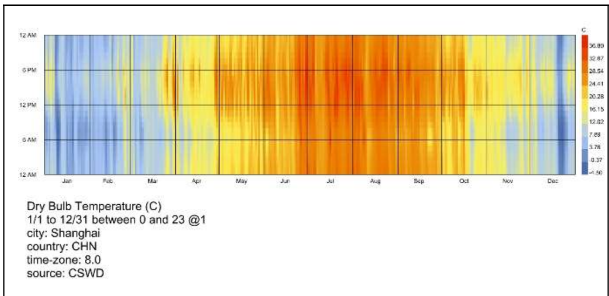
Chapter5. Conclusion

5.1 Research conclusion: Induction of samples of Shanghai Shikumen residential space climate construction

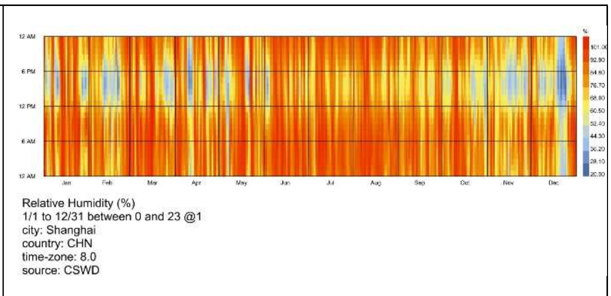
5.1.1 Climate characteristics and cultural background

（1）Climate characteristics

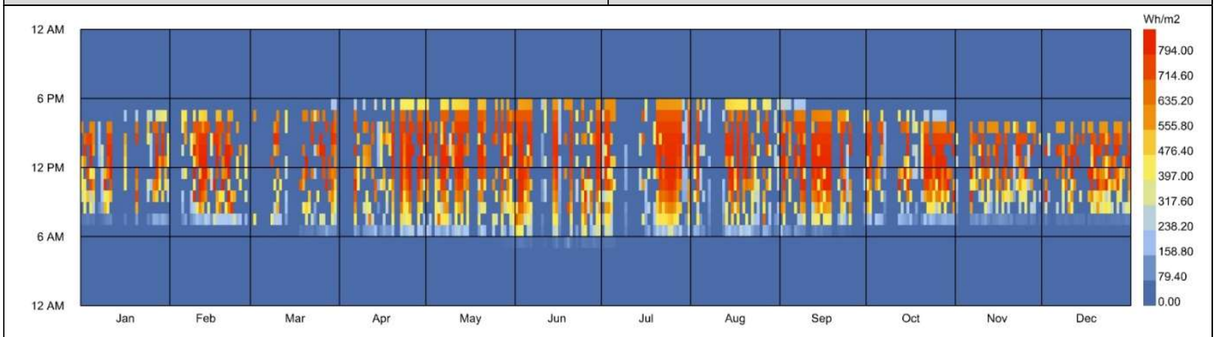
Shanghai is located in the Yangtze River Delta region, with flat terrain and the Huangpu River running through it. Shanghai has a subtropical monsoon climate, with a maximum temperature of 40°C in summer and a minimum temperature of minus 4.5°C in winter. The annual average sunshine time is more than 5 hours, and the prevailing wind direction throughout the year is southeast wind with an average wind speed of 3.2m/s. The proportion of thermal comfort in the outdoor space is 44% throughout the year, and 15.47% in the indoor space, and it is relatively concentrated in spring and autumn, and the indoor and outdoor thermal environment is not good in winter and summer.



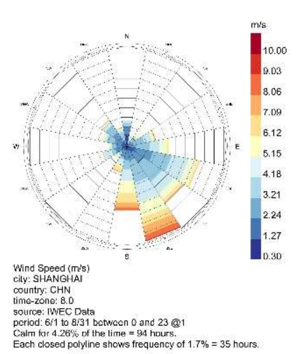
Annual dry bulb temperature



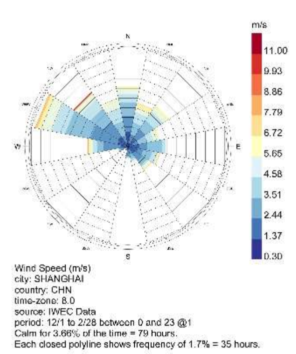
Annual relative humidity



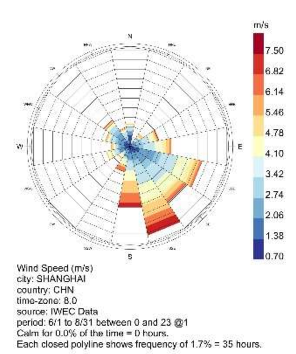
Annual solar radiation



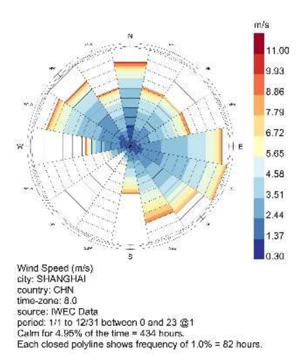
Summer wind rose



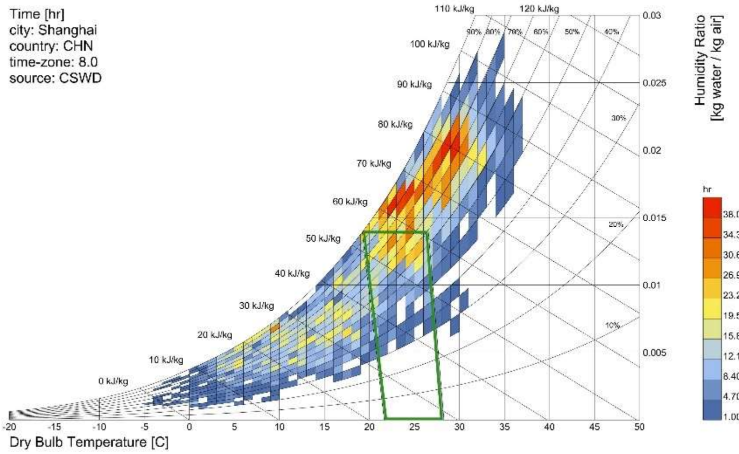
Winter wind rose



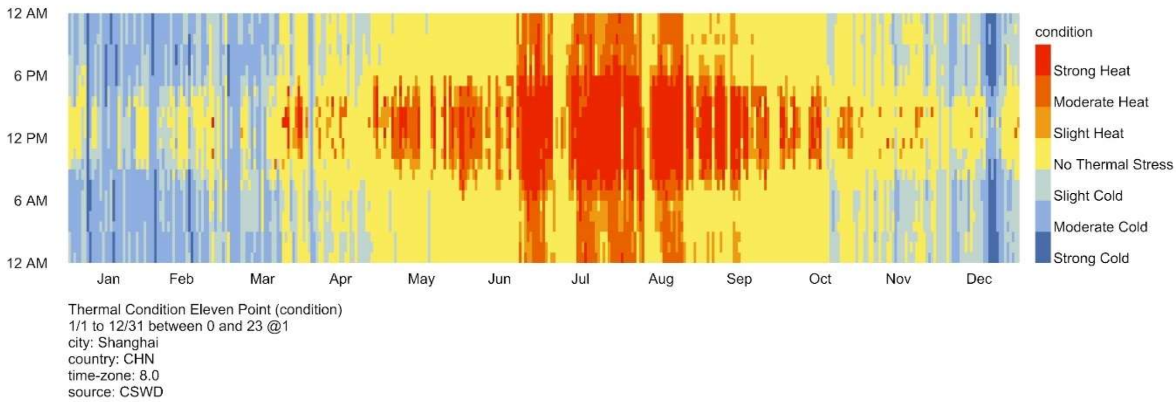
Summer comfort wind rose



Annual Wind Rose Chart



Enthalpy Chart of Shanghai Area

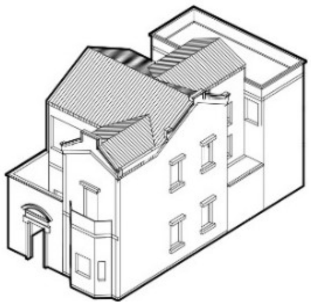
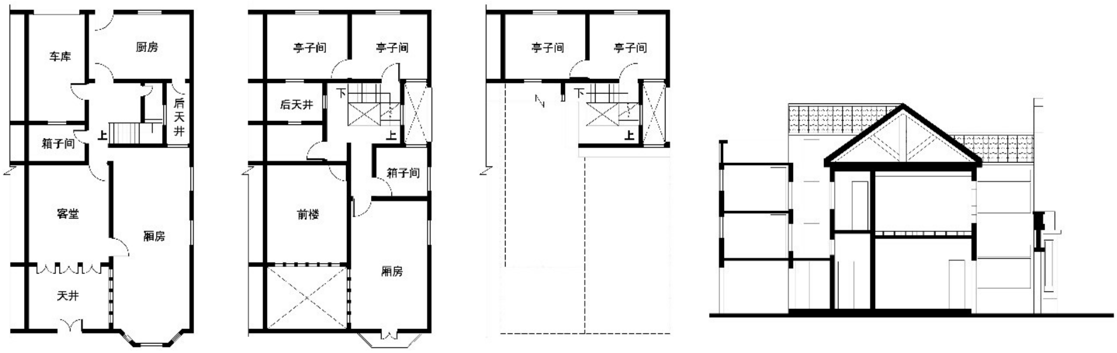


Shanghai UTCI

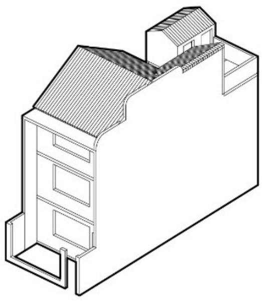
（2）Cultural background

Shanghai is one of the cities with the most rapid urbanization in modern China. Before the 13th century, it was only a fishing village. Since the opening of the port, social turmoil has led to a large influx of people around Shanghai and overseas immigrants. The transformation of urban social life style and the blending and collision of various cultures have profoundly affected the birth and development of Shikumen. From 1890 to 1920, with the vigorous development of the modern construction industry, Shikumen also ushered in the peak of a large number of construction. Later, with the development of Shanghai's urban modernization, Shikumen gradually declined, and today Shikumen is gradually disappearing in the high-density Shanghai city.

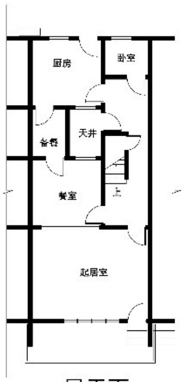
5.1.2 Building Type

<table>
<tr><th colspan="2">With garden type</th></tr>
<tr><th>Pthoto</th><th>Prototype axonometric</th></tr>
<tr><td> </td><td></td></tr>
<tr><th colspan="2">Typical Type Drawings</th></tr>
<tr><td colspan="2">

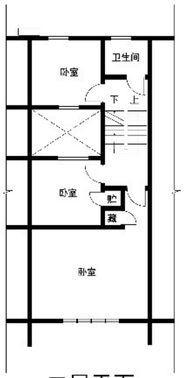
一层平面 二层平面 三层平面 剖面</td></tr>
</table>

<table>
<tr><th colspan="2">Without garden type</th></tr>
<tr><th>Pthoto</th><th>Prototype axonometric</th></tr>
<tr><td> </td><td></td></tr>
</table>

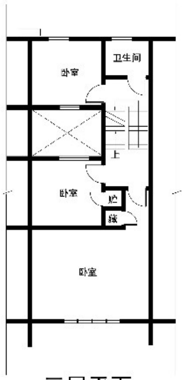
Typical Type Drawings



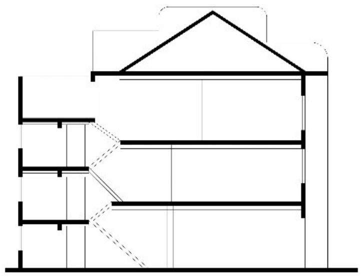
一层平面



二层平面

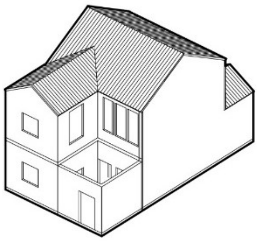
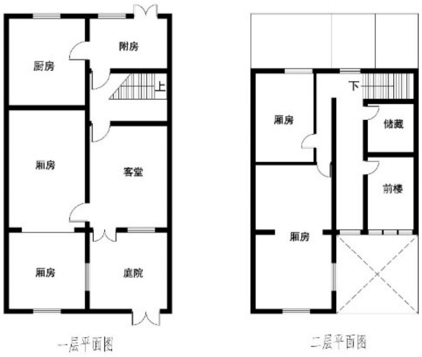


三层平面

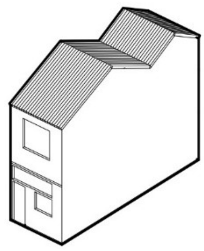
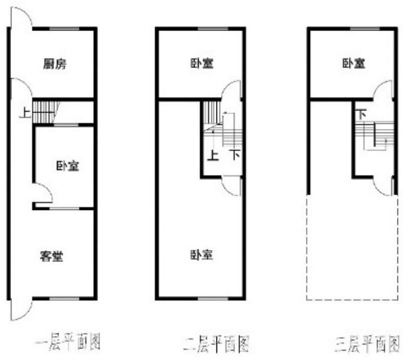


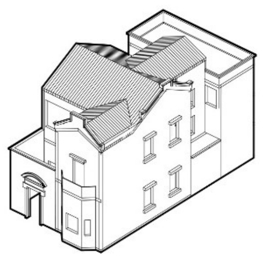
剖面

5.1.3 Data from the survey sample

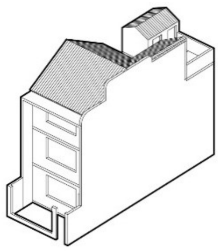
Sample No.		SKM-01	Location		121.5°E	**Photo**
Name		Wangyun Road 146 Long			31.2°N	
Function		Residential	**Type**		Early Shikumen	
Location	**City**	Shanghai	**Plane**	**Room**	2	
	District	Huangpu		**Depth**	1	
	Street	Wangyun Road 146 Long	**Storey**		2	**Simplified model**
Orientation		14° East by South	**Roof form**		Hard gable roof	
Construction time		About 1920	**Area/㎡**		About 93 ㎡	
Preservation status		Good	**Building Area/㎡**		About 157 ㎡	
Current use		Idle to be demolished	**Protection level**		NO	
Sample Plane						
						

Sample No.		SKM-02	**Location**		121.5°E	**Photo**
Name		Shunchang Road 504 Long			31.2°N	
Function		Residential	**Type**		Cantonese-style Lilong	
Location	**City**	Shanghai	**Plane**	**Room**	1	

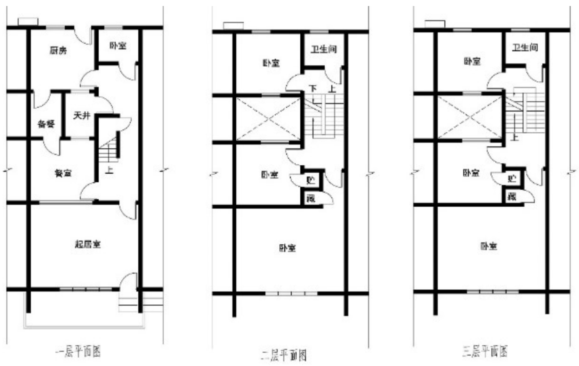
	District	Huangpu		**Depth**	1	
	Street	Lane 504, Shunchang Road	**Storey**		Front:2 Back:3	**Simplified model**
Orientation		20° south by east	**Storey**		Hard gable roof	
Construction time		1926	**Roof form**		About 32 ㎡	
Preservation status		Good	**Area/㎡**		About 74 ㎡	
Current use		Idle to be demolished	**Building Area/㎡**		NO	
Sample Plane						
						

Sample No.		SKM-03	**Location**		121.5°E	**Photo**
Name		Siming village			31.2°N	
Function		Residential	**Type**		Later Shikumen Lilong	
Location	**City**	Shanghai	**Plane**	**Room**	2	
	District	Jing'an		**Depth**	1	
	Street	Lane 913, Yan'an Middle Road	**Storey**		Front:2 Back:3	**Simplified model**
Orientation		19° south by east	**Roof form**		Hard gable roof	
Construction time		1932	**Area/㎡**		About 132 ㎡	
Preservation status		Good	**Building Area/㎡**		About 260 ㎡	
Current use		Residential	**Protection Level**		Municipal	

Sample Plane

Sample No.		SKM-04	**Location**	121.5°E		**Photo**
Name		Jinghua new village		31.2°N		
Function		Residential	**Type**	New style Lilong		
Location	**City**	Shanghai	**Plane**	**Room**	1	
	District	Jing'an		**Depth**	1	
	Street	Lane 820,Julu Road	**Storey**		Front:2 Back:3	**Simplified model**
Orientation	28° south by east		**Roof form**		Hard gable roof	
Construction time		1937	**Area/㎡**		About 93 ㎡	
Preservation status		Good	**Building Area/㎡**		About 252 ㎡	
Current use		Residential	**Protection Level**		Municipal	

Sample plane



5.1.4 Space-climate mechanism

（1） Space climate selection

① Terrain selection

The terrain in Shanghai is flat, and the terrain selection of Shikumen Lilong residential buildings is mostly limited by the requirements of urban planning, and mostly conforms to the urban spatial structure divided by the urban road network.

② Climate choice

The prevailing wind directions in Shanghai in summer and winter are 22.5° south by east and 22.5° north by west respectively. The Shikumen Lilong dwellings conform to the development of urbanization and adopt a high-density construction method. The environmental performance of alleys, courtyards, patios and indoor spaces must meet the needs of daily use. Considering the direction of heat and wind, Shikumen dwellings mostly face south by east 20°-30°, and the roof inclination angle is between 25°-30°. Within the above range, Shikumen Lilong can obtain a more balanced wind and heat environment from the main alley to the indoor space at all levels. (Figure 51Figure 52)

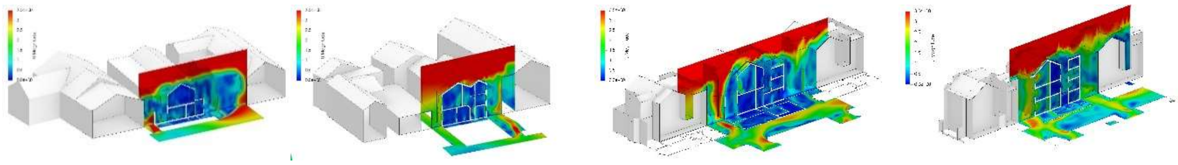


Figure 51 Wind azimuth angles of 35°, 45°, 40° and 50° source: self-drawn

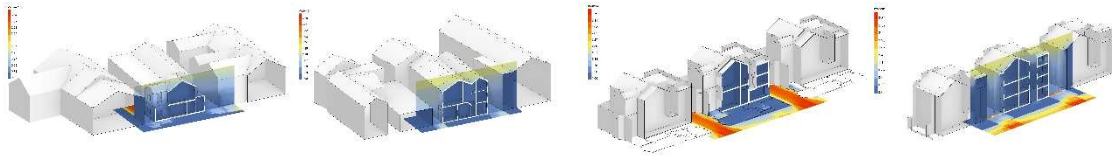


Figure 52 Thermal azimuth angles of 14°, 20°, 19° and 28° are indicated Source: self-drawn

③ Contextual choice

Shanghai Shikumen Lilong houses are one of the representatives of the urbanization transformation of traditional houses. It originated from the traditional houses in the south of the Yangtze River, so it has the characteristics of adaptability to the climate in the south of the Yangtze River. And in the process of Shanghai's rapid urbanization, it gradually absorbed the influence of various cultural background residential types such as western townhouses, and gradually evolved into various types of residential buildings such as early and late Shikumen.

（2） Physical space type

① Basic Morphological type

The samples show that the residential spaces in Shikumen Lilongs are hierarchical. The differences in the morphology types of the four samples are mainly manifested in the two levels of groups and buildings. Group level: The overall plan layout of the samples with a later construction time is more regular, and the primary and secondary alleys have a clear hierarchy, and the proportion of negative body shape at this level is about 20%. Building level: The number of bays in residential buildings with a later construction time is reduced, and the width-to-depth ratio of a single building is reduced to obtain higher construction density. The negative shape at the volume-intermediate level accounts for about 10% (Figure 53).

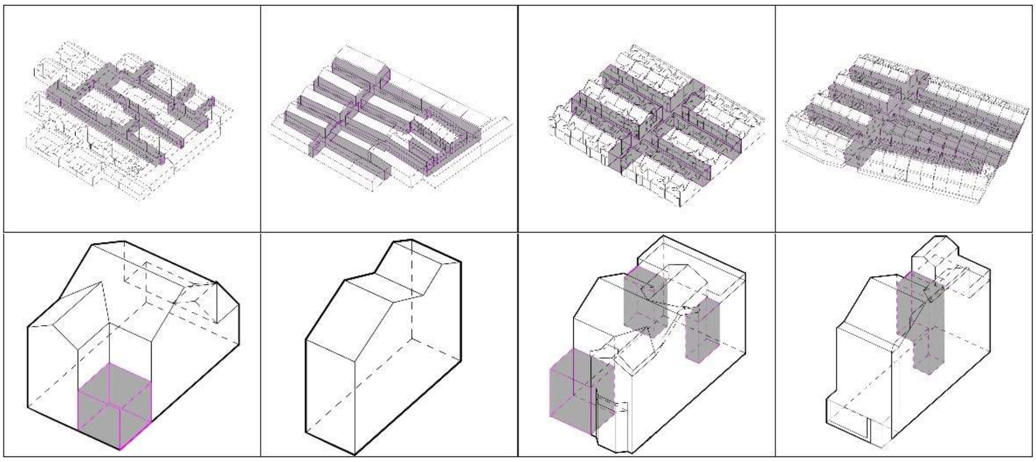


Figure 53 Void body distribution of sample Source: self-drawing

② Related parameters of void body

The negative shape aspect ratio distribution of the sample is relatively discrete, the group-group level aspect ratio is between 1.5-2.8, the value of the courtyard is between 1-1.5, and the back patio is between 1.8-4.3. Overall, samples 3 and 4 performed better than samples 1 and 2 in negative body shape space environment performance. The ratio is negatively correlated with the internal wind and light environment performance of the negative body shape, and positively correlated with the thermal environment. Considering the contradictory nature of negative body shape parameter adjustments to wind, light, and heat regulation, it is comprehensively verified that the value of secondary alley in without courtyard samples is about 1.5, and that of patios is about 4. The height-to-width ratio of alley in some courtyard samples is about 2, and the height-to-width ratio of the courtyard is about 1.5. The value of the patio is to ensure that the indoor light is as close as possible to 4, so as to enhance the thermal pressure and ventilation effect of the patio.（Figure 54Figure 55）。

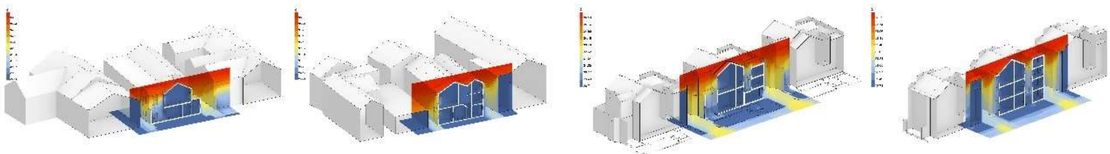


Figure 54 The radiation level indication of sample with void body aspect ratio 2.4, 2.8, 1.8, 2.1 Source: self-painted

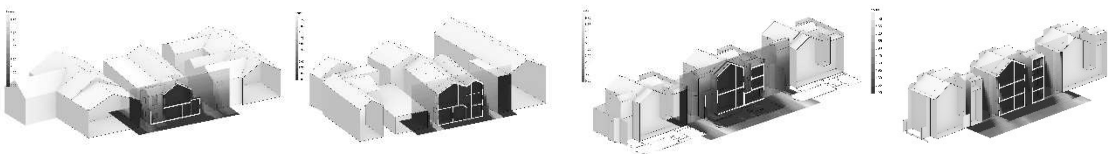


Figure 55 The shadow density indication of sample with void body aspect ratio 2.4, 2.8, 1.8, 2.1 Source: self-painted

③ Building shape coefficient

The individual Shikumen dwellings are closely connected, and groups are separated by lanes. It can be calculated that the building shape coefficients of the four sample buildings are basically between 0.41 and 0.45. The shape coefficients of the samples with a later construction period are smaller, and the shape coefficients of the single-room samples are even smaller.

（3） Space climate gradient

Different from other traditional dwellings, the space-climate gradient of the Shikumen Lilong residential sample is mainly composed of outdoor open-air space-heat receptors-non-regulated space. The outdoor open-air space is divided into two levels: "group" and "building" according to its space level. In the samples, the group-level outdoor open-air spaces are mainly main alleys and secondary alleys, and the building-level outdoor open-air spaces are mainly courtyards and patios. The thermal receptor spaces in Shikumen are mainly functional spaces such as living room, wing room, kitchen and bedroom, while non-regulated spaces are mostly storage and transportation spaces. There is an obvious climate gradient attached to the above spatial level in the sample（Figure 56Figure 57Table 50）.

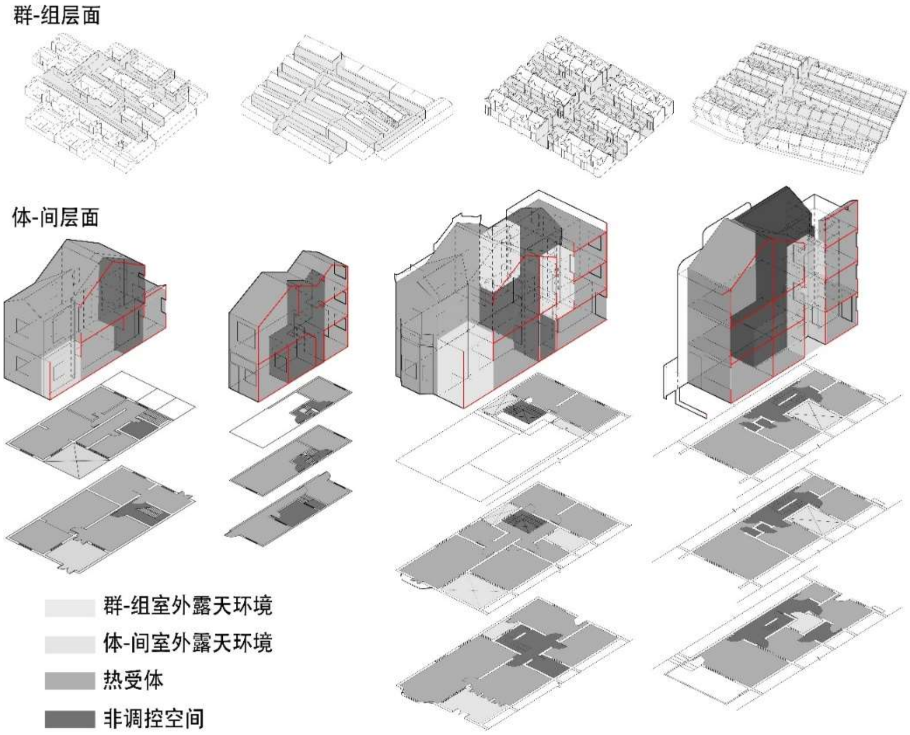
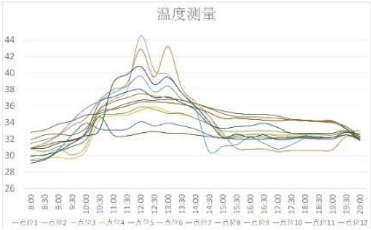
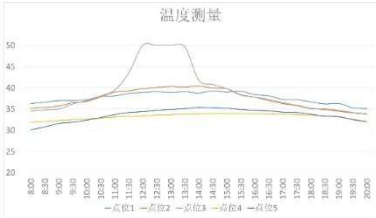


Figure 56 Sample space climate gradient Source: self-drawing

Table 50 The measured temperature and humidity data of the sample in summer

Temperature data	
SKM-01	SKM-02
	
SKM-03	SKM-04
	
Humidity data	
SKM-01	SKM-02
	
SKM-03	SKM-04
	

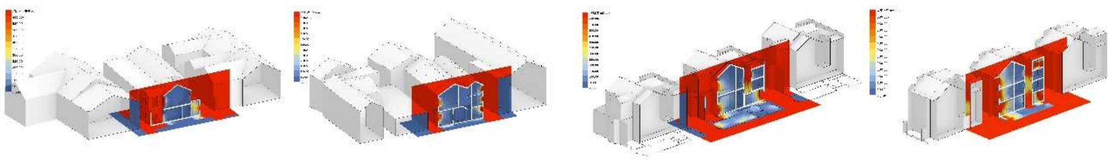


Figure 57 Diagram of sample light environment gradient Source: self-drawnClimate control interface

There are mainly three types of climate control interfaces in traditional dwellings: open type, selective type and isolated type. There are two types of climate control interfaces in the sample Shikumen Lilong houses: selective and isolated. The interface distribution of sample selection type and isolation type is shown in Figure 58. Among them, the ratio of the selective interface to the isolation interface of samples 1 and 3 is 2.5:1, and that of samples 2 and 4 is 1:2.5. The north-south interface of Shikumen is generally a selective interface, and the east-west interface is an isolated interface, so the number of bays directly affects this value. As a selective interface, the north-south interface can better guide the wind and thermal environment. The openable area of the south-facing interface is about 20% for double-room samples 1 and 3, and about 30% for single-room samples 2 and 4. .

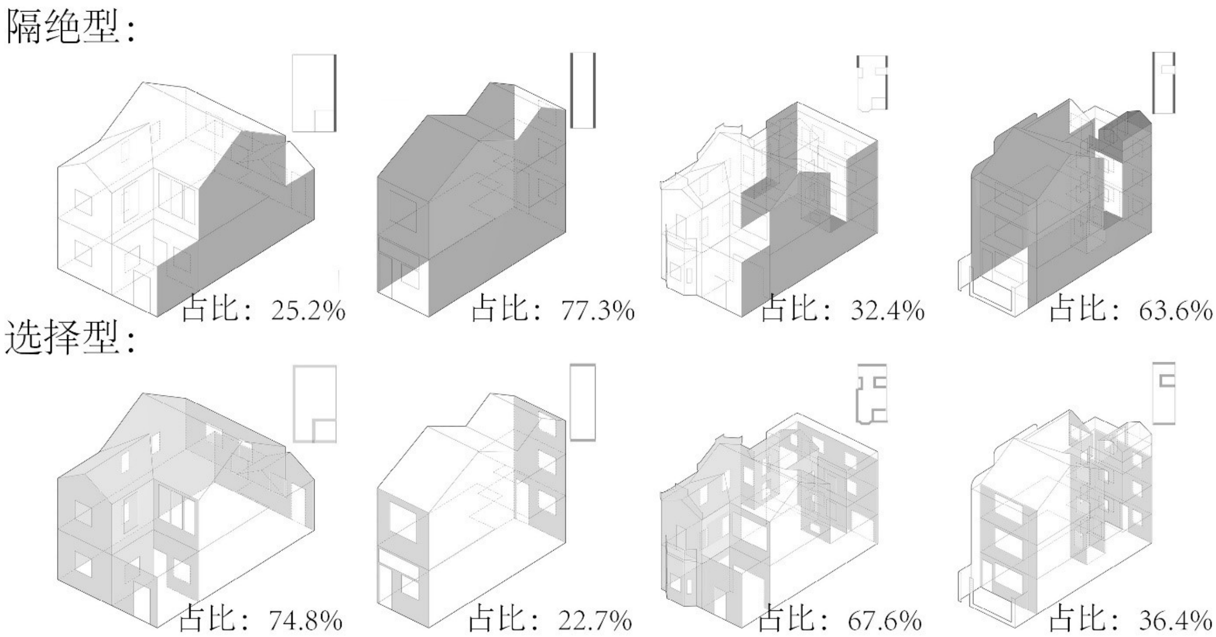
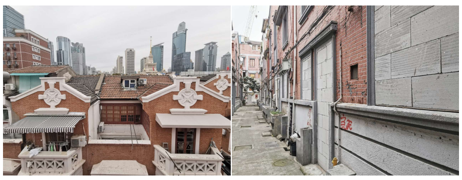
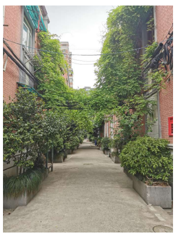


Figure 58 Proportion and distribution of sample interface types Source: self-drawn

（4） Performance-oriented structure

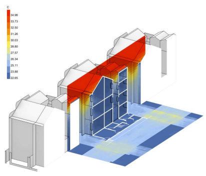
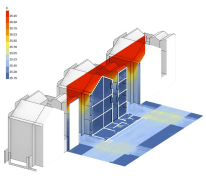
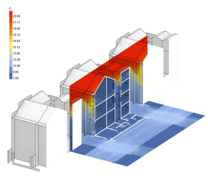
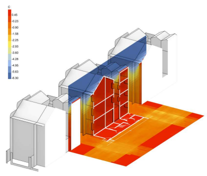
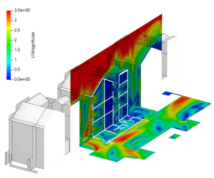
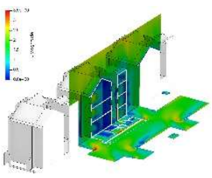
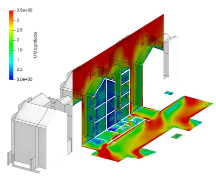
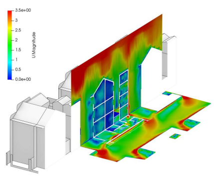
The performance-oriented structures in Shikumen dwellings mainly include four types: to suppress conduction and radiation, enhance evaporation and convection. The performance-oriented structures of the actual survey samples are shown in Table 51.

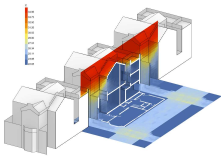
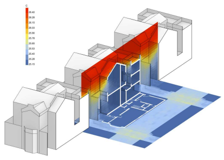
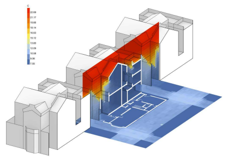
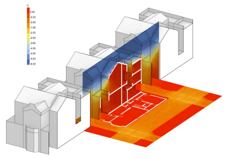
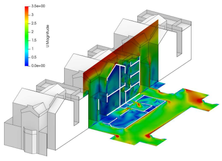
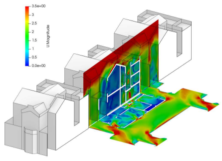
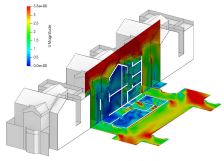
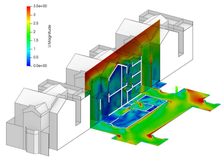
Table 51 Performance-oriented construction table

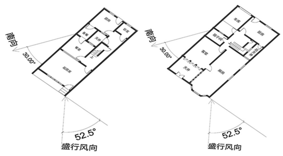
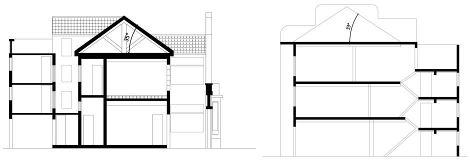
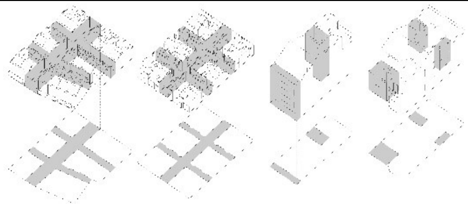
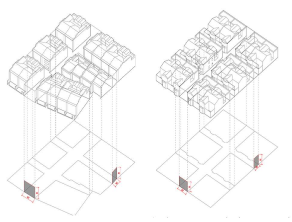
Structure-enhance convection	The dormer window can be opened on the roof, the ventilation holes are opened toward the second alley, and the ventilation holes run through the second alley-entrance garden-living room-back room-back patio	 
Strucrture-Enhance Evaporation	Plant green plants on both sides of the main alley, landscape vegetation in the home garden, and arrange water points such	  

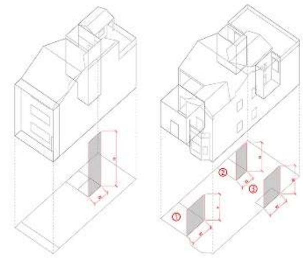
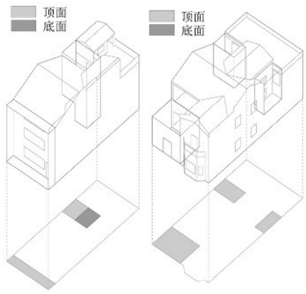
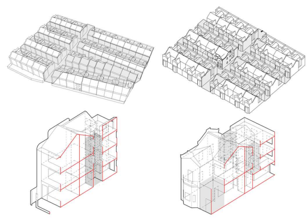
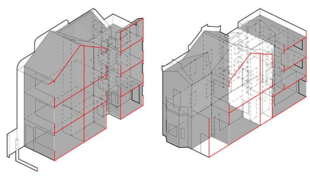
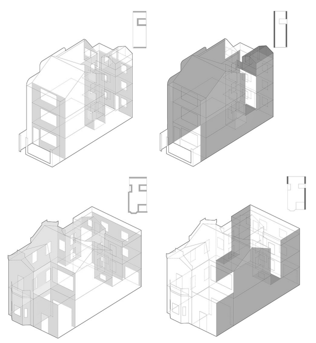
	as washbasins in the secondary alleys and patios	
Structure-Restrain Conduction	Brick or concrete enclosure interface	
Structure-Restrain radiation	Overhanging blocks on the second floor, overhanging eaves at the top, planting green plants for sunshade along the south-facing interface, and horizontal and vertical sunshade components	

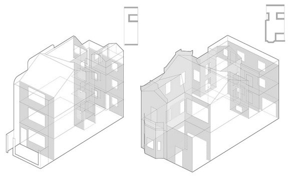
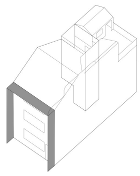
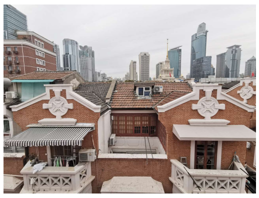
5.1.5 Space-climate configuration

Space-climate configuration of Shikumen dwellings in Shanghai			
With garden type			
Temperature Distribution - Summer Solstice		Temperature Distribution - Winter Solstice	
			
Airflow Distribution - Summer Solstice		Airflow Distribution - Solstice Day	
			
Daylight 14:00	Night 0:00	Daylight 14:00	Night 0:00

<table>
<tr><th colspan="4">Without garden type</th></tr>
<tr><th colspan="2">Temperature Distribution - Summer Solstice</th><th colspan="2">Temperature Distribution - Winter Solstice</th></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><th colspan="2">Airflow Distribution - Summer Solstice</th><th colspan="2">Airflow Distribution - Solstice Day</th></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Daylight
14:00</td><td>Night
0:00</td><td>Daylight
14:00</td><td>Night
0:00</td></tr>
</table>

<table>
<tr><th colspan="2">Configuration parameters</th><th>Configuration parameter diagram</th><th>Energy mechanism</th></tr>
<tr><td rowspan="2">Space climate selection</td><td>Building azimuth</td><td>
The azimuth of the building is 30° south by east</td><td>Energy capture</td></tr>
<tr><td>Roof slope angle</td><td>
Building roof slope angle 30°</td><td>Energy capture</td></tr>
<tr><td rowspan="2">Physical space type</td><td>Percentage of void body</td><td>
The proportion of void body at the group level is 20%, and the proportion of negative figure at the building level is 10%.</td><td>Energy isolation</td></tr>
<tr><td>Alley aspect ratio</td><td>
Alley aspect ratio 1.5:1 and 2:1</td><td>Energy isolation</td></tr>
</table>

	Courtyard, Patio Aspect Ratio	 The patio aspect ratio is 4.3:1, ①The patio aspect ratio is 1.5:1, ②The patio aspect ratio is 2.8:1 and ③1.8:1	Energy isolation
	The mouth-to-bottom ratio of alleys, courtyards, and patios	 The mouth-to-bottom ratio of the courtyard is 1:1	Energy isolation
Space climate gardient	Outdoor open space	 The outdoor environment accounts for 30%	Energy damping
	Heat receptor	 Spatial distribution of thermal receptors	Energy damping
Climate control interface	The proportion of various interface types	 No courtyard sample: selection type: isolation type interface = 1: 2.5 Sample with courtyard: selection type: isolation type	Energy isolation

		interface = 2.5: 1	
	The proportion of openable area	 No courtyard sample: North-south openable area accounted for 25%, 17% indicated There are courtyard samples: the north-south openable area accounts for 28% and 12%	Energy isolation
	Comprehensive shading coefficient	 The comprehensive shading coefficient is 0.86	Energy isolation
Performance-oriented structure	Structure-enhance convection	 	Energy dissipation
	Structure-enhance evaporation	 	Energy dissipation
	Structure-restrain conduction	 	Energy isolation

	Structure-restrain radiation	 	Energy isolation

5.2 Research innovation

This research is one of the sub-projects of "Study on Building Space Climate Configuration in Hot Summer and Cold Winter Region Based on Form Energy Law and Its Adaptability Analysis". In addition, there are four parallel sub-projects of Jianghuai folk houses, Jiangxi patio-style houses, Dongyang Shisanjiantou houses and mountain houses in Northwest Fujian. This study is based on the existing green building research foundation of Taihu Lake Basin residential buildings, Huizhou residential buildings, stilted houses in Hunan, Hubei, Sichuan and Guizhou, and Hakka residential buildings on the Hunan-Jiangxi border by Fengtu Architecture Studio, and made the following innovations in research methods and achievements:

(1) Method innovation——Space-climate Mechanism: Expand the research field of space-climate mutual mechanism from single building to neighborhood level. Combing the synergistic mechanism of "climate adaptation-spatial form-energy construction" in Shikumen dwellings, crossing the knowledge boundary between architectural space form and climate energy. Reveal the translation structure between energy flow and configuration adjustment, and further develop the theoretical research on green buildings in hot summer and cold winter regions.

(2) Achievement innovation-energy construction diagram: systematically sort out the characteristic construction presentation that reflects climate rationality and energy logic. Construct a sample of Shikumen residential space climate configuration. Draw the characteristic energy structure diagram, and couple the classic section diagram showing the construction characteristics with the performance simulation calculation analysis. Realize the key transfer of green building research from theory to method, and play a normative and guiding role in the practice of green building by revealing the type of "climate-space-energy" relationship.

5.3 Research Insufficiency and Prospect

Due to the limitations of the author's personal research ability, writing level and research time, there are still many shortcomings in this study:

(1) The classification of Shikumen Lilong dwellings relies more on literature research and lacks the support of first-hand information.

The selection of samples still has a certain degree of randomness, and the significant influencing factor of the position of the sample in the group-group is not well considered in the initial sample selection process.

(2) Most of the existing well-preserved Shikumen dwellings are still used for residential or commercial functions, and the internal spatial pattern of some samples has been modified many times, but the impact of the modification of the indoor space on the indoor wind, light

and thermal environment is not discussed in this paper .

(3) During the actual survey and survey, the application of active adjustment measures such as air conditioners and exhaust fans in some samples reduced the effective data of the survey and challenged the integrity of the internal environmental data of the samples.

(4) The research on the indoor humidity environment is limited to the field survey data, and due to the influence of precipitation during the sample collection stage, the data is highly accidental. Due to time issues, this study did not discuss it.

(5) Due to force majeure, the collection of environmental meteorological factors on typical weather days in winter cannot be carried out smoothly.

Based on the perspective of "space-climate-energy" synergy, this research studies the space-climate mechanism of the urbanization transformation of Shikumen, an atypical traditional dwelling. It is an exploration of the theoretical research field of environmental regulation from a single building to a neighborhood scale. The complexity of the urban space environment brings greater challenges to the research on the regulation of the residential building environment. There are still many deficiencies in the work done in this paper, but in the foreseeable future, the research on urban-building environment regulation will become more and more profound and full.

References

[1] Alison Kwok, Walter Grondzik. THE GREEN STUDIO HANDBOOK: Environmental Strategies for Schematic Design, Second Edition[M]. New York: Routledge Press, 2011.

[2] H Fathy. Natural Energy and Vernacular Architecture[M]. Chicago: The University of Chicago Press, 1986.

[3] Victor Olgyay. Design With Climate: Bioclimatic Approach to Architectural Regionalism[M]. New Jersey: Princeton University Press princeton, 1967.

[4] R.Banham. The Architecture of Well-tempered Environment[M]. London: The Architectural Press/The University of Chicago Press, 1969.

[5] Dean Hawkes, Jane McDonald and Koen Steemers. The Selective Environment: An approach to environmentally responsive architecture [M]. London; New York: Spon Press, 2002.

[6] Peter Frederick Smith. Architecture in a climate of change: a guide to sustainable design[M]. Boston: Architectural Press, 2001.

[7] Thomas Randall. The Environments of Architecture[M]. London: Routledge, 2007.

[8] Varis Bokalders, Maria Block, Ronald Wennersten. The whole building handbook： how to design healthy， efficient and sustainable buildings [M] Translated by Zhang Tong , Gu Zhenhong. Nanjing: Southeast University Press，2016.

[9] Ian L. McHarg. Design with nature [M]. Translated by Rui Jingwei. Beijing: China Architecture and Building Press，1992.

[10] Baruch Givoni. Man, Climate and Architecture [M]. Translated by Zhang Qinnan. Beijing: China Architecture and Building Press，1967.

[11] Krishan, Arvind. Climate responsive architecture : a design handbook for energy efficient buildings [M]. Translated by Liu Jiaping, Zhang Jiliang, Tan Liangbin. Beijing: China Architecture and Building Press，2005.

[12] Zhang Tong. Holistic regionalism of architecture [M]. Nanjing：Southeast University Press，2003.

[13] Zhang Tong. Green north:sustainable urbanism and architecture in scandinavia [M]. Nanjing：Southeast University Press，2009.

[14] Liu Xianjue. Architecture of ecology [M]. Beijing: China Architecture and Building Press，2009.

[15] Wang Shaozhou, Chen Zhimin. Lilong architecture [M]. Shanghai:Shanghai Scientific and Technology Literature Press, 1987.

[16] Wang Shaozhou. Catalogue of Modern Chinese Architecture [M]. Shanghai:Shanghai Scientific and Technology Literature Press，1989.

[17] Cao Wei. Shanghai housing after its opening to foreigners [M]. Beijing: China Architecture and Building Press，2004.

[18] Deng Qingtan. Illustration of the history of China modern architecture [M]. Huazhong University of Science & Techonlogy Press, 2012.

[19] Wu Liangyong. Introdution to sciences of human settlements [M]. Beijing: China Architecture and Building Press，2001.

[20] Wang Li. Green Building Design: Architectural Wind Environment [M]. Shanghai: Tongji University Press，2014.

[21] Lin Borong. Optimization method of green Building performance simulation [M]. Beijing:

China Architecture and Building Press，2016.
[22] Lv Aimin. Responsive architecture: ecological strategy in Continental climate area [M]. Shanghai: Tongji University Press，2003.
[23] Song Yehao. Combining natural overall design [M]. Beijing: China Architecture and Building Press，2003.
[24] Green Building Research Center of Xi'an University of Architecture and Technology. Green Building M].Beijing：China Planning Press，1999.
[25] Gu Jie. HVAC Design and Calculation Methods [M]. Beijing: Chemical Industry Press, 2013.
[26] Wu Jiang. History of Shanghai architecture:1840-1949 [J]. Shanghai: Tongji University Press, 1997.
[27] Zhong Wenzhou. FORM AND ENERGY RESEARCH ON ARCHITECTURAL MODEL OF ENVIRONMENTAL REGULATION [D]. Southeast University,2021.
[28] Min Tianyi. Research on the Climate Adaptation Mechanism and Environmental Mediation Performance of Architectural "Opening" System in Taihu Basin’s Vernacular Dwellings [D]. Southeast University,2020.
[29] Lin Yifeng. The Analysis of Thermal Adaptive Alba-Model of UrbanMorphology in Humid Temperate Climate [D]. Southeast University,2021.
[30] Liu Qiao. THE ANALYSIS OF THERMODYNAMIC MODEL OF ARCHITECTURE IN CLIMATE REGION OF HOT SUMMER AND COLD WINTER , CLIMATE REGION OF HOT SUMMER AND WARM WINTER [D]. Southeast University,2019.
[31] Chen Bin. A RESEARCH ON THERMODYNAMIC MODEL OF ARCHITECTURE IN COLD REGIONS AND SEVERE COLD REGIONS [D]. Southeast University,2019.
[32] Xiao Wei. ADAPTIVE SHAPERESEARCHON THE SHAPE-DESIGNSTRATEGYOF SPACE-CONDITIONINGOFGREENBUILDING [D]. Southeast University,2018.
[33] Yang Liu. Climatic Analysis Techniques and Architectural Design Strategies for Bio—climatic Design[D]. Xi'an University of Architecture and Technology,2003.
[34] Mao Yan. Study on Climate Adaptability of Human Beings to Thermal Combort in China [D]. Xi'an University of Architecture and Technology,2007.
[35] Luo Shanshan. The Development of Shanghai Lilong and Its Suggestions to Modern Design [D]. Shanghai Jiaotong University,2007.
[36] Zhu Jun. Eco-Morphology strategies of space-conditionging in architecture design [D]. Nanjing：Southeast University，2009.
[37] Su Ling. RESEARCH ON THE DESIGN STRATEGY OF ECOLOGICAL BUILDING ENVELOPE IN HOT-SUMMER & COLD-WINTER REGION ——ECO-POTEVIO PROJRCT, CHINA PUTIAN SHANGHAI INDUSTRIAL PARK AS AN EXAMPLE [D]. Nanjing：Southeast University，2008.
[38] Zheng Jinlan. STRATEGIES OF SPACE-CONDITIONING IN GREEN ARCHITECTURE DESIGN [D]. Nanjing：Southeast University，2011.
[39] Li Yiyuan. RESEARCH ON THE GREEN ARCHITECTURE OF CONTEMPORARY CHINA——PUBLIC BUILDINGS [D]. Nanjing：Southeast University，2012.
[40] Chen Fei. Architecture and climate[D]. Shanghai: Tonji University，2007.
[41] Li Jianbin. Study on Generation and Application of the Eco-Building Experience in Traditional Dwellings [D]. Tianjin: Tianjin University，2008.
[42] Chen Yuqing. Design with Climate [D]. Wuhan: Huazhong University of Science and Technology，2005.

[43] Fan Min. An Approach to Ideas and Works of Hassan Fathy [D]. Xi'an: Xi'an University of Architecture and Technology，2009.

[44] Tian Yincheng. Research on the Climatic Adaptability of Traditional Residential Courtyards Type [D]. Xi'an: Xi'an University of Architecture and Technology，2013.

[45] Hu Zhichao. Study on the Site Design Strategy of Modern Buildings Based on the Morphological Pattern of Folk Building in the South of Yangtze River [D]. Southeast University, 2017

[46] Wang Jianhua. Study on Responsive Measures of Traditional Dwellings Basis on Jiangnan Climate [D]. Zhejiang: Zhejiang University,2008.

[47] Han Pei. RESEARCH ON COLD ACCLIMATION DESIGN OF ARCHITECTURES IN THE COLD REGION BASED ON BIOLOGICAL ACCLIMATIZATION[D]. Harbin :Harbin Institute of Technology,2016.

[48] Zhao Qun. Research on the Ecological Experiences and Pattern Language of Traditional Residential Building [D]. Xi'an: Xi'an University of Architecture and Technology, 2005.

[49] Zhang Tong. Environment Regulation and Space—conditioning：the Disciplinary Autonomy and Design Methodology of Sustainable Architecture [J]. Architect, 2019(06):4-5.

[50] Zhang Tong. SPACE-CONDITIONING PASSIVE ENERGY-SAVING DESIGN AT THE GREEN OFFICE BUILDING OF CHINA POTEVIO GROUP SHANGHAI INDUSTRIAL PARK [J]. Ecological City and Green Building. 2010（1）:82-93.

[51] Zhang Tong. Space Conditioning Architects' 'Air Conditioning' Strategy [J].DomusChina.2010(07/08).

[52] Zhang Tong. SPACE CONDITIONING, PERFORMANCE DRIVING: STUDY ON THE SYLLABUS OF THE 4TH YEAR STUDIO OF GREEN ARCHITECTURAL DESIGN, SOUTHEAST UNIVERSITY [J]. Urbanism and Architecture.2015(11).

[53] David Leatherbarrow and Richard Wesley, Performance and style in the work of Olgyay and Olgyay[J]. Arq: Architectural Research Quarterly, 2014, 18(2): 170.

[54] Min Tianyi, Zhang Tong. Analysis on the Climate Adaptability of the "Opening" Elements of Rural Dwelling in Suzhou [J]. Journal of Human Settlements in West China, 2015,30 (02): 25-35

[55] Wu Haoran, Zhang Tong, Sun Bai, Ma Chi. Performance Mechanism of Building Envelope and Key Strategies of Interactive Facade Design [J].Architect,2019(06):25-34.

[56] Shou Tao, Zhang Tong, Liu Qiao. The Research of Architectural Thermodynamic Model of Huizhou Vernacular Architecture [J]. Architect,2019(06):35-44.

[57] Xiao Wei, Zhang Tong. Performance Mechanism of Building Formation and Key Strategies of Adaptive Formation Design [J]. Architect,2019(06):16-24.

[58] Cai Shiran, Zhang Tong. THE NATURAL DIMENSION AND SUSTAINABLE DESIGN STRATEGIES OF GREEN INTELLIGENT BUILDING [J]. Urbanism and Architecture, 2018(16):5.

[59] Xiao Yiqiang, Wang Jing, Lin Hankun. Think of Architecture Space Design Base on Energy-saving Strategies [J]. Huazhong Architecture 2010（06）.

[60] Xiao Yiqiang, Lin Hankun. The Study of Climate-adaptable Model Scale of Space in Bamboo-house in Guangzhou [J]. South Architecture. 2013（02）.

[61] Li Lixue. Knowledge, Discourse and Paradigm Historical Scenario and Contemporary Frontier of Energy and Thermodynamic Architecture [J]. Time Architecture.2015（2）. 10-15.

[62] Zhang Wei , Gao Zhi , Ding Wowo. Outdoor thermal comfort indices: a review of recent studies [J]. Journal of Environment and Health,2015,32(09):836-841.
[63] Shou Tao, Liu Qiao, Zhang Tong. Environmental Regulation and Typological Construction: A Comparative Study on the Architectural Thermodynamic Model of Courtyard Dwellings [J]. New Architecture,2021(05):123-129.
[64] Li Gang. From Epidermis to Chamber Apparatus--Analysis of Ecological Strategy of Three Foreign Buildings [J]. Architectural journal. 2004（3）.
[65] Zhang Jing. Architectural Climatic Design from Traditional Techniques [J]. Huazhong Architecture,2006(08):61-62.
[66] Tang Zilai. The Theory and Method of Western Urban Spatial Structure Research [J]. URBAN PLANNING REVIEW,1997(06):1-11+63.
[67] Liu Gang. Urban Reform of Shanghai Shi-ku-men Lilong Community Around 1958 [J]. New Architecture,2017(06):30-34.
[68] Liu Gang. FROM INDIVIDUAL CONSTRUCTIONS TO URBAN CLUSTERING:AN EMPIRICAL STUDY ON A GROUP OF RESIDENTIAL BUILDINGS OF EARLY MODERN SHANGHAI [J]. Urbanism and Architecture,2015(10):44-46.
[69] Huang Jinyu, Song Yang. Initial Research on the Origin of Construction Shape of Cantonese Style Lilong [J].Shanghai Urban Planning Review,2007(01):40-43.
[70] Lin Huijiao, Ma Hongyun, Zhang Mi. Analysis of the variation characteristics of human thermal comfort in summer of China from 1980 to 2019 based on UTCI [J].Climate Change Research,2022,18(01):58-69.
[71] Mao Gang, Duan Jingyang. Design ideas combined with climate [J]. Journal of World Architecture,1998(01):6-9.
[72] Zhu Xiaodong. Layout Comparison between Shanghai Terrace Housing and Rowhousing in Recent Years [J].Housing Science,2002(05):14-16.
[73] Zhang Ming, Lou Chenghao. Evolution of Shanghai Lilong Architecture [J]. Science,1988(04):312-314.
[74] Liu Gang. Reflection on Shanghai Shikumen Lilong Rehabilitation [J]. Heritage Architecture,2016(04):1-11.
[75] Wang Shaozhou. The emergence and development of modern residential buildings in Shanghai's alleys [C]// Architectural History Academic Committee of the Chinese Architecture Society. Architectural History and Theory (Volume 3 and 4). Jiangsu People's Publishing House,1982:248-255.
[76] Min Tianyi, Zhang Tong. Research on the "Opening" Paradigm in Response to Climate: The Case of Vernacular Architecture Construction System in Taihu Basin [J]. New Architecture,2021(05):4-10.
[77] Nie Lansheng,Ma Jian. THE ORIGINS AND DEVELOPMENTS OF TOWN HOUSES [J].World Architecture,2002(08):16-21.
[78] Chang Q.Shanghai Shikumen Lilong:Transformation process and regeneration models(in Chinese).Sci Sin Tech,2023,53:681–692,doi:10.1360/ SST-2022-0248.
[79] MUTHESIUS S. The English Terraced House [M]. New Haven:Yale,1982.
[80] Lou Chenghao,Xue Shunsheng.Laoshanghai Shikumen[M].Shanghai:Tongji University,2004