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The Analysis of Thermal Adaptive Alba-Model of Urban Morphology in Humid Temperate Climate
副热带湿润气候条件下热适应性城市形态的阿尔巴模型

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The Analysis of Thermal Adaptive Alba-Model of Urban Morphology in Humid Temperate Climate

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Abstract

The characteristics of city form contain the typological significance of thermal adaptability because of the region's climate conditions and natural resources. From the perspective of thermal adaptability and environment mediation, the paper takes the humid temperate climate as the research scope. It takes the Alba as the study case to analyze the formation and evolution mechanism of urban forms under these climatic conditions.

The paper first proposes a ternary external energy system model, urban regulation system, and human body reaction system. Then from the base of analyzing their interaction from the principle of thermal mechanism, the paper proposes the environmental physical factors that affect thermal comfort. Taking urban form as the research subject, the paper believes that urban form includes the design and organization of urban blocks, streets, and negative space, covering the whole city Urban public space and building interior space. On this basis, this paper analyzes the urban form and puts forward the formation factors and variables of urban form.

Secondly, this paper analyzes the morphological characteristics of traditional towns in different climatic regions of Italy, obtains the urban morphological types in different climatic regions of Italy, and extracts Alba, a small town with a humid temperate climate in northern Italy, as the research object. In this case, this paper makes a qualitative and quantitative study on the relationship between urban form and environment physical of Alba and analyzes its characteristics Main mechanism of action.

Finally, this paper extracts the analysis model from the base of the morphological characteristics of Alba. Taking the humid temperate climate as the premise, from the qualitative and quantitative point of view, supplemented by the performance simulation analysis, this paper analyzes the internal mechanism of the interaction between the physical properties of the different urban environment and urban form and constructs the urban structure under the Humid Temperate Climate Thermal adaptive Alba-Model of urban morphology.

Key words: Humid Temperate Climate, Environment Mediation, Thermal adaption of Urban Morphology, Alba-Model

Catalogue

1. Introduction

1.1 Origin of the project

In the author's second year of graduate studies, the author successfully applied for a one-year exchange program of double degree between Southeast University and Politecnico di Torino from 2019 to 2020 in Torino, Italy. When the author first arrived in Italy, he was profoundly impressed by its towns. Unlike the Chinese cities under modernization, most Italian towns have formulated strict preservation plans, where the urban texture of old town area have been well preserved. Therefore, most towns in Italy still maintain their Roman-, Baroque-, or Medieval-era town fabric. In addition, in the field of architecture and urban studies, Italian-related research is very in-depth. For example, the research results of Italian Typo-morphology[1] have a significant influence and even influence a group of Modernist architects' methodology and philosophy. Consequently, Italian Typo-morphology has irreplaceable contributions to theoretical research and practice of architecture. In Politecnico di Torino, the author participated in the studio about Typo-morphology hosted by Professor Trisciuoglio Marco, during which the author deeply realized the importance of Urban Form.

However, in China, since the Reform and Opening-up, cities have promptly developed, the superimposition between new buildings and old, and the expansion of city blocks at extremely rapid rate lead to the emergence of some large-scale cities. Some of them are exposed to some severe problems, as the lack of urban Landscape and large depletion of energy. In this context, the research on Sustainable Urbanism becomes the focus again, in which related concepts such as Sustainable Urbanism[2], Resilient city, and High-density city have been widely proposed and discussed. Especially the research on urban morphology is essential content.

1.1.1 Research Background

In ancient city construction, people had a rich and diverse understanding of the relationship between city form and climate. In the ancient Greece era, Hippodamus adopted a grid system to its street system in the planning of Miletus (an ancient Greek state). In his book "Air, Water, and Site" he emphasized the significance of air, soil, and environment to a city. In ancient Rome, the architect Vitruvius systematically summarized the selection of a city site, street layout, city form and architectural design, demonstrating the relationship between the city and the climate[3]. The Nolli Map completed by Giambattista Nolli in 1748 clearly showed Roman city form by figure-ground,

[1] Marco Trisciuoglio,董亦楠.可置换的类型 ： 意大利形态类型学研究方法与中国城市[J].建筑师,2017(06):22-30. 文中将"Typo-Morphology"翻译成为形态类型学。

[2] 萨拉陆阳，张艳. 城市与形态 ：关于可持续城市化的研究 : Cities and forms on sustainable urbanism[M]. 中国建筑工业出版社, 2012.文中将"Sustainable Urbanism"翻译成为可持续城市化。

[3] 维特鲁威，罗兰，豪，陈平. 建筑十书. 北京大学出版社; 2017. Accessed April 15, 2021.

which reflected the relationship between public space and private space. In Nolli Map, the outdoor and indoor public spaces formed a continuous space system, which partially reflected the climate exchange interface between the city and the external environment.

The same city construction concepts also existed in ancient China, which reflected people's preliminary understanding of the relationship between city form and climate. "Zhou Li·Kaogong Ji" records: "when the ancients architect built a city, they conceived the city plan as a nine-li(about 4.5Km) square, and every side had three doors. It had a grid street system within the city, which had nine north-south paths and nine east-west paths; Each path can ride nine carriages simultaneously(about 14.4m). The east of the palace was a temple, and the east of it was an altar. The south of the palace was where ministers approached the emperor. The north of the palace was where the fair was.". Another description in this book writes: "when the architects built a city, they hung a plumb line to ensure whether the plan was horizontal, and they observed the shadow of a plumb line to ensure whether the column was erect. In addition, architects made a sundial to observe its shadow to confirm the sunrise and sunset shadow. They referred to the shadow in midday and the position of Polaris to set the length of time."

Since the 20th century, the world's population has proliferated, and the economy develops continuously. The updating rate of construction techniques has accelerated, leading to the advent and development of new urban forms. In 1933, the architect and urban planner Le Corbusier published the book "La Ville Radieuse," which provided a theoretical model for the development of modern cities. Le Corbusier believed that highway systems, skyscrapers, large-scale urban blocks, and concentrated urban green land should become the essential elements of modern urban morphology[4]. These elements can make cities more compact, more convenient for transportation, and more comfortable for residents. However, with population growth and changes in transportation ways, some modern cities that use automobiles as the leading way to travel have caused severe traffic congestion. Population growth has led to city expansion. Hence, cities that had been over-expanded would increase the distance from where people work and where they live, which in turn increases their dependence on vehicles. In this contradiction, the modern urban form has caused too much energy waste. Additionally, the maintenance of large areas of urban green parks and parking lots also requires tons of labor, funds, and other resources. When there is not enough city management, some urban wasteland comes.

Corresponding to the modern newly constructed cities are some traditional Italian towns. They do not lose their original characteristics in the modernization process, whereas they carry out urban construction based on maintaining the historical urban texture. The urban form of these traditional towns is quite different from that of modern cities. The main characteristics of the former one are

[4] 柯布西耶, 金秋野, 王又佳. 光辉城市. 中国建筑工业出版社; 2011.

courtyard-style block layouts and a complex street network. The historical town structure formed a network of streets like leaf-veins. The spatial sequence of square-street-building was divided into the spatial characteristic of public-semi public-private. Arcades, porches, courtyards, and parks further provided more possibilities for the combination of public spaces. These indoor-outdoor spaces were adapted to the daily life of residents, creating a great space experience. Confronting the increasingly severe environmental problems in modern cities, people have begun to explore a different urban development model from the past half a century, seeking the harmonious development of humans and nature in the new era. In this way, traditional Italian towns can become a case study of sustainable cities.

1.1.2 Research Significance

This paper selects Alba, a small Italian town located in the Humid Temperate Climate, as a research case to study its characteristics of thermal adaptability. Meanwhile, it builds a Thermal Adaptive Alba-Model in urban form.

Analyzing traditional Italian towns in terms of thermal adaptability, we can study the relationship between their urban forms and natural environment, contributing to re-establishing the harmonious relationship among city, nature, and people in today's urban design. Traditional Italian towns have built people's comfort based on the combination of external energy systems, the bioclimatic environment, and urban regulation systems. After a long period of development and evolution, these towns have formed their current urban form. In these cases, the morphological design strategies and thought dominated by thermal adaptability and aimed at comfort and energy-saving have essential theoretical and practical guiding significance for today's urban design.

In terms of research cases, the urban form of Alba, a small Italian town selected in this article, is characterized by a courtyard-style block layout. Not only do the traditional towns in Italy, but towns in some Middle East and East Asia also have the characteristics of courtyard-style urban textures. Therefore, this article's research on Alba can make a certain degree of comparison and application to worldwide towns in the same climate zone. In addition, in related urban research, the research objects can usually be divided into four levels: region, city or village, block, and building. Most of the existing related research focuses on the macro-scale(region) and micro-scale(building), and researchers pay less attention to the mesoscale(block). This article focuses on small towns in Italy and takes the urban form at the block scale in the courtyard-like urban texture as the primary research target. It is conducive to in-depth urban research at the mesoscale.

In terms of theoretical level, this article combines two aspects of typo-morphology theory and sustainable city theory, and in the meanwhile commits to building a bridge between two sides. Research on Typo-Morphology focuses on urban transformation, historical and cultural protection, and urban public space evolution. In contrast, sustainable city theory focuses on the macro field such as Eco-city, Sponge-city, and Low-carbon city. Based on two aspects of research, this article believes that the object of Typo-Morphology has close relationships with Climate Adaptation and Energy Consumption and so on, which are closely related to the hot issues of sustainable city research. There is an intersection between these two theoretical systems, and there is an inseparable relationship between related concepts. This article explores this intersection field, which is of positive significance.

1.1.3 Research Perspective

Different urban forms are caused by different eras, forms of production, and different levels of science and technology. Moreover, the formation of urban forms is always affected and restricted by nature, society, politics, and the economy.[5] Precisely because of the various factors that affect the urban form, people should start with diverse directions to study urban form. From the perspective of exploring the thermal adaptability of the urban form, the author selects the urban form elements related to the urban environment for analysis targets, focusing on the research on the comfort of urban space. The Environmental Physical Properties in urban space, such as solar radiation, air temperature, wind speed, are primarily affected by the urban form. Various Environmental Physical Properties in urban city combines and forms urban microclimate. Relevant research shows that there is an inseparable connection between urban microclimate and urban morphology.[6] Except for taking the thermal adaptability of urban form as a research perspective, this article also focuses on the relationship between urban form and human activities. Urban space is a place for people to make communication and activities. Human behavior can influence the formation and changes of urban form from all aspects; human comfort is also inseparable from the Environmental Physical Properties. Hence, the relationship between urban forms and human activities is also an aspect on which the author focuses.

Besides, from the perspective of climate adaptation for urban form, the author explores the mechanism of energy flow and material circulation behind the urban form. The preservation, release, and transmission of energy connect the city's various systems to form an organism. The energy in the city includes natural energy and artificial energy. The former refers to the energy that the city obtains directly from nature, such as solar energy and wind energy, which are closely related to the local climate; the latter refers to the energy collected, processed, and transported by humans using equipment systems such as electricity and natural gas. In architectural design, the design method using natural energy is called Passive Design, and the design method using artificial energy is called Active Design. With the development of various equipment systems, architects and urban planners have gradually ignored passive design, and discussions on energy have also focused on professional

[5] 齐康, QI Kang. 城市的形态 / Urban Morphology. 现代城市研究 / MODERN URBAN RESEARCH. 2011;(5):92-96.
[6] 丁沃沃，胡友培，窦平平.城市形态与城市微气候的关联性研究.建筑学报，2012(7) :16-2

fields such as HVAC. This research focuses on the natural energy system of the city, explores the laws of energy flow behind the urban form, breaks through the limitations of previous studies that only focus on the energy flow in a single building, and extend the energy issue to the city or village level and block level.

1.2 Core Concepts of Research

1.2.1 Urban Morphology

Urban Form refers to the characteristics of the changing spatial forms that constitute urban development[7]. According to the definition, urban form refers to a tangible form of matter. However, many external factors affect the urban form. For example, economy, society, politics, and culture all can cause different degrees of influence on the urban form. Therefore, the features embodied by the urban form are more complicated. While the matter form can be described, it also has the attributes related to the urban spirit, such as urban image, social value, historical culture.

For one thing, the characteristics of the urban form can be described by schema or diagram language in two-dimensional and three-dimensional using geometry, archaeology, statistics, and geology. Urban form cannot be simply regarded as a study of matter form because cities are vivid, complex, culturally meaningful entities in the real world. For another, urban form is the matter basis of every system in the city, including transportation, Urban ecosystems. Therefore, urban form is affected by multiple factors and has the characteristics of diversification, complexity, and relevance.

The urban form can be divided into five related levels: the first is the residents in the city and their activities. A city is a place for people to do communication and activities; the second is the city's road system, which is fundamental for the city's functions. The third is the block plots in the city. Their organization and arrangement determine the main morphological characteristics of the city. The fourth is the functions and place attributes of city blocks, which affect the city's operation and daily activities. The fifth is the Environmental Physical Properties of the city, including factors such as sunlight, wind, and pollutants that can change the urban microclimate, which is closely related to the flow of energy within the city. All these five factors have complex interaction relationships and influences between each other and the whole.[8]

1.2.2 Thermal Adaptive Model of Urban Morphology

In the self-organization construction of a city, it is necessary to rely on external matters and energy. During this long time, people have long-term experience and wisdom in using natural resources to build a city. This model allows the city to form a stable form that adapts to the external environment and is conducive to living. It also allows the city to show different types in different climates. The Thermal Adaptive Model of Urban Morphology is an analytical model that describes

[7] 齐康, QI Kang. 城市的形态 / Urban Morphology. 现代城市研究 / MODERN URBAN RESEARCH. 2011;(5):92-96.
[8] Salat, Serge, Françoise Labbé, and Caroline Nowacki. Cities and Forms on Sustainable Urbanism. S.l.: CSBT, 2011. Print.

the morphological characteristics of cities in a specific climate zone. It can provide a basis for urban spatial organization and urban planning by analyzing and studying the thermal adaptability mechanism of the urban morphology. Therefore, the Thermal Adaptive Model of Urban Morphology is an analytical model that comprehensively reflects the climate and environment of the region where the city is located and its relevant urban morphology. It has the characteristics of type-induction, fabric visibility, and quantitative calculation.

1.2.3 Environmental Regulation

"Environmental Regulation," as a primitive motive for humans to build buildings and cities, has two main ways- "combustion" and "construction."[9] Corresponding the combustion way relying on external power, people adopt appropriate forms and construction methods to regulate the environment according to the local climatic characteristics. In this way, it can narrow the gap between the physical performance of the environment and the comfort range of the human body and maintain a more comfortable thermal balance through the adjustment of the building. The essence of this control method is the preservation, release, and transmission of energy. Therefore, all appropriate buildings and cities can be comprehended as energy configuration," which is the form solidification and order expression of this energy process.

1.2.4 Space-conditioning

"Space-conditioning" and "Air-conditioning" are two related concepts. Air-conditioning mainly refers to active adjustment methods that rely on power equipment such as ventilation systems, refrigeration systems, and heating systems. However, Space-conditioning is an environmental regulation that returns to the spatial paradigm. During the construction process, the spatial paradigm enables to realize in- and outdoor environmental comfort, control of energy consumption and carbon emission through effective in- and outdoor space organization, reasonable building shape, and construction system.[10] The dimension of Space-conditioning can be extended to the entire city. Building a city by constructing reasonable city public space, block group-shaped and internal courtyard space, can improve the comfort of indoor and outdoor environment and reduce the city's overall energy consumption.

1.3 Research Status

1.3.1 Research on Urban Thermal Adaptability

The research on urban Thermal Adaptability can be divided into two aspects. One is Urban Energy System and its related research, including sustainable development, green, low-carbon, zero energy consumption, and energy saving. The other one is climate adaptability and related research,

9 Reyner Banham. The Architecture of Well-tempered Environment [M]. London: The Architectural Press/Chicago: The University of Chicago Press, 1969.
10 张彤.Space Conditioning 建筑师的"空调"策略[J].DomusChina,2010(07/08):100-104

which focuses on different levels of urban form, including urban structure, block form, building form.

Among the relevant researches on Urban Energy Systems, the most representative one is the research on energy conversion in space by Dirk Sijmons and others in Netherland.[11] They used specific cases and visual images to break the fortress between energy and space, established the spatial dimension in energy research and the energy cognition in space design, and transformed energy supply and energy conversion into challenges of culture and space designs. Based on energy analysis platforms such as GIS and BIM, the team of Professor Perry Yang[12] from the Georgia Institute of Technology in the United States researched the world's typical urban morphology and established a cognition of the relationship between "urban morphology and energy performance," and then proposed energy-efficient design strategies aimed at the existing urban environment. Serge Salat et al. edited "Research on Sustainable Urbanization-Cities and Forms," which conducted in-depth research on the environmental performance of urban forms. They carried out qualitative and quantitative analyses from different angles such as urban density, urban texture, climate adaptability, and energy. They also explored the advantages and disadvantages of city sustainability by comparing traditional European cities and Le Corbusier-style modern cities. In addition, Mohsen Mostafavi and Gareth Doherty of Harvard University wrote a book called "Eco-Urbanism." They thought energy is an important issue when Eco-city is discussed because it covers many topics such as the structure of city energy, renewable energy, zero-energy-consumption blocks, climate-adaptive design, and sustainable transportation. Qiu Hong[13] proposed low-carbon-oriented urban design concepts, elements, issues, strategies, and performance analysis methods, constituting a method system for climate-friendly urban spatial environmental design.

In addition to the urban energy system, there is also a wealth of research on the relationship between the spatial form and environmental physical properties at different levels in the urban form.These studies involve many aspects of the city's scale attributes, urban texture characteristics, urban building types, and the utilization of mixed functions. The research methods tend to be scientific simulation verification and quantitative analysis.Gupta[14] assessed the climate adaptability characteristics of three urban block forms in the dry and hot climate zone: Pavilion, Street, and Court. And he summed up the advantages of continuous courtyard-style texture with larger surface area, shallower depth, and narrow space in hot and dry climate.Carlo Ratti[15] uses the LT model and the DEMs model method to calculate the energy consumption of some areas of the city based on the urban texture of London in the United Kingdom, Toulouse in France and Berlin in Germany,

[11] Dirk Sijmons.Landscape and energy,designing transition.NAI010Publishers,Rotterdam hardcover,2012
[12] Yang,Perry P.J.2015.Energy Resilient Urban Form:A Design Perspective, in Energy Procedia 75(2015),2922-2927
[13] 邱红．以低碳为导向的城市设计策略研究[D]．黑龙江:哈尔滨工业大学,2011.
[14] GUPTA A.Solar radiation and urban design for hot climates.Environment and Planning B:Planning and Design,1984,11:435-454.
[15] Carlo Ratti,Nick Baker,Koen Steemers.Energy consumption and urban texture.Energy and Buildings.2005(37):762-776

thereby establishing the relationship between urban form and energy. Ding Wowo[16] conducted a research on the correlation between urban microclimate and urban morphology, and extracted related concepts such as urban texture morphology and comfort indicators. Li Baofeng[17] and others believe that the formation of urban microclimate is not only affected by macro-climatic conditions, but also by heat transfer in urban space. In this case, the morphological elements of urban blocks have a direct impact on the heat transfer process, and thus become the main factor affecting the urban microclimate.

1.3.2 Research on Urban Morphology

The study of morphological typology in Italy has rich accumulation and inheritance. It is a way to interpret and recognize traditional cities and is a tool for future-oriented design. Italian morphological and typological scholars, such as Muratori, Caniggia, and Murat, advocated studying the entire city from an architectural entity composed of bricks and stones. People should deliberately ignore the economic and social factors that affect the development of historical towns but focus on the form and type of buildings and the urban form they constitute. Through detailed literature research and field surveying and mapping, the scholars drew a unique map- a "typological map" for the research city to reveal the form and structure of the city. They believed that the morphological structure of the city is derived from the history of the city. By drawing typological maps of different historical periods, it can explore the scientific explanation of the reasons for the city formation.

In the 1960s, the Italian architect Saverio Muratori[18] taught the course "Architectural Space Typology" at the Venice School of Architecture, leading students to conduct research based in Venice. His research team members continued the 18th-century architectural thinking about "typology," and constructed a series of historical periods in Venice. They used the results to comprhend the morphological evolution process of specific areas of the city, thereby guiding the construction of the city center and the regeneration of the historic city. Muratori constituted Italian contemporary architectural theory and the fundamental concept of Typology, which profoundly influenced many scholars and architects. Gianfranco Caniggia[19] is one of the most influential persons. Caniggia is committed to creating a scientific system that can interpret any urban settlement. In the book "Reading City-Como," published based on the study of the traditional Italian city Como, "Structure" and "Structural" become commonly used terms in the book. Caniggia believes that the "structure" of the city originates from the history of the city, and architects can describe the history of the city by depicting typological maps of different historical periods.

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[16] 丁沃沃，胡友培，窦平平.城市形态与城市微气候的关联性研究.建筑学报，2012(7) :16-2

[17] 陈宏,李保峰,张卫宁. 城市微气候调节与街区形态要素的相关性研究[J]. 城市建筑,2015(31):41-43.

[18] Muratori, Saverio. Studi per Una Operante Storia Urbana Di Venezia 1. Roma: Istituto Poligrafico, 1960. Print.

[19] Caniggia, Gianfranco. Lettura Di Una Città Como. Roma: Centro Studi Di Storia Urbanistica, 1963. Print. Studi per Una Storia Operante Delle Città.

Augusto Cavallari Murat[20], director of the Institute of Architectural Technology of the Politecnico di Torino, is another crucial Italian scholar of Typo-morphology. He researched Torino based on "speculative surveying and analysis." In 1968, the research results were compiled into two critical works-"Urban Form and Architecture of Torino in the Baroque Period" and "From Classical Hypothesis. To Neoclassical Conclusion".

The selected case In this article about the research on the urban morphology of Alba, Augusto Murat, a professor at the Politecnico di Torino, published in the book "Tessuti Urbani in Alba" in 1975, in which he made a detailed study of the urban morphology within Alba historical urban area. The book describes in detail the changes in Alba's urban texture over time and the transformation and changes of buildings within Alba (Fig. 1, Fig. 2). Murat used Urban Linguistics and, based on the recent Alba's urban cadastral map, to depict the Typo-morphological map of the city at two crucial times. In the meanwhile, he also carried out a constructive analysis of the urban space. Murat's research on Alba provides the author with fundamental map data for the analysis of Alba. It deeply impresses the author's cognition of Alba's urban space, which is also of great significance.

Fig. 1 The Typo-Morphology map of Alba, Italy.
Source: "Tessuti urbani in Alba"

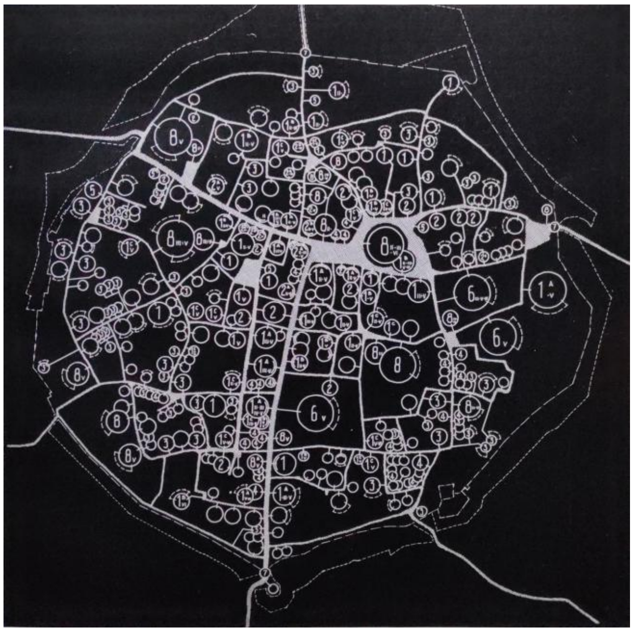


Fig. 2 Analysis of the Typo-Morphology of Alba, Italy.
Source: "Tessuti urbani in Alba"

As the concept of sustainable development has been widely accepted worldwide, the research on urban morphology has also expanded from exploring the reasons for the urban formation to the sustainability field. The Sustainable Urban Morphology series "Compact City-A Sustainable Urban Morphology" edited by Mike Jenks et al. uses the concept of "compact city" as the main clue to study the problems and solutions faced by cities in developed countries. This book summarizes the Compact City from five aspects： theory, society and economy, environment and resources,

[20] Cavallari Murat, Augusto, and Politecnico Di Torino Istituto Di Architettura Tecnica. Forma Urbana Ed Architettura Nella Torino Barocca Dalle Premesse Classiche Alle Conclusioni Neoclassiche. Torino: UTET, 1968. Print.

evaluation and testing, and implementation. In his book "Designing City-Towards a more sustainable urban morphology, " Hildebrand Frey[21] studies matter form and structure in countries and urban zone from the perspective of sustainability. In this book, the most critical content is to evaluate and analyze different sustainability of five city models- core city, starlike city, satellite city, linear city, and multi-center network city or regional city, through the discussion of four essential elements- density, open space, traffic flow, and function mix and flexibility.

There are complete and comprehensive technical methods and schematic language systems in urban morphology based on Italian urban Typo-morphology. Moreover, they have profound theoretical analysis and case verification for the different dimensions of urban spatial form. The actual case study is also very in-depth, which has significant reference value. This theoretical foundation provides this article with tools and methods for analyzing urban morphology. It is a template for a specific analysis of urban form. It also provides a feasible direction that is visible and has hierarchical graphical language for the Thermal Adaptive Model of Urban Morphology.

1.3.3 Environmental Conditioning Theory

Influenced by traditional natural philosophy, the construction of ancient Chinese houses and villages followed a simple ecological concept, reflecting that the Chinese showed high respect for nature and adapted themselves to nature. In the long-term coexistence and interaction with nature, Chinese people spontaneously formed a respectful attitude towards the natural environment, including geomorphology and hydrology. Meanwhile, they had accumulated lots of building experience that they cleverly used natural conditions to organize ventilation and lighting, sought advantages but avoided disadvantages for specific conditions, and created comfortable living and activity spaces. This traditional concept, "Feng Shui," contains the earliest Environmental Conditioning and is an integral part of knowledge in the pre-scientific era. In the 1st Century BC, the Italian ancient Roman architect Vitruvius discussed the relationship among city, architecture, climate, and human beings in "De Architectura," which produced an architectural theory based on the external environment. The theory of Environmental Conditioning has sprouted incredibly early in the world.

After entering the 19th century, the rapid development of construction equipment represented by air-conditioning systems made it easier to obtain stable and comfortable environmental physics inside the building. In this way, the development of architecture can be temporarily separated from the constraints of the external natural environment, and the city can easily cut off the transmission and exchange of energy from the external natural environment. Building, city, and natural environment are isolated from each other. Until 1962, American ecologist Rachel Carson[22]

[21] Frey H. Designing the City : Towards a More Sustainable Urban Form. E & FN Spon;
[22] Hamblet WC. Silent Spring Publication and Response. Salem Press Encyclopedia. 2020.

described the difficult situation after the deterioration of the earth's environment in her book "Silent Spring." Due to this book, environmental issues were re-considered seriously. When the world energy crisis broke out in the 1970s, architects began to rethink the relationship between architecture and the environment. They started to combine emerging disciplines and researched architectural design methods that combine the environment during the design process.

In 1960, Reyner Banham[23] published "Architecture of the Well-tempered Environment," which established the theoretical framework of Western ecological architectural design. In 1963, the Ogoya brothers (Victor Olgyay, Aladar Olgyay)[24] put forward the concept of "bioclimatic regionalism" in the book "Design with Climate: Bioclimatic Approach to Architectural Regionalism," which established a connection between climate conditions and human comfort needs. In 1964, Bernard Rudolfsky studied and explored worldwide architecture in different regions and climatic characteristics in his book "Architecture without Architects," which impacted the study of architecture form and climate correlation. In 1976, Baruch Givoli put forward the methods and theories of climate design in the book "Human· Climate· Architecture."

In terms of Environmental Conditioning theory in China, in 2009, Zhang tong[25] of Southeast University, in his book "Green Nordic: Sustainable Cities and Architecture," used exceptional cases in the Nordic region as the research objects to introduce a knowledge system of sustainable urban construction in Nordic from various levels, such as urban planning, block design, architecture, and landscape design. This system is a reference for the sustainable urban development of China. In the book "Energy-saving Design in Architectural Creation," Liu Jiaping[26], a professor from Xi'an University of Architecture and Technology, systematically introduced the concept and method of energy-saving in the architectural design process. Song Yehao[27] from Tsinghua University conducts theoretical and practical research on ecological architecture, sustainable architectural design, and traditional Chinese vernacular architecture.

According to the development of Environmental Conditioning theory and the results produced at home and abroad, it can be seen that the conditioning of city and architecture environment has existed since ancient times. However, it was not until the middle of the last century that a systematic design theory was formed. Environmental Conditioning theory mainly focuses on architectural design, but less focuses on the city scale. With the simultaneous development of climatology research, architects have also paid attention to the characteristics of different changes in urban morphology in response to climate elements under different climatic conditions. Especially in China,

[23] Reyner Banham.The architecture of the well-tempered environment.Chicago;University of Chicago Press,1984.
[24] Victor Olgyay, Aladar Olgyay, Donlyn Lyndon, Victor W. Olgyay, John Reynolds, and Ken Yeang. Design with Climate. REV - Revised ed. Princeton: Princeton UP, 2015. Web.
[25] 张彤. 绿色北欧 : 可持续发展的城市与建筑 : Sustainable Urbanism and Architecture in Scandinavia. 东南大学出版社; 2009.
[26] 刘加平 (教师), 谭良斌 (教师), 何泉 (教师). 建筑创作中的节能设计. 中国建筑工业出版社; 2009.
[27] 宋晔皓. 结合自然整体设计——注重生态的建筑设计研究[M]. 北京: 中国建筑工业出版社,2000.207

where the climate varies significantly from place to place, it can provide many research templates. Therefore, China has made significant progress in the scope and depth of research.

1.4 Research Methods

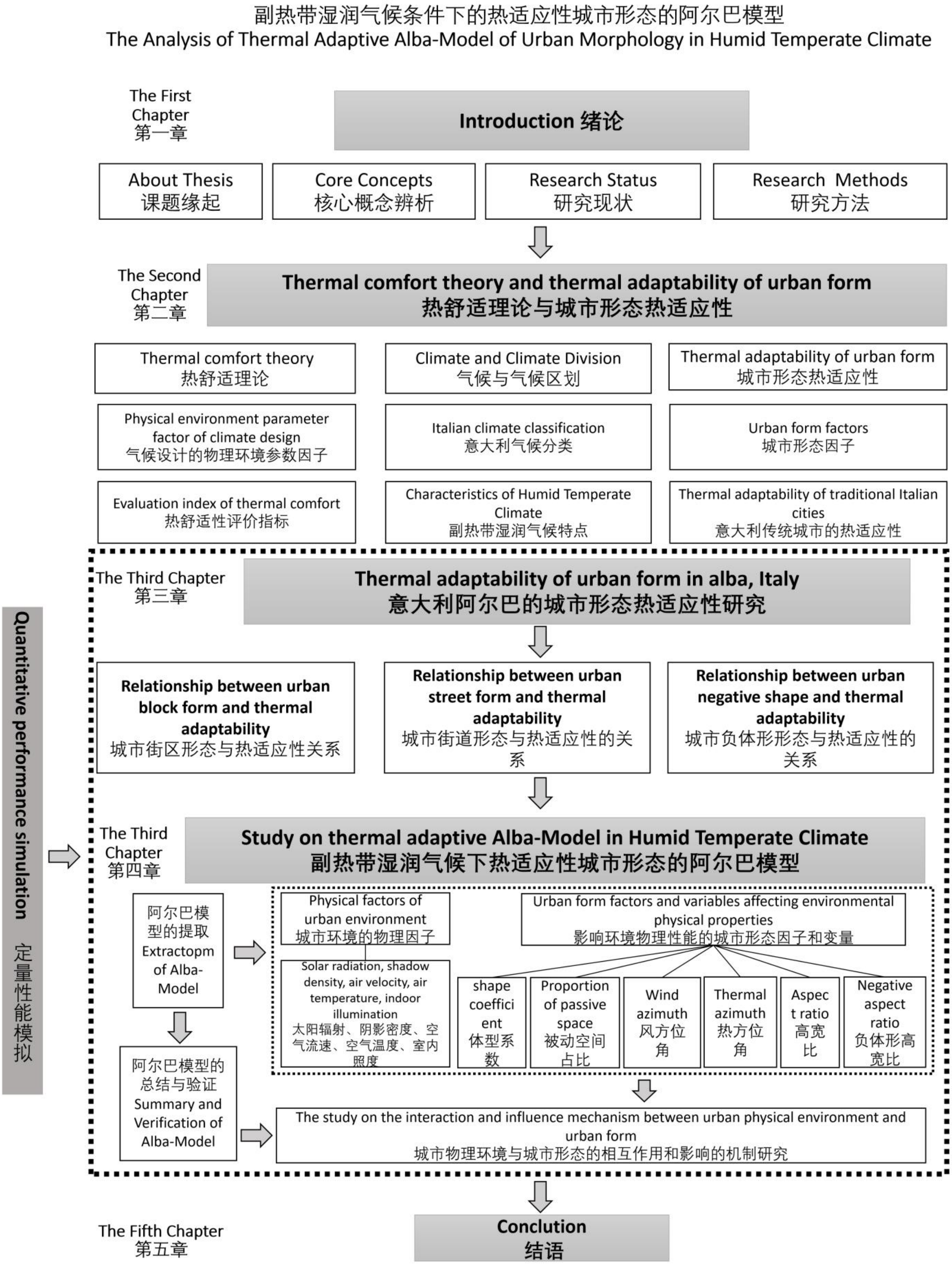
This paper mainly adopts the following three research methods:

(1) Literature reading: Research on domestic and foreign literature and books related to urban morphology, urban energy, space conditioning, performance-based simulation, urban microclimate, etc., and establish the theoretical basis of the article.

(2) Field investigation and mapping: select Italian city Alba(located in Humid Temperate Thermal Climate zone) for field investigation and mapping, enhance the intuitive perception of Italian urban morphology and environmental physical characteristics and obtain first-hand information.

(3) Performance simulation analysis: select Ecotect, EnergyPlus, Open Studio, CFD, ladybug, and other performance simulation software to conduct quantitative performance simulation of urban morphology, establish the visual graphic language and provide a scientific basis for research results.

1.5 Research Framework



2. Thermal Comfort Theory and Thermal Adaptation of Urban Form

In ancient Rome, Vitruvius's book "De Architectura" had detailed records on the climate environment, urban form, and human comfort. Selecting the city site, he thought that a higher terrain should be chosen to ensure sufficient sunlight. At the same time, in street layout, the relationship between the street system and vital public buildings should be considered, and the square should be used to increase the permeability of the city. The relationship between the External Energy System, the Urban Conditioning System, and the Human Response System has been initially considered in these descriptions. These three systems (Fig. 3) are interlinked and interact with each other in the urban construction process. Thus it has formed stable urban morphological characteristics throughout the urban construction. In this case, the urban form is differentiated under different climatic environments, forming diverse urban forms with their characteristics.

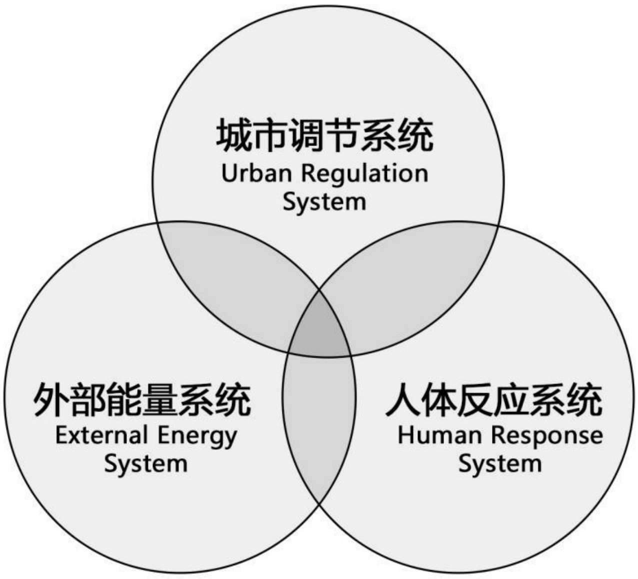


Fig. 3 Ternary model of city, environment, and the human body. Source: the author's drawing

For one thing, the physical performances of the urban environment would be affected by various climatic factors, such as temperature, humidity, wind velocity, and wind direction. It is also significantly influenced by urban morphology, such as urban layouts, urban fabric types, block density, street form, and urban substrate material. The differences in urban forms lead to differences in physical performances such as solar radiation, shadow density, air temperature, and air velocity, which would further influence the comfort index of the human body. To face changes in the physical performances of the external environment, people can adapt themselves to the environment, add or remove clothes, and adjust their behaviors in different climates. Compared with the individual's adaptation to the external environment, adjusting the corresponding parameters of the urban form can expand the human body's comfort zone, allowing more people to perform various activities comfortably in the urban space. Therefore, it is of great significance to pay attention to the influence of urban form on the environmental physical performances of urban space.

The zone that interacts with the thermal and wind environment in the city are mainly the Urban Boundary Layer, Urban Canopy, and Urban Street Canyon.[28] The levels of the three areas are from large to small, and they are nested layer by layer. The Urban Boundary Layer contains the Urban Canopy and the Urban Street Canyon, and the Urban Canopy contains the Urban Street Canyon.

Firstly, The Urban Boundary Layer refers to the atmosphere close to the earth's surface and is affected by the frictional resistance of the urban surface. The effect of the Urban Boundary Layer on the urban environment mainly refers to the phenomenon formed by the atmospheric circulation being affected by the urban surface, also called the Turbulence Layer Effect. This effect has a great impact on the overall wind environment of a city. Secondly, Urban Canopy refers to the atmosphere below the height of buildings in the city. When natural wind passes over the city, buildings with different heights will cause complicated wind velocity conditions and direction.

Moreover, the vertical interface on both sides of the building produces a turbulence effect, making the urban airflow environment more complicated. In terms of the thermal environment, the absorption, reflection, and refraction of sunlight on the outer building surfaces would affect the temperature of the building surface and the interior of the building. Thirdly, the Urban Canyon generally refers to the continuous place in the horizontal direction, where people can hold public activities.

Overall, In the Urban Boundary Layer, the heat gain and loss balance formula of the interaction between the city and the external environment is:

$$Q_n + Q_f \pm Q_h \pm Q_e = Q_s$$

In this formula, Qn refers to the net radiated heat in the surface of the city, Qf refers to the anthropogenic heat release in the urban surface layer, Qh refers to the convective heat exchange between the atmosphere and the outside in the urban surface layer, Qe refers to the latent heat exchange in the urban surface layer, and Qs is the heat storage in the subsurface layer in the urban surface layer.

The heat balance equation can be learned that except for the anthropogenic heat release and the heat storage in the subsurface layer, the net radiative heat gain, convective heat exchange, and latent heat exchange are closely related to the thermal and wind environment in the city.

[28] 丁沃沃，胡友培，窦平平.城市形态与城市微气候的关联性研究.建筑学报，2012(7) :16-2

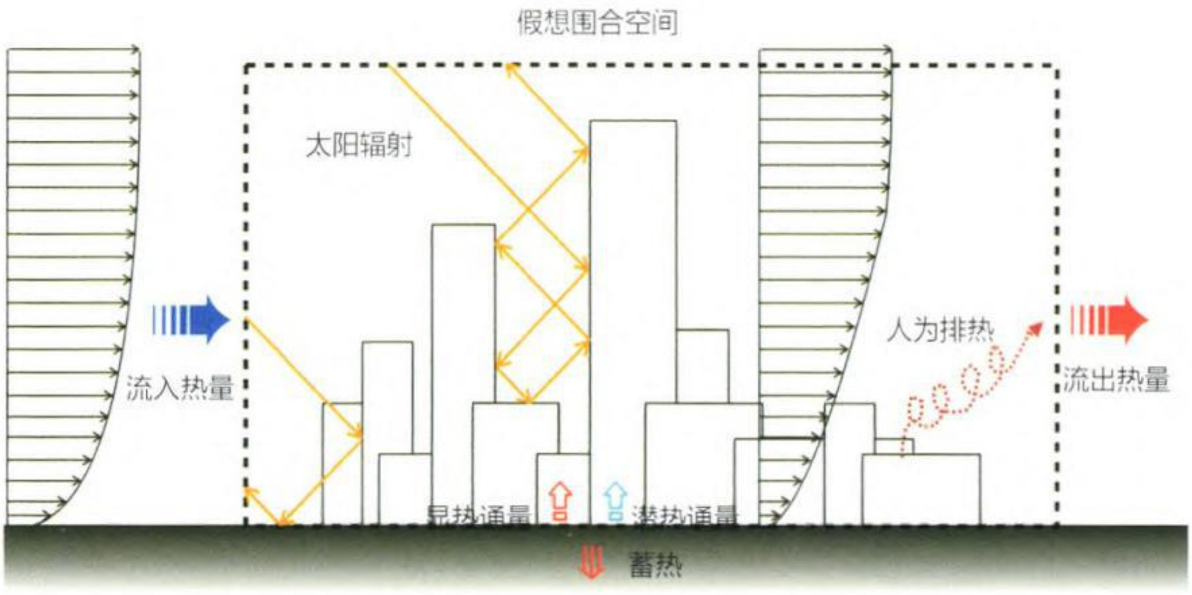


Fig. 4 Conceptual diagram of heat transfer within urban space Source: “Study on the correlation between urban microclimate conditioning and from factors of blocks”

Through heat conduction, convection, radiation, and evaporative cooling, urban morphology can influence urban space's wind and heat environment. In the above ways, the urban form can be adjusted by either enhancing or inhibiting methods. Moreover, the difference in temperature and humidity caused by season changes in a year would also affect the adjustment methods of urban morphology.

2.1 Thermal Comfort Theory

2.1.1 Overview of the Thermal Comfort Theory

In order to maintain its normal body temperature, the human body needs to continuously exchange material and energy with the urban environment, thus achieving a dynamic thermal equilibrium. The heat exchange between the human body and the outside world can be carried out mainly using radiation heat exchange, convection heat exchange, and evaporation heat exchange, a process that the basic formula can express.

$$M \pm R \pm C - E = Q$$

In the formula, M is the heat produced by human metabolism, R is the radiation heat exchange, C is the convection heat exchange, E is the evaporation heat exchange, and Q is the heat change of the human body. When the value of Q tends to 0, the human body's heat production and heat dissipation reach the equilibrium state. On the one hand, the human body regulates its heat production through breathing and sweating, and on the other hand, it makes up for the lack of body conditioning through dressing and other means. Whether it is physiological conditioning or external conditioning, reaching thermal equilibrium is influenced by the external physical environment.

These influencing factors include solar radiation, shadow density, air temperature, air flow rate. They interfere with the process of the human body reaching thermal equilibrium by affecting the intensity of radiation heat exchange, convection heat exchange, and evaporation heat exchange.

2.1.2 Environmental Physical Factors Affecting Thermal Comfort

2.1.2.1 Environment Physical Factors Affecting the Comfort of Urban Space

1) solar radiation

The surface of a city gains heat from the sun's short-wave radiation and dissipates it by radiating long waves outward. During the daytime, the surface temperature of the city increases due to the absorption of solar radiation. The heat gain of the city surface and the heat gain of the building surface are closely related to solar radiation, while the temperature of the building interior and the temperature of the outdoor activity ground are related to the heat gain. Therefore, the solar radiation received by the city has an important influence on thermal comfort. The influencing factors of solar radiation include latitude, weather condition, altitude, and sunshine length. For the urban environment, the length of sunshine determines the amount of solar radiation absorption, long sunshine time, strong solar radiation, short sunshine time, weak solar radiation.

2) shadow density

The shadow density describes the number of hours of shadow coverage on a given day for a neighborhood surface with a given neighborhood morphology and characterizes the ability to receive direct natural light, i.e., the higher the shadow density, the lower the ability to receive direct natural light. To calculate the shadow density, we first need to delineate the typical daily surface shadow area mapping of a given neighborhood area on a given day of the year and then calculate the average of shadow coverage hours for each selected target point.

Generally speaking, in hot climates, higher shadow density helps prevent public spaces from being long-time exposed to direct sunlight. In cold climates, lower shadow density can increase the length of time that outdoor public space can get direct sunlight, promoting the length of time of outdoor activities in winter and human health. In addition, compared with courtyard space under the same other conditions, street space with higher shadow density is more beneficial to create a comfortable urban space. Those buildings set back from the noisy street can provide shade for the street and a pleasant indoor environment by utilizing the introverted courtyard to promote lighting and ventilation.

3) air flow velocity

The wind is an important factor that constitutes climatic conditions, and the main parameters are wind direction, wind speed, and wind temperature properties. Among them, the airflow velocity is the most important indicator that affects urban space comfort. In summer and transitional seasons, a comfortable outdoor ventilation environment can create a suitable outdoor walking environment and increase residents' activity time outdoors, which is more helpful for human health and comfort. At the same time, the increase of outdoor wind speed can form larger wind pressure on the building surface and promote natural ventilation indoors: in winter, excessive wind speed in urban space will improve the efficiency of convective heat exchange, and the human body will dissipate heat too quickly and lead to a reduction of comfort. In the outdoor environment, the average wind speed is less than 5m/s is more comfortable. When the wind speed is greater than 6m/s, and there is turbulence, people will feel uncomfortable. The minimum wind speed is kept above 2m/s to ensure the quality of outdoor air.

2.1.2.2 Environment Physical Factors Affecting Thermal Comfort of Building Space

1) air temperature

Air temperature, also known as air temperature, is a physical quantity that indicates how hot or cold the air is. The heat in the air mainly comes from solar radiation. After the solar radiation reaches the ground, part of it is reflected, which makes the ground warm, and then the ground transfers the heat to the air through radiation, conduction, and convection, which is the main source of heat in the air. Air temperature is the most important factor for human comfort and plays a leading role in the thermal conditioning of the human body. The air temperature in the city is the result of the ground layer, the heat gain and heat loss of the building envelope, and the ventilation in the city acting together in a state of heat balance. According to China's "Design Code for Heating, Ventilation, and Air Conditioning," the standard indoor thermal comfort temperature is 26-28℃ in summer and 18-22℃ in winter. In addition, the vertical and horizontal distribution of the air temperature field inside the room will have a greater impact on the thermal comfort of the human body.

2) air flow velocity

The appropriate wind speed formed by the indoor air flow in the building during the season with a suitable climate can effectively improve indoor thermal comfort. The air with a higher flow speed can accelerate the convective heat exchange on the human skin surface on the one hand and improve the heat dissipation efficiency of the human body. Another aspect can improve the rate of evaporative heat dissipation. There is a suitable range of indoor air flow rates corresponding to different temperatures in high temperature, above which will lead to excessive heat gain, and below which will lead to low evaporative heat dissipation efficiency. In colder regions with lower temperatures, the airflow speed will increase the amount of heat dissipated by the human body, resulting in the loss of human heat, and is therefore inappropriate. In the indoor environment, natural ventilation, wind speed is less than 0.2m / s when the human body does not feel, indoor wind speed is greater than 0.5m / s, less than 1.5m / s is more comfortable.

2.1.3 Thermal Comfort Evaluation Index

2.1.3.1 Indoor Thermal Comfort

In the 1970s, Danish professor Fanger (1970) constructed a thermal comfort equation based on human thermal equilibrium and a large amount of experimental data on human thermal comfort and proposed a Predicted Mean Vote (PMV) based on this equation.PMV depends on the human thermal load (TL), which is equivalent to the thermal storage rate S in the thermal comfort equation, so the PMV equation applies to the thermal environment with stable and uniformly distributed thermal parameters around the human body. Neither applicable to the non-stable thermal environment nor the thermal environment with non-uniformly distributed parameters around the human body. Since the PMV thermal comfort model was proposed, some experimental field results have deviated from the predicted results of the PMV thermal comfort model, but as the most comprehensive thermal comfort evaluation index so far, it is still widely used in the evaluation of indoor comfort of buildings.

2.1.3.2 Outdoor Thermal Comfort

Outdoor thermal comfort plays an important role in the evaluation of thermal comfort in urban environments. Predicted Mean Vote (PMV), Predicted Percentage Dissatisfied (PPD), Effective Temperature (ET), and standard Effective Temperature (SET) are all indices proposed by the indoor environmental standards. However, outdoor thermal comfort and indoor thermal comfort are quite different. First of all, outdoor environmental factors such as solar radiation intensity are in dynamic changes in different seasons of the year and at different times of the day and are affected by factors such as cloudiness and atmospheric pollution. Secondly, the absorption, reflection, and refraction of solar radiation on the surface of urban buildings and the blocking and deflecting of wind make the changes of outdoor thermal environment very complex. Finally, in the outdoor environment, the diversity of individual activities increases significantly, and the metabolic levels vary greatly among individuals, making the evaluation of the outdoor thermal environment even more difficult.

Hoppe proposed the Physiological Equivalent Temperature (PET) index based on the MEMI model, which can be used specifically to evaluate outdoor thermal environment comfort. It is defined as the air temperature at which human skin temperature and body temperature reach the same thermal state as a typical indoor environment under certain environmental conditions. In 1990, Hoppe proposed to construct a common international index for thermal comfort evaluation, and after comparing and screening many human heat balance models, he developed Universal Thermal Climate Index (UTCI) based on Fiala's multi-node human Physiology and thermal Comfort (FPC).

The UTCI model divides the human body into an active system with regulatory functions and a passive system for heat transfer. The active system simulates behaviors, such as human metabolism, weakening and strengthening skin blood flow, sweating, and shaking. The passive system needs to consider the differences of the human body in the different parts of skin, bones, and muscles. Meanwhile, the passive system needs to simulate each segment's metabolism, heat transfer, and accumulation.[29] The UTCI model has a complex structure and is widely used in meteorological services, urban planning, and other fields.

2.2 Climate and Climate Classification

2.2.1 Concept and Classification of Climate

Climate refers to a comprehensive, statistically-based general description of climate elements, including temperature, humidity, air pressure, wind, precipitation, and atmospheric composition, over an extended period and within a specific region. The climate of a place is influenced by its latitude, topography, altitude, snow and ice cover, and the condition of nearby bodies of water and their currents. The main components of climate are wind, solar radiation, natural light, temperature, humidity, precipitation. These climate elements are the sources of energy in the external energy system.

Climate can be classified according to the average range and impressive range of different meteorological elements, most often using temperature and precipitation. The most commonly used classification system is the Köppen climate classification, developed by the German climatologist Vladimir Peter Köppen.

The Köppen climate classification is first divided into five main climate zones (A, B, C, D, E) based on the global climate, among which the rest are humid climate except B (arid zone), and each zone is divided into several climate types based on temperature and precipitation, taking into account annual and monthly temperature, as well as seasonal changes in rainfall and vegetation distribution. (Table 1)

Table 1Three classifications in the Köppen climate classification

main climate zones	Precipitation	temperature
A (Tropical) B (Arid) C (Temperate) D (Continental) E (Polar)	W (Desert) S (Steppe) f (Rainforest) s (Savanna, Dry summer) w (Savanna, Dry winter) m (Monsoon)	h：(Hot) k：(Cold) a (Hot summer) b (Warm summer) c (Cold summer) d (Very cold winter) F (Eternal frost (ice cap)) T (Tundra)

The equatorial zone (tropical climate) is mainly characterized by high temperatures throughout the year, with monthly average temperatures above 18° C. Its climate can be divided into tropical rain forest climate (Af), tropical monsoon climate (Am), and tropical wet and dry or savanna

29 闫业超,岳书平,刘学华,王丹丹,陈慧.国内外气候舒适度评价研究进展[J].地球科学进展,2013,28(10):1119-1125.

climate (Aw) according to precipitation; arid zone climate can be divided into desert climate (BW) and semi-arid climate (BS); warm zone climate refers to the hottest monthly average temperature greater than 10° C, the coldest monthly average temperature between -3° C and 18° C, and can be divided into three climate types according to the precipitation season: dry summer warm climate (Cs), dry winter warm climate (Cw) and normal wet warm climate (Cf); subrigid zone refers to the hottest monthly average temperature above 10℃ and the coldest monthly average temperature below 0℃ and can be divided into normal wet, cold temperature climate (Df) and dry winter cold temperature climate (Dw) according to the precipitation type; the polar zone is divided into tundra climate (ET) and ice cap climate (EF).

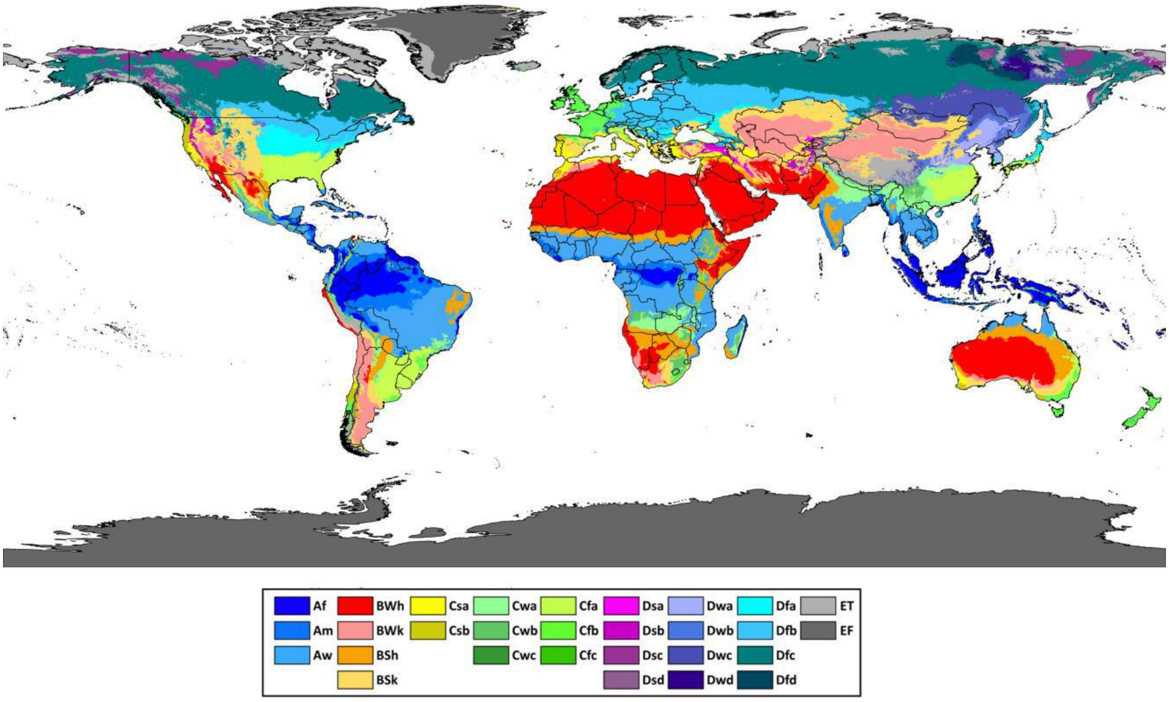


Fig. 5 Climate types around the world in the Köppen climate classification (Source: www.google.com)

2.2.2 Distribution and Characteristics of Humid Temperate Climate

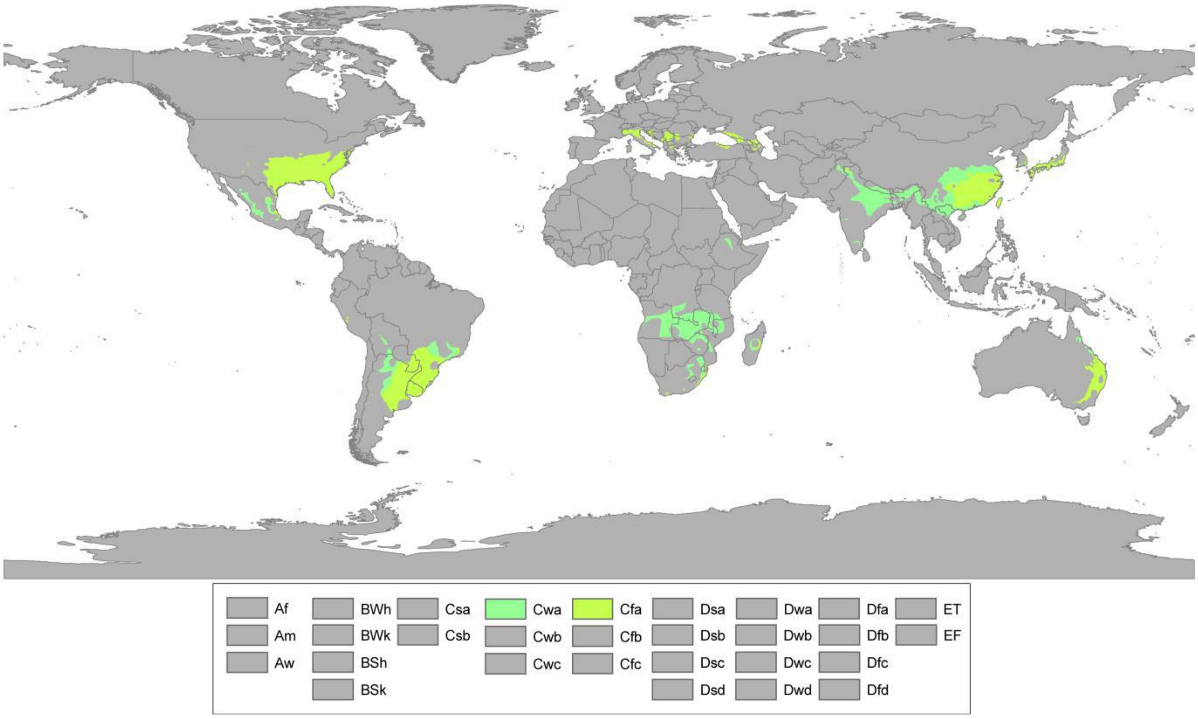


Fig. 6 Distribution areas of Humid Temperate Climate (Cfa) in the Köppen climate classification.
Source:www.google.com

The Cfa type in the Köppen climate classification is the Humid Temperate Climate, which is also known as subtropical monsoonal humid climate, summer rainfall warm humid climate, summer rainfall warm temperate climate. The Humid Temperate Climate(Fig. 6)
is Mainly located in the southern foothills of the Himalayas and Alps, the plains of the southeastern Unite States, southeastern China, the south of Argentina, Uruguay and Brazil, and parts of Australia. This climate is usually located on the southeastern side of all continents, between 25° and 40° latitude, where it is often located near coastal areas. In Asia, North America, and South America, the subtropical humid climate zone extends from coastal areas to vast inland plains, covering a larger area than other regions in the world. In these regions, the climate shows more obvious seasonal changes, showing mixture properties of Continental Climate and Marine Climate. In contrast, the Humid Temperate Climate at the southern foot of the Alps presents more properties of the Continental Climate, with larger annual and daily temperature ranges.

In the Humid Temperate climate zone where the monsoon climate is more obvious, like Southeast Asia, rainfall usually peaks in summer. In these regions, the sun's altitude angle in summer is high, and the surface temperature rises quickly, which is likely to form seasonal rainfall peaks. Other regions have an average amount of rainfall in summer but do not occur drought. This climate zone in Asia and North America receives little rainfall in winter, with water shortages and mountain fires.

2.2.3 Climate Distribution in Italy

Italy is located on the northern coast of the Mediterranean in southern Europe, between 36° 28′ and 47° 6′ north latitude and between 6° 38′ and 18° 31′ east longitude. Its territory includes the southern foot of the Alps, the Po River Plain, and the Apennine Peninsula, Sicily, Sardinia, and many other islands. Italy's topography is complex and diverse, such as mountains, plains, rivers, and lakes widely distributed throughout the country. The entire country is located on the Italian peninsula, long and narrow, with a maximum distance of 540 km from east to west and 1290 km from north to south, and a latitudinal direction is spanning 12°, making Italy's climate extremely diverse and rich.

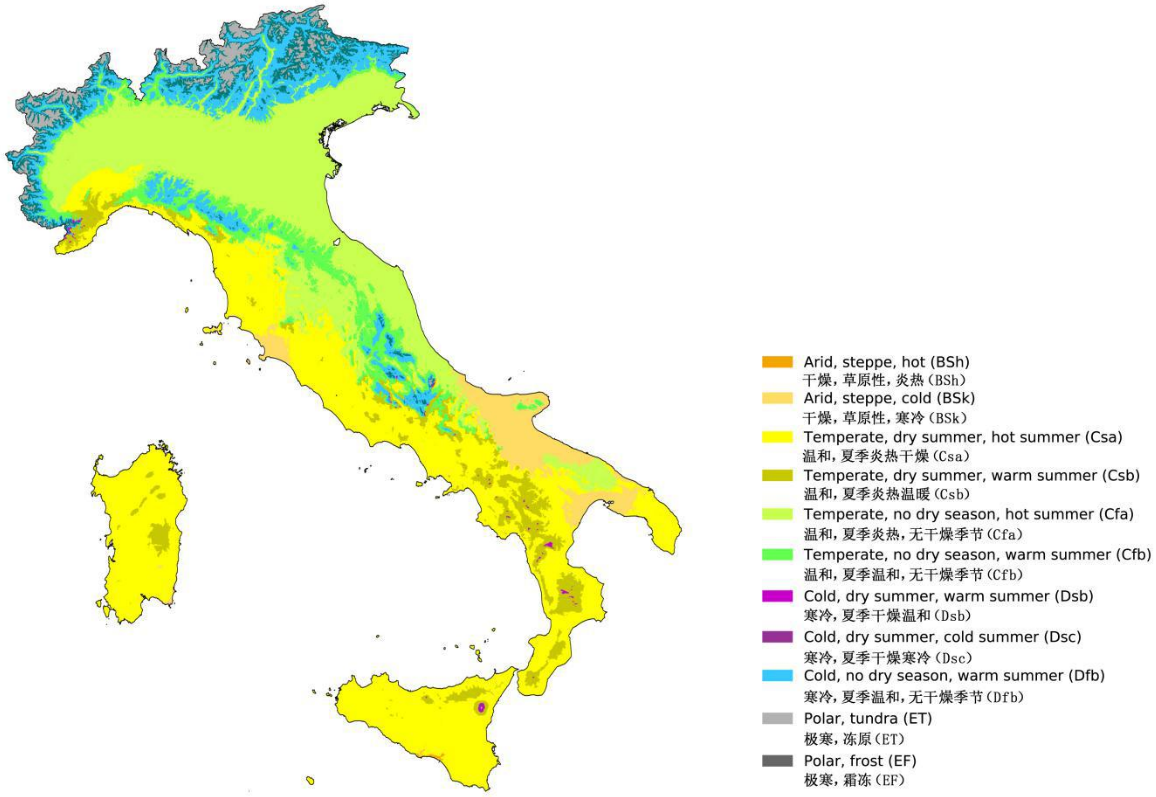


Fig. 7 Map of Köppen climate in Italy. Source: www.google.com

As can be seen from the Köppen climate map of Italy (Fig. 7), most of Italy lies within the classification of the warm zone (C). In Liguria, Tuscany, and most of the southern coastal areas, the climate generally conforms to the characteristics of the Mediterranean climate(Csa), with mild winters and warm summers. The average temperature in January is 2 to 10° C, and the average temperature in July is 23 to 26° C, which is generally dry and comfortable. In the northern and central parts of the peninsula, the climate is mostly Humid Temperate Climate(Cfa), especially in the northern Po River basin, with hot summers and cold winters. The average temperature in January is 2 to 4° C, and the average temperature in July is 20 to 24° C. There are some areas in the Sub-Cold (D) classification in the Alpine mountains, with the obvious characteristic of vertical distribution. The temperature in this area gradually decreases with the altitude rise. This area is the region with the lowest temperature in the whole country. The average temperature in the months with more snow in winter is between -12 and 1° C, and the average temperature in July is 4 to 20° C. In southern Puglia, some regions are located in the arid zone (B), with higher temperatures throughout the year.

In terms of annual rainfall, Italy’s wettest regions are the Alps and the eastern Liguria region (with an average annual rainfall of 2,500 to 3,500 mm). There is a small amount of annual rainfall in low-lying plains far away from the mountains. For example, along the Po River, the annual rainfall drops to 700 to 1200 mm. The rainfall in the coastal areas further dropped to 500 to 600 mm.

In terms of solar radiation(Fig. 8), the coasts of Sardinia and Sicily have the highest annual solar radiation, with more than 2,600 hours of sunshine per year, an average of more than 7 hours per day, and annual average solar radiation above 200MJ/m^2. However, in the Lazio region of Tuscany, the annual average radiation drops to 160 to 180 MJ/m^2. In the Po Valley areas such as Piedmont, Lombardy, and Emilia-Romagna, the annual average radiation drops to 140 to 180MJ/m^2. The lowest solar radiation in Italy occurs in the Apennine Mountains, with annual average radiation below 140MJ/m^2.

In terms of annual average cloud cover(Fig. 9), the lowest value of annual average cloud cover appears in southern Sicily, at 2750okta(eight components). The cloud cover in the Po River Valley is between 4000 and 4250 oktas, and the highest value Appears in the Apennine Mountains, above 4500 oktas.

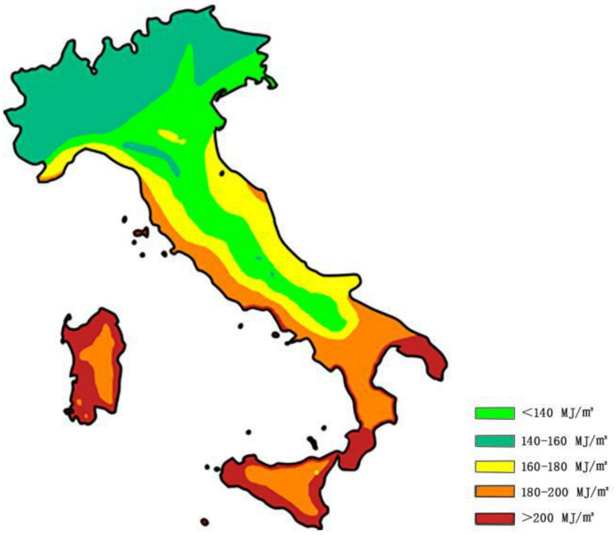


Fig. 8 Distribution of average annual sunshine hours in Italy Source: www.google.com

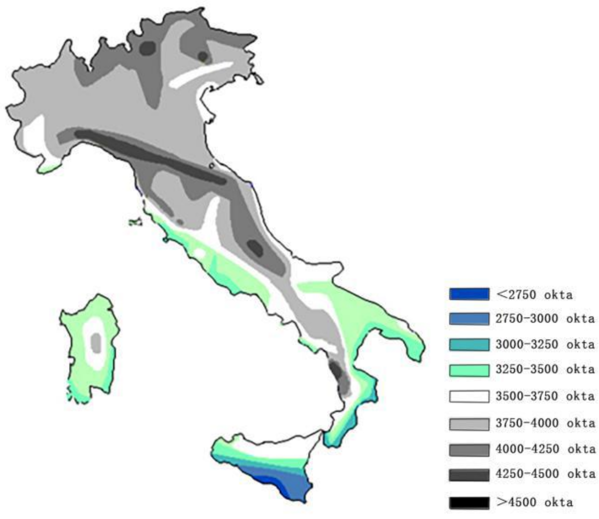


Fig. 9 Distribution of annual average cloud cover in Italy Source: www.google.com

2.3 **Thermal Adaptation of Urban Morphology**

2.3.1 The Association Between Urban Morphology and Thermal Environment

In terms of individual buildings, developing Regional Architecture based on environmental and climatic characteristics has a long history. The construction of traditional buildings represented by traditional houses is affected by both the social environment and the natural environment. The social environment includes economics, humanities, laws, and other aspects, while the natural environment refers to the objective material environment based on climatic factors. In the course of historical development, due to the limitations of economic and technical conditions, traditional houses rely more on passive design strategies to improve the thermal comfort of the human body. Therefore, the architectural forms and construction methods of traditional buildings have a high degree of correlation with the natural environment and have the characteristics of Thermal Adaptability. The Regionalism and Nativeness embody in traditional buildings are the results of the adaptation of the building to the environment, and the differences of regional culture, in turn, strengthen the characteristics of traditional buildings.

The roof forms of traditional buildings worldwide have a strong correspondence with the climate zone in which they are located. For example, traditional buildings in the form of flat roofs mostly appear in tropical areas, and traditional buildings in the form of vaults mostly appear in hot and dry areas. However, traditional buildings in the form of sloped roofs mostly appear in Temperate areas, and the colder the temperature or, the more rainfall, the higher the slope of the roof (Fig. 10). In addition, the value of the window-to-wall ratio of the exterior wall in traditional buildings is also closely related to the climate zone in which it is located. In extreme climatic areas such as severely cold areas or hot and dry areas, people control the window-to-wall ratio of the outer wall to a small value to withstand the cold wind or sun rays. In areas with a milder climate, when the buildings form a mutual shielding relationship, people try to enlarge the window-wall ratio of the outer wall as much as possible to get more sunlight. Overall, some basic morphological features of traditional buildings worldwide are closely related to the local climatic conditions. The architectural forms located in the same climate zone have similarities, while the architectural forms located in different climate zones have different manifestations.

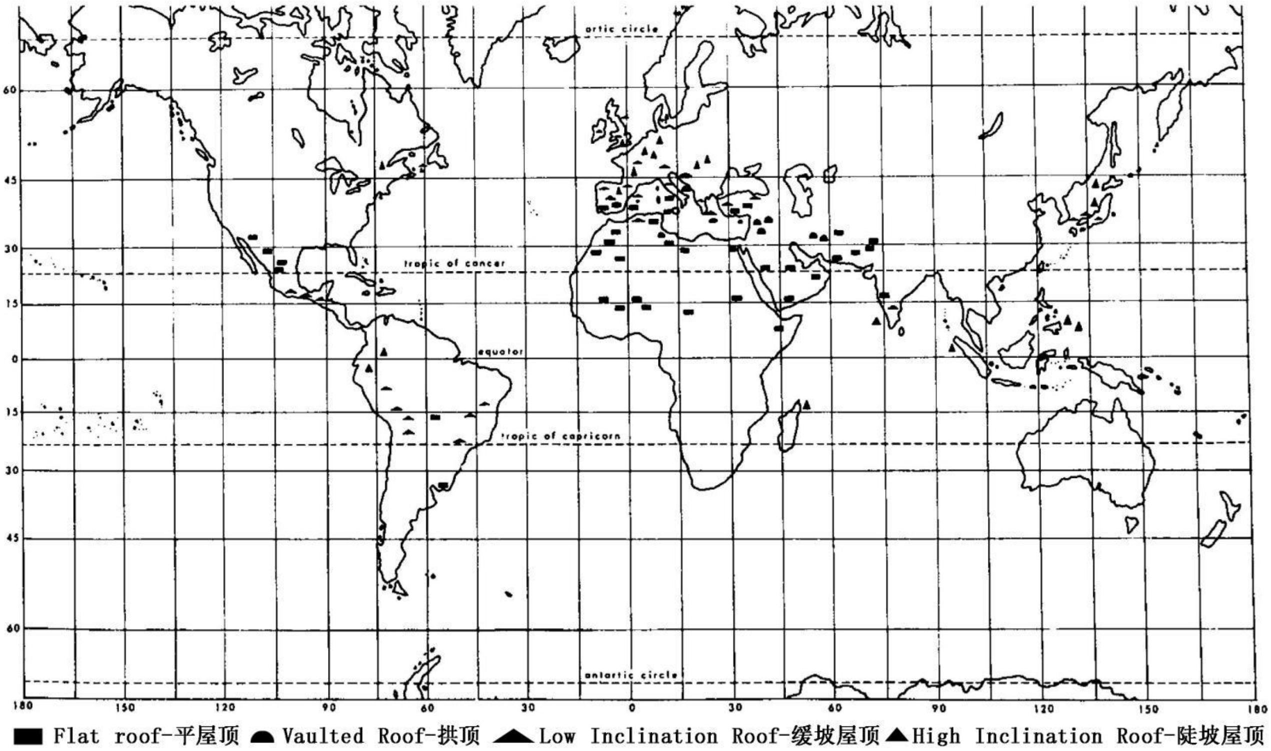


Fig. 10 Distribution map of main roof forms of traditional buildings around the world. Source: “Design with Climate”

Traditional buildings adapt to the local climate conditions in terms of construction methods architectural forms and architectural language and match the local climate conditions in terms of the combination of buildings. Compared with modern cities, traditional towns and villages are more closely related to individual buildings. Similar building units are superimposed on the plane in an organized arrangement and combination to form settlements. Therefore, the thermal adaptability of the building unit can be well developed into the thermal adaptability of the settlement. Traditional settlements around the world can be regarded as entities with material forms. They interact with the air, wind, water, and sunlight to carry out matter circulation and energy exchange with the external environment. It reaches a balance between environmental physical performances and the human body's comfort.

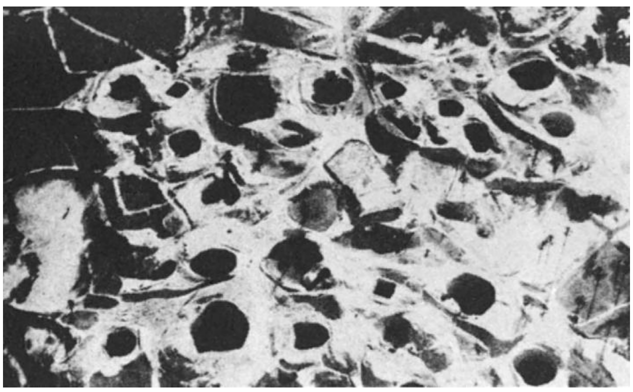


Fig. 11 Cave dwelling settlements in Tunisia. Source: “Deisgn with Climate”

Fig. 12 Pit Yard Residential Settlement in China. Source: “Design with Climate”

When settlements are in areas with more extreme climatic conditions, the external climate has a more obvious influence on the settlement morphology, such as the Settlement of Troglodytes in Tunisia and the Subterranean Settlement in China (Fig. 11, Fig. 12). The climatic environment composed of the same strong sun rays and extremely low rainfall has formed similar settlements in two regions of the world far apart. The reason is that the surface soil covering the building space has a relatively large Thermal Mass, which makes the building space relatively cool in summer and relatively warm in winter. The opening area facing upward in the settlement is small, which can shield more summer sun rays to achieve the effect of cooling down.

Compared with settlements located in hot and dry areas, settlements located in hot and humid areas pay more attention to evaporation and cooling through airflow while shielding the sun. Located in Dali Village, Guizhou, in the Hot Summer and Warm Winter Area of China, the roof and transparent building space used to shade the sun are conducive to the ventilation and cooling of the village in summer (Fig. 13). For settlements located in relatively warm areas, it is necessary to balance cold protection and warmth in winter and shading and cooling in summer. The suitable building shape and window-to-wall ratio in the small Swiss town of Chur enable the town to maintain a more comfortable environment throughout the year (Fig. 14).

Fig. 13 Photo of Dali villiage, Guizhou Province, China. Source: photo by the author

Fig. 14 Aerial photo of Chur, Switzerland. Source: photo by the author

Since the late 20th century, the continuous expansion of modern cities has caused serious urban climate and energy problems, such as the Urban Heat Island Effect and energy shortages. Guided by the sustainable cities theory, academics have begun to pay attention to the environmental adaptability of traditional towns, especially the traditional European towns. The adaptation to the environment formed in the historical development of traditional cities and towns reduces the energy demand and forms a vision of life in which people and nature live in harmony. Scholars studied the Torino traditional city blocks and the modern city blocks – take Le Corbusier’s glorious city as an example. Compared with the types of cities advocated by Modernism, they have found that traditional towns have significantly higher urban density, lower heating requirements. Meanwhile, traditional towns also have higher natural light acquisition and natural light availability and more reasonable form factors of urban texture.[30] Therefore, it can be explained that, compared with the development model of modern cities, the urban texture of traditional towns is more adaptable to the environment. Without considering the influence of modern equipment on space comfort, traditional towns' energy efficiency and urban space comfort are higher than those of modern cities.

Fig. 15 The urban texture of Torino in the area of 400m ×400m. Source: *"Cities and Forms-Research on Sustainable Urbanism"*

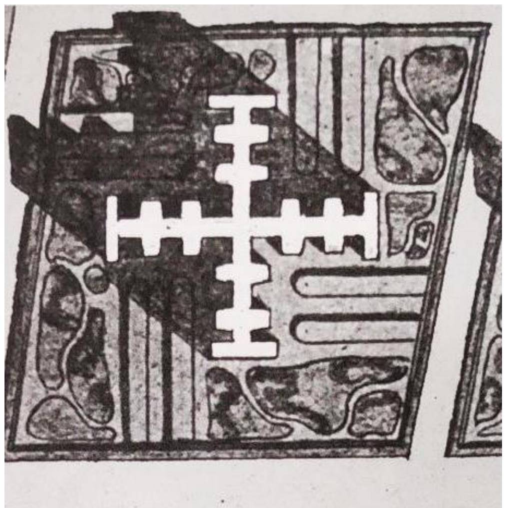


Fig. 16 The urban texture of Glorious City in the area of 400m×400m. Source: *"Cities and Forms-Research on Sustainable Urbanism"*

2.3.2 The Classification of the Urban Morphological Index Affecting the Physical Properties of the Environment

It can be seen from the above that the areas that interact with the thermal and wind environment in the city are mainly the Urban Boundary Layer, the Urban Canopy, and the Urban Canyon. Among them, at the level of the Urban Canopy, what corresponds to the urban form is the Urban Texture, while at the level of the Urban Canyon, what corresponds to the urban form is the form of the urban street space. The Urban Texture can be further divided into two aspects: structure and entity. The structure mainly refers to the composition characteristics of streets and blocks in the city, such as street orientation, block orientation, city nodes. The entity mainly refers to the form of buildings in a specific block. The form of urban street space represents the long and narrow urban space formed by the facades of buildings on both sides of the street. In addition, in the courtyard-like urban texture, the courtyard space enclosed by the four or three sides of the building is also an important part of the urban texture.

30 Serge Salat,《城市与形态-关于可持续城市化的研究》，书中将柯布西耶式的城市肌理与西方传统连续庭院式城市肌理进行多方面的对比研究，认为传统城市形态更加灵活且适应外界环境。

Therefore, this article divides the urban form into three parts: block, street, and Negative Form for discussion. In urban design, a block refers to an area surrounded by roads and is an important part of the Urban Structure. In this article, the block shape mainly refers to the shape of the building space in the block, that is, the sum of the indoor space formed by the envelope structure in the block. The street morphology includes the structural elements in the urban texture and the urban street space referred to in the urban street layer gorge. Therefore, the street morphology has urban-scale orientation, nodes and other characteristics, and specific morphological characteristics of street space. Negative Shape is a concept that is generated relative to the Positive Form. In this article, the Negative Form is the shape of the courtyard space enclosed by the four or three sides of the building in the block, and the Negative Space is the general term for the inner courtyard space in the city. In addition, the city street space defined by the two sides of the building and the city square defined by different blocks are also in line with the definition of the negative shape of the city. However, due to its uninterrupted continuity in space, this article will discuss it in the category of street form.

In terms of the urban form factors that specifically affect the physical performance of the urban space environment, the block shape includes the block shape coefficient and the passive space ratio. The street shape includes the street aspect ratio and the street azimuth angle. The negative shape includes the negative shape area ratio and the negative shape aspect ratio.

2.3.3 Urban Morphological Index Affecting the Physical Properties of the Environment

2.3.3.1 Block Shape Coefficient

The Shape Coefficient refers to the ratio of the external surface area of a building in contact with the external environment and the volume enclosed by it, expressed by the formula F/V. In this formula, F refers to the external surface area of the building, and V refers to the volume of the building. The concept of the Shape Coefficient is generally used in the calculation of the parameters of the building form. In this paper, the Block Shape Coefficient represents a similar concept to that in the urban environment. In the urban environment, the calculation method of defining the Block Shape Coefficient is the ratio of the sum of the surface area of the building in contact with the external environment and the sum of the volume surrounded by the building, that is, S=F/V.

Known from the definition, the Block Shape Coefficient has a strong relationship with the arrangement and combination of buildings in the block. For an individual building, the Shape Coefficient has a great relationship with the texture of the building. When the Floor Area Ratio is the same, the courtyard buildings' Shape Coefficient is largest, the panel buildings' is in the middle, and the tower buildings' is the lowest. In contrast, for urban blocks, the texture of continuous and densely arranged buildings has a lower Block Shape Coefficient, while the texture of relatively scattered buildings has a higher Block Shape Coefficient. Therefore, the Block Shape Coefficient is closely related to the compactness of the urban texture and is slightly different from the individual building Shape Coefficient law.

The Block Shape Coefficient can be used to describe the energy and matter exchange potential of block buildings with the external environment through the enclosure interface, such as ventilation, lighting, heat gain, and heat dissipation. Generally speaking, the larger the Block Shape Coefficient, the more energy exchange between the block buildings and the external environment, and the more drastic the internal temperature changes, and vice versa. Body Shape Coefficients in various urban forms must be carefully considered, which has a complicated relationship with external climatic conditions. In winter cold-preservation, towns with larger Block Shape Coefficients have larger heat dissipation areas for block buildings, so they are not suitable for construction in areas with cold winters. A town with a smaller Block Shape Coefficient and a higher degree of compactness are conducive to reducing the heat dissipation of the block building in the cold climate. For another, in terms of summer cooling, towns with larger Block Shape Coefficients are more conducive to indoor ventilation and building cooling, but the outer surface of block buildings can also get more solar radiation. In a town with small Block Shape Coefficients, the individual building of the block can block the sun's rays for each other. However, the lower outer combined surface area also reduces the potential for natural ventilation.

In "Building form and environmental performance: Archetypes, analysis, and an arid climate,"[31] architect Carlo Ratti presented a set of building form prototypes. They used a simple Fresnel diagram to indicate these urban form prototypes(Fig. 17). In the Fresnel diagram, the area between each concentric ring is the same as the area occupied by the central square, while the thickness of the concentric rings decreases as the distance from the central point increases, but the surface area of the figure formed by the concentric rings increases; In another simplified model proposed in the article(Fig. 18), under the premise that the area occupied by the grey part-that is, the volume does not change. As each graphic forms a new subdivided graphic at the next level, the surface area of its graphics continues to expand, and eventually, a simplified courtyard-style urban form model is formed.

[31] Carlo Ratti, Dana Raydan, Koen Steemers. Building form and environmental performance:archetypes,analysis and an arid climate,Energy and Buildings35(2003)49-59,Elsevier.

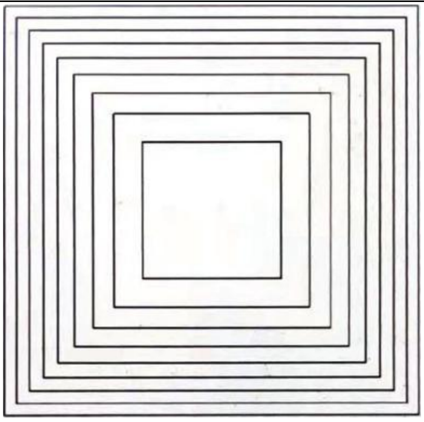


Fig. 17 Fresnel diagram. Source: "Building Forms and Environmental Performance: Prototypes, Analysis, and Arid Climate"

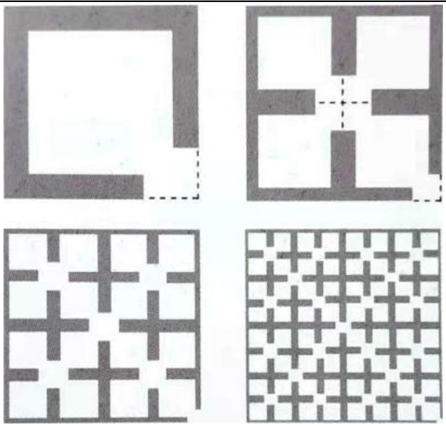


Fig. 18 Simplified model of exchange membrane surface optimizaiton

The block shape coefficient is closely related to the various indicators of the block buildings, including the Building Coverage Ratio and the Floor Area Ratio. Building Coverage Ratio refers to the ratio of the total Building Area to the Planning Construction Land Area. The Floor Area Ratio represents the Gross Floor Area of buildings on the ground to the area of planned construction land.

This article uses the concepts of Architecture Construction Ratio, Block Construction Ratio, Built Block Density, and Overall Urban Density to expand the Building Coverage Ratio and Floor Area Ratio concepts to make it a suitable description of urban form. The Building Area Ratio is similar to the Building Coverage Ratio, which is the ratio of the base Building Area in the selected area to the City Area. The Block Area Ratio is the ratio of the Block Area to the urban land area within the selected range. The density of built blocks is the ratio of the gross construction area of the above-ground buildings to the area of the block in the selected area. The gross density of a city is the ratio of the gross construction area of the above-ground buildings in the selected area to the area of the city.

The overall urban density index is generally smaller than the built-up density index, and this gap is especially huge in modern cities. For example, in the Lujiazui area in central Shanghai, the density of a block composed of skyscrapers may be above 20. However, taking the entire Lujiazui area as the calculation area, the gross urban density is only 1.2, which is far from the density of the built-up block with a single block as the calculation range. This result is closely related to the large-scale public green space and infrastructure land in the city. In contrast, the layout of buildings in traditional towns is relatively compact, and there are almost no large-scale public green landscapes in towns. Hence, the gap between the total density of the city and the density of built-up blocks is small. Comparing modern cities and traditional towns, the indicators of Building Coverage Ratio and Block Coverage Ratio are quite different. Generally speaking, the Building Coverage Ratio and the Block Coverage Ratio of traditional towns are greater than those of modern cities.

The total urban density, the density of built-up blocks, and the building coverage of the same traditional town in different periods of development or different climatic zones differ significantly.

For example, the urban texture of Paris in different development periods (Fig. 19) shows that the urban texture before 1800 has 83% building coverage and 4.9 built-up block density; the urban texture formed from 1851 to 1914 has 66% building coverage and 5.8 built-up block density. In the urban texture formed between 1940 and 1967, the building coverage dropped to 19%, while the density of built-up blocks dropped to 1.1. It shows that the density characteristics of the urban texture are quite closely related to the historical development of the city. The author’s below analysis of the historical center texture of small towns in different climatic zones in Italy will also show that different climatic zones also have a strong influence on built-up Block Density and urban gross density.

Fig. 19 Comparison of texture within the 200M*200M area in Paris at different times Source: *“Cities and forms on sustainable urbanism”*

There is also a complicated relationship between the parameters related to the Block Shape Coefficient in the urban form and the climate environment. In general, as the density of built-up blocks and the city's total density increase, the city's physical environmental performance will decline to a certain extent, and the thermal comfort will also decrease accordingly. However, in terms of the degree of impact on urban thermal and wind environments, there is a difference between the type of urban texture, building height, and depth. The blocks of traditional towns adopt the courtyard type of urban texture pattern, where the building coverage of the blocks is extensive, and thus the number of enclosed building stories need only reach a height of 4-6 stories to achieve a high density of the built-up block. The large Building Coverage Ratio and Block Coverage Ratio of traditional towns can limit the temperature difference. It ensures a high density of built-up blocks while making full use of natural light and bringing fresh air and sunlight into the house through the courtyard.(Table 2)

Table 2 Density Types of Different Enclosed Cities Source: “Cities and forms on sustainable urbanism”

Selected areas	200m*200m	200m*200m	200m*200m	200m*200m	200m*200m
Form/Urban Form	Roman style	Medieval Style	Medieval Style	Expansion area	Baroque style
Building occupancy rate/ site selection area (%)	77	85	74	39	49
Neighborhood occupancy rate (%)	82	91	87	63	60
Number of building floors	6	3	6	5	6
Density of built-up blocks	4.9	3.2	5.8	3.2	3.6
Total urban density	4.6	3.0	4.9	1.9	3

2.3.3.2 Passive Space Ratio

Passive Space refers to the building space within 6 meters from the outer envelop structure. According to empirical measurement, the indoor space of a building located within 6 meters of the envelope structure is regarded as an area that can take advantage of the outer world's natural light and ventilation potential (Fig. 20). The Passive Space Ratio refers to the ratio of the total area occupied by passive space to the total Building Area.

Passive Space is directly related to the block buildings' depth and the Block Space Coefficient. Generally speaking, the greater the building's depth, the lower the proportion of Passive Space, and under the same other conditions, the smaller the Block Space Coefficient. Vice Versa.

Although there is a corresponding relationship between the proportion of The Passive Space and the Block Space Coefficient, the relationship between Passive Space and the climate environment is significantly different from the Block Shape Coefficient. Unlike the Block Shape Coefficient pointing to cold preservation, the proportion of the Passive Space is more pointing to natural ventilation and daylighting in spring and autumn. According to the meaning of passive space, the greater the proportion of passive space, the more areas in the city can be naturally ventilated and lighted by passive technologies. In winter, a lower proportion of passive space can reduce the Block Shape Coefficient, reducing the building's heat load. However, the low proportion of passive space makes it difficult for some building spaces to be naturally ventilated and use natural light in the transitional seasons, dominated by spring and autumn, which greatly increases the Cold Load of the building. Therefore, the proportion of passive space quantifies the possibility of radiation, ventilation, and light exchange between urban space and the natural environment, that is, the possibility of using passive technologies that do not require the use of fossil fuels.

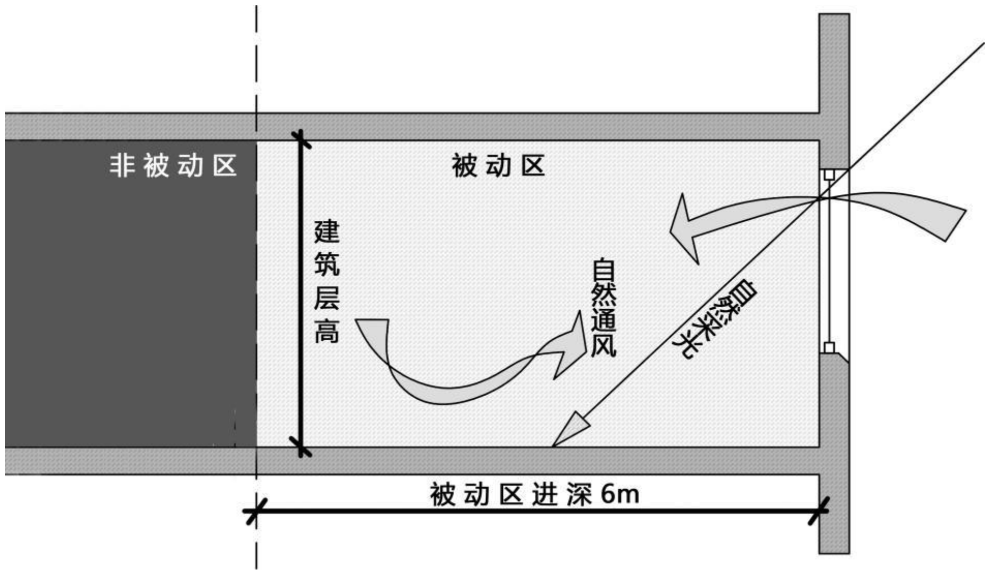


Fig. 20 Definition of Passive Space. Source: the author's drawing

With the widespread application of active technologies such as air-conditioning, the cognition of the Passive Space is gradually forgotten. The proportion of passive space in modern urban morphology has shown a significant downward trend. For example, the proportion of passive space in Berlin in the selected area of 400m*400m is only 61%, which is much smaller than the 84% proportion of passive space in Toulouse[32]. The construction of high-rise office buildings, residential towers, large public buildings, and other large and deep buildings in modern cities is one reason for the decline in the proportion of passive space. The operation of these buildings requires frequent use of active system equipment, which consumes a lot of fossil energy. The most significant phenomenon is that artificial lighting is still needed indoors during the day, and the air conditioning or ventilation systems are still needed for air circulation in spring and summer.

Compared with modern cities, the proportion of passive space in traditional towns is relatively high, which is related to the massive use of the passive system to exchange energy with the outside world most of the year. According to research, except for the newly built large public buildings and landmark buildings, the proportion of passive space in the urban form of Historic Areas of Paris is between 95% and 100%[33] (Fig. 21). although having good natural ventilation and lighting efficiency is common in traditional towns, when specific to traditional towns in different climate zones, changes in the proportion of passive space may still affect the physical performance of the city.

[32] Carlo Ratti,Nick Baker,Koen Steemers.Energy consumption and urban texture.Energy and Buildings.2005(37):762-776

[33] Salat, Serge, Françoise Labbé, and Caroline Nowacki. Cities and Forms on Sustainable Urbanism. S.l.: CSBT, 2011. Print.

Fig. 21 Percentage of passive space in the urban morphology of the histoic district of Paris. Source: *"Cities and forms on sustainable urbanism"*

2.3.3.3 Street Aspect Ratio and Azimuth

This article defines the street aspect ratio A as the height H to the width W of the street cross section, A=H/W. The aspect ratio of the street is an important indicator to measure the shape of the street, and it impacts the air temperature and air velocity of the street space.

In terms of air temperature, the deep street space is lower than the shallow street space. Therefore, the deep street space has a more pleasant temperature in the hot summer, while the shallow street space can introduce more solar radiation in winter, and the temperature will be more suitable. The cold alleys in traditional residences in Lingnan, China, are a typical example of using high street aspect ratios to organize ventilation in summer and provide shade for outdoor walking environments. In terms of air velocity, due to the obstruction of urban buildings, the air usually generates turbulent flow in the street space (Fig. 22). the greater the street aspect ratio, the less obvious the turbulence phenomenon, and the smaller the street aspect ratio, the more obvious the turbulence phenomenon. Therefore, a larger street aspect ratio can shield the wind to a certain extent.

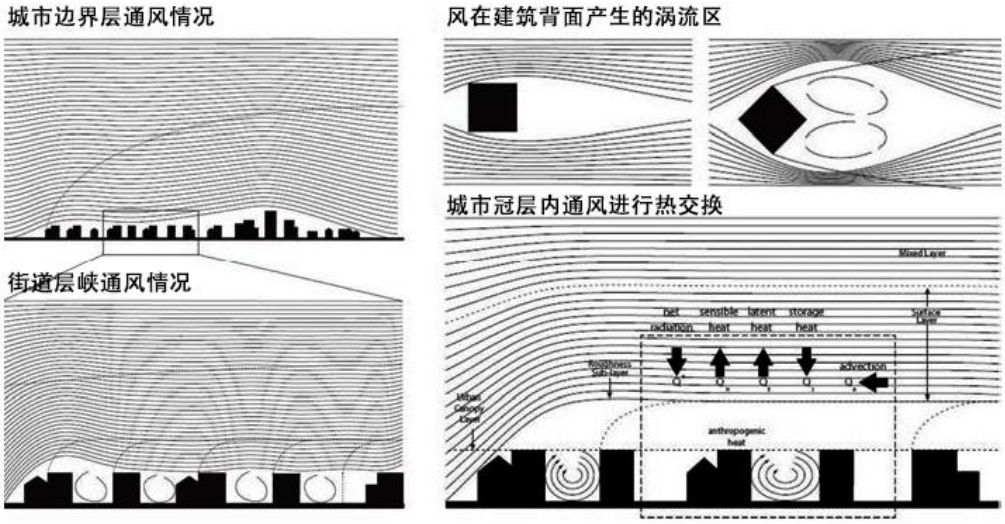


Fig. 22 Schematic diagram of natural ventilation in street space. Source: *"Sun, Wind & Light, Architectural Design Strategies"*

Street azimuths include street thermal azimuth (α) and street wind azimuth (β), both of which are equally important to the street's environmental physical performances. Street wind azimuth refers to the smaller angle between the main street grid and the dominant wind direction, while thermal azimuth refers to the smaller angle between the main street grid and the north-south direction. Street azimuth can affect environmental physical performances in the three following ways.

One is the ventilation condition of the street grid. Streets with the same direction as the dominant wind in the city are more likely to bring outside winds into the city, increasing the wind speed in the streets and improving pedestrian comfort while carrying away pollutants from the city. According to the research, a street grid with 15 to 30 degrees from the dominant wind direction of the city in summer can ensure the introduction of wind while increasing the wind pressure between building interfaces and promoting wind pressure ventilation in the city. In winter, the direction of the street should be shielded from the dominant winter wind, and being perpendicular to the winter wind or at an angle of 45 degrees or more is a more appropriate choice.

Second is the sunlight and shade area on the streets and sidewalks. Generally speaking, streets with smaller thermal azimuths have less sunlight, and stress with larger thermal azimuths has more areas exposed to direct sunlight. Streets with a thermal azimuth angle of about 45 degrees have a large sunshine area on the streets in winter, and one side of all the streets with orientation is under shade in summer, which is suitable for hotter areas.

Third, the sunlight and ventilation potential of the buildings along the street. Streets with larger or smaller thermal azimuths can allow buildings along the street to get more solar radiation suitable for cold winter areas. A street with a certain angle of wind azimuth can increase the wind pressure on the building surface to a certain extent, which would promote the natural ventilation of the building interior.

2.3.3.4 Negative Shape Area Ratio and Aspect Ratio

Fig. 23 Urban negative shape space in the medina plan of Keban City Source: *"Cities and forms on sustainable urbanism"*

Known from above, the negative shape space in the city is a concept relative to the city's physical space. The city's negative shape space is closely attached to the city's physical space, presenting the form characteristics of being completely open or semi-open. Compared with other spaces, the negative shape space owns its environmental physical performance. The negative shape space of the city has a close relationship with the surrounding architectural space and the open space of the city. In cities, the negative shape space includes the traffic space inside the block, such as the internal road space and corridor space of the block, the public space of the block, such as the internal courtyard space of the block, the internal arcade space of the block, and residential space such as the open space inside the block.

In 2010, Southeast University was invited to participate in the thematic design course of the 12th Venice International Architecture Biennale-the "City of Holes" design course, which put forward the concept of "holes." The "hole" in the city has a corresponding relationship with the negative shape space of the city in this article. The concept of "holes" refers to a structure that generally exists in the natural world and the artificial world. It is regarded as a continuous and integral structure in curriculum design rather than an isolated and discrete individual. It continuously interacts with the natural world and dynamically seeks a balance with sunlight, air, and fluidity.

The "hole city" is a concept opposite to the "object city." The course believes that whether it is a traditional European city or a traditional Chinese city and village, both arise from the relationship between buildings and other fields. The consistency lies in connecting individuals into a dense overall structure, so the concept of density plays a vital role in these cities. As shown in Fig.24 and 25, although they are in different regional cultures, Lucca in Italy and the traditional blocks of Nanjing in China have a similar continuous urban structure system. The same building types are connected and combined to form a city with an overall meaning. Unlike the low-connectivity, low-efficiency, and sprawling urban structure of the "object city" formed by superimposing single loose buildings, the "porous city" first imagines that the city starts from an overall volume with a density of 100%. Then, holes are created to receive sunlight and air in nature and exchange energy with the outside world.

Fig. 24 Aerial View of Lucca in Tuscany, Italy. Source: *"Pores City"*

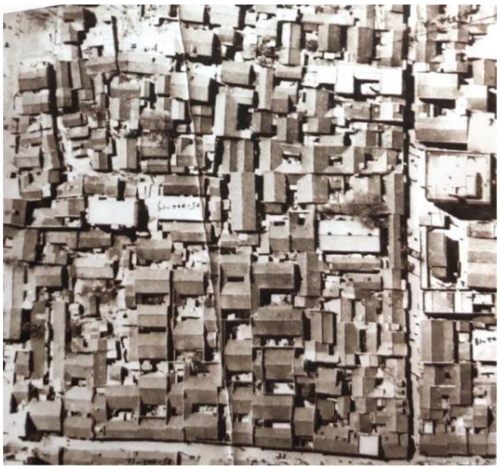


Fig. 25 Satellite Map of Nanbuting block in Nanjing, China. Source: *"Pores City"*

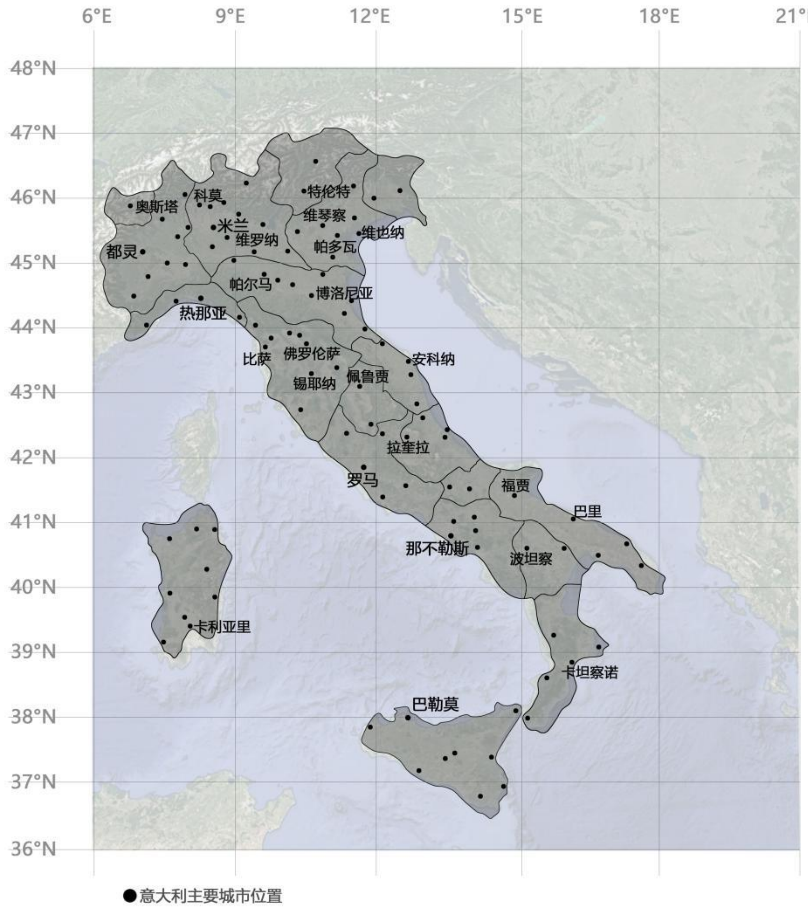
The concept of "holes" has similarities with negative-shaped spaces. They are both a description of the internal enclosed space contained in the continuous urban structure. It is closely related to the material and energy exchanges between the city and the external environment and the physical properties of the city's environment. The negative shape space in the city mainly plays a role of transition, optimization, and buffering in affecting the performance of the physical environment. Given the diversity and complexity of the negative figure space, this article uses two factors, the negative figure aspect ratio, and the negative figure area ratio, to describe the negative figure space in the city.

The negative figure aspect ratio (B) refers to the ratio of the height H to the width W of the negative figure space inside the block, that is, B=H/W. In traditional towns, the most common negative shape space is the courtyard space enclosed by buildings inside the block. The shape is generally rectangular. The form is relatively symmetrical, related to the external environment through the upper opening. Therefore, the depth of the negative body shape is of great significance in affecting the physical properties of the environment. Under the condition that the height of the buildings in the block is similar and remains constant, the deeper the depth of the negative shape, the larger the buffer space between the urban bottom space and the external environment. Its space physical environment performance is stable, but at the same time, it can obtain less wind and natural light.

The area ratio of the negative figure (D) refers to the ratio of the area of the negative figure space inside the block to the block area. It can be seen from the above that in traditional cities and towns, the building occupancy rate is relatively high, and the number of building floors is relatively low. Compared with the urban form of vertical extension in modern cities, this kind of plane-extended urban form has much more solar radiation from roofs than building facades and urban surfaces. Therefore, for traditional cities and towns, the spaces that people often use, such as urban public spaces and indoor spaces of buildings, receive a direct correlation between the total amount of solar radiation and the area ratio of negative body shapes. The area ratio of the negative body shape directly determines the total energy exchange between the urban form and the external environment. Therefore, for the thermally adaptive types of traditional towns, the negative body shape area ratio is a key variable.

2.3.4 Thermal Adaptation of Traditional Italian Towns

2.3.4.1 Types of Thermal Adaptation in Traditional Italian Towns



城市	大区	人口（万）
罗马	拉齐奥	270.5
米兰	伦巴第	130.3
那不勒斯	坎帕尼亚	97.5
都灵	皮埃蒙特	90.1
巴勒莫	西西里	66.7
热那亚	利古里亚	61.6
博洛尼亚	托斯卡纳	37.3
佛罗伦萨	托斯卡纳	36.6
巴里	普利亚	32.5
卡塔尼亚	西西里	30.2
威尼斯	威尼托	26.9
维罗纳	威尼托	26.1
墨西拿	西西里	24.5
帕多瓦	威尼托	21.0
蒂利亚斯特	弗留利-威尼斯朱莉亚	20.5
塔兰托	普利亚	19.6
布雷西亚	伦巴第	19.0
普拉托	托斯卡纳	18.6
摩德纳	艾米利亚-罗马涅	18.0
帕尔马	艾米利亚-罗马涅	17.7
佩鲁贾	翁布里亚	16.2
雷焦艾米利亚	艾米利亚-罗马涅	15.9
卡利亚里	撒丁	15.9

数据来源：https://wenku.baidu.com/view/a06121096e1aff00bed5b9f3f90f76c660374c14.html

Fig. 26 Distribution map of major cities in Italy and a data table of cities with a population of 150,000 above. Source: Drawing based on the satellite map and relative data

In addition to the vast and sparse rural areas, Italian cities and towns mainly include large cities with a population of more than 500,000, such as Rome, Milan, Naples, Turin, Palermo, and Genoa; medium-sized cities with a population of 200,000 to 500,000, Such as Bologna, Venice, Florence, Bari; small towns with a population of 50,000 to 200,000 such as Bergamo, Alba, Vicenza, Foggia, Ferrara. The urban population in Italy accounts for more than 90% of the total population, and the degree of urbanization in the entire country is very high.

The geographical distribution of Italian towns is closely related to the topographic and climatic characteristics of Italy. These towns mainly can be divided into coastal cities on the Mediterranean coast and the southern peninsula, such as Genoa, Rome, Naples, and Palermo; Cities that bred in the vast and fertile Bataan plains in the southern Alps, such as Turin, Milan, Bologna, Venice; cities such as Siena and Perugia in the mountains of central Italy, and Foggia in the hotter areas of Puglia. (Fig. 26)

Modern Italian towns are expanded based on historical towns, so the urban fabric formed in each historical period is intertwined and layered within the city. The new urban area with lower building density is built around the old urban area, and some newly constructed taller houses also replace the lower houses in the old urban area, thereby increasing the floor area ratio of the central urban area. However, fortunately, due to Italy's strict historical city protection policy, the historical urban fabric of most cities has been preserved, and the buildings in some historic urban centers have retained their shape since the late Middle Ages (Fig. 27).

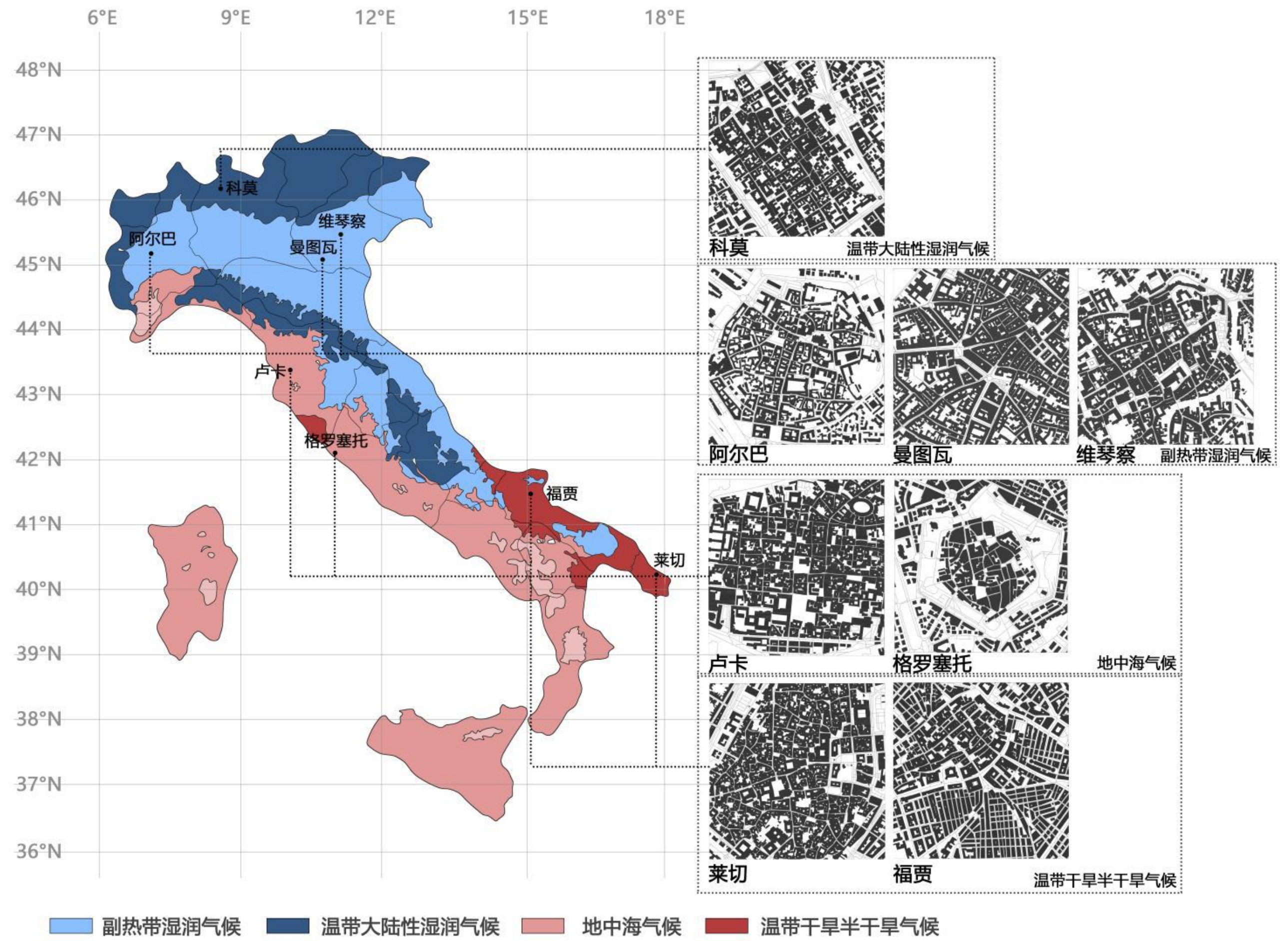
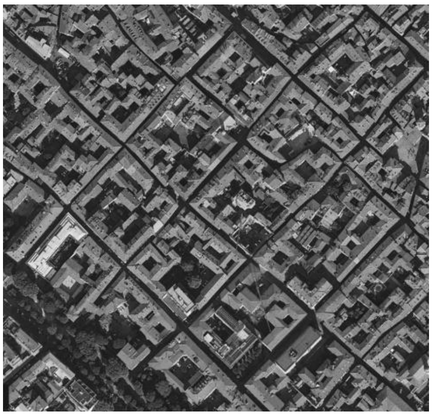


Fig. 27 The texture map of Italy's cities in different climate zones. Source: the author's drawing

In order to eliminate the interference of other factors such as politics, economy, development level, and modern urban development to the greatest extent, this paper selects eight small and medium-sized Italian towns as samples to analyze the types of thermal adaptability of Italian cities. With a population of less than 120,000, these small and medium-sized Italian towns have a long history. The urban fabric and buildings in the historic district are relatively well-preserved, and the urban fabric of various historical periods can be easily distinguished. Geographically, they are distributed from north to south, respectively Como in the northernmost Alps, Alba, Mantua, and Vicenza in the northern Po River basin, Lucca and Grosseto on the Mediterranean coast Foggia and

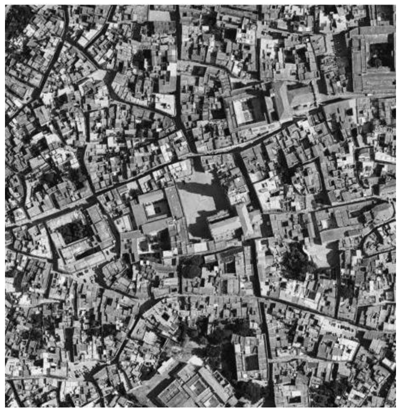
Lecce in the Puglia region. A sample (400M*400M) of the historical city center area of the same area was selected from these eight cities and towns for analysis. The relationship between the urban morphological characteristics of Italian cities and the climate zone they are located in is explored by calculating indicators such as building land occupation rate, block land occupation rate, built-up block density, and total urban density.

From the urban texture map of the selected towns, these towns have a similar courtyard urban texture. The courtyards enclosed by buildings are like windows opening to the sky in the city, playing the role of material and energy exchange between the city and the external environment. However, due to the different climate zones in which cities and towns are located, there are obvious differences in the size of blocks, the sense of enclosure of blocks, the scale and size of courtyards, etc. From the satellite maps of the three towns (Fig. 28), within the same 800m*800m range, Como, Lucca, and Lecce present urban texture features of different scales. The scales of streets, blocks, and buildings show continuity from large to small—correspondence between courtyard-style urban texture and external climate.



Como

Lucca



Lecce

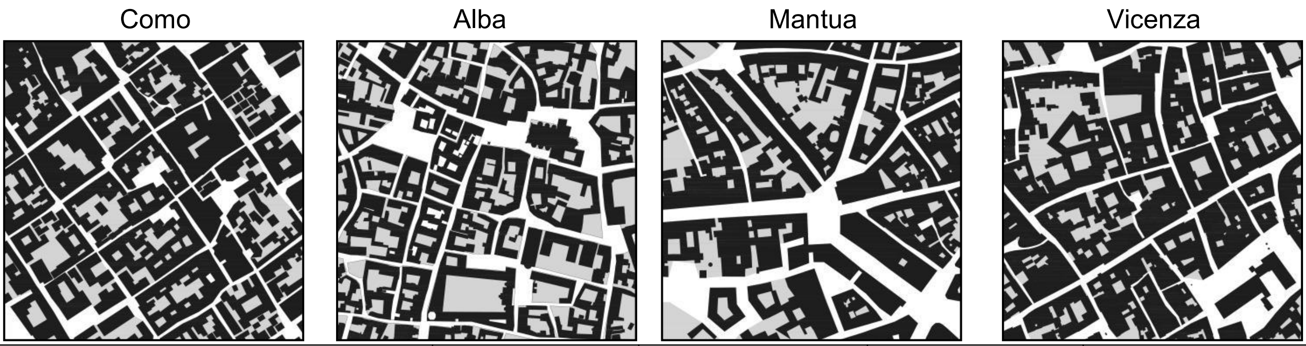
Fig. 28 Comparison of satellite images of Como, Lucca and Lecce (from left to right) at the same scale. Source: Export from satellite image software

Como, located above the Alps, has the most enclosed courtyard (Fig. 28). The continuous building interface facing the street encloses a moderately sized courtyard that can withstand the cold winter wind and prevent it from entering the courtyard. A moderately scaled courtyard can ensure that the building receives adequate sunlight in winter while not receiving too much sunlight in summer. The higher built-up block density (2.87) enables the building to have a lower body coefficient inside the block, avoids excessive heat exchange with the outside world, and reduces the building's heating demand in winter.

Alba, Mantua, and Vicenza, located in the Badan Plain in the Po River Basin, have very similar urban textures. The compact and narrow blocks located in the center of the historical city contrast with the larger block plots in the urban expansion area (Table 3). The building area and density of built-up blocks in the expansion area are smaller than those in the city center. Mantua and Vicenza have a large permanent population, and the level and scale of urban development are relatively high, so they present a relatively high density of built-up blocks and overall urban density. Among the developed blocks, the block is divided into many small courtyards smaller in scale than the internal courtyard formed by Como. This kind of hole-like inner courtyard can provide shelter and improve the indoor thermal comfort of the building in the hot summer, while the shallower building gets enough natural light through the courtyard in winter.

Lucca, Grosseto, Lecce, and Foggia on the Mediterranean coast and the southern peninsula show a courtyard-like texture different from other towns (Table 3). These four towns' blocks are divided more finely by streets, and the area occupied by the blocks is also lower than that of the four northern towns, between 60% and 70%. It means relatively deep and narrower block blocks and more transparent urban street space. The area of courtyard space enclosed by buildings in smaller blocks has also decreased by a large percentage compared to northern towns. This trend is particularly reflected in towns with a hot and arid climate on the Salento Plain in southern Italy. Lecce and Foggia have a difference of only 6% and 8% between the block land occupation rate and the building land occupation rate, which is in sharp contrast with other towns. Carpet-like low-rise buildings (2-3 floors) spread across the town, forming narrow streets and inner courtyards to block the hot summer light. In a hot and dry climate, the night temperature will be significantly lower than the daytime temperature. The thermal mass of the surface area of the larger enveloping structure of the continuous courtyard town texture can receive solar heat during the day and reduce the temperature peak. At night, the excess heat is released again to reduce the temperature difference between day and night.

Table 3 Analysis of the morphological types of Italian towns. Source: The author's drawing



	Como	Alba	Mantua	Vicenza
Selected areas	400m*400m	400m*400m	400m*400m	400m*400m
Block Type	Closed block	Closed block	Compact Block	Compact Block
Building occupancy rate/ site selection area (%)	68	56	56	63
Neighborhood occupancy rate (%)	83	79	75	78

Number of building floors	3-4	2-4	3-4	3-4
Density of built-up blocks	2.87	2.26	2.63	2.57
Total urban density	2.37	1.78	1.97	2.01

Lucca

Grosseto

Lecce

Foggia

Selected areas	400m*400m	400m*400m	400m*400m	400m*400m
Block Type	Compact Block	Closed block	Compact Block	Compact Block
Building occupancy rate/ site selection area (%)	66	46	68	54
Neighborhood occupancy rate (%)	77	55	74	62
Number of building floors	3-5	2-3	2-3	2-4
Density of built-up blocks	3.32	2.49	2.09	2.21
Total urban density	2.57	1.37	1.55	1.36

In a hot and dry climate, the night temperature will be significantly lower than the daytime temperature. The thermal mass of the surface area of the larger enveloping structure of the continuous courtyard town texture can receive solar heat during the day and reduce the temperature peak. At night, the excess heat is released again to reduce the temperature difference between day and night. If you divide the courtyard area enclosed by the buildings in each block by the total area of the block, the author can get the data of the negative figure area ratio (D) of the cities and towns in Italy (Table 4)

It can be seen from Table 4 that, except for Como, which has a higher block density and total urban density, the negative figure area ratio of other cities and towns shows a decreasing characteristic, and the negative figure area ratio of Alba is 29.49%. Mantua and Vicenza, which belong to the Humid Temperate Climate, have a lower negative body area ratio than Alba, but they remain relatively high. Lucca and Grosseto are located on the coast of the Mediterranean Sea. In winter, the warmer climate causes their area to be reduced compared to the towns along the Po River, while Lecce and Foggia, the hottest and driest climates, have their area ratios reduced to about 10%. On the other hand, Como's enclosed block development model and deeper building plan can appropriately reduce energy consumption in winter and ensure the city's high-density development needs. Therefore, under a lower negative body-to-area ratio, Como also adapts to the local climate characteristics.

Table 4 Negative shape area ratio for Italian cities

Cites	Como	Alba	Mantua	Vicenza
Negative shape area ratio（%）	17.99	29.49	24.85	19.66
Cities	Lucca	Grosseto	Lecce	Foggia
Negative shape area ratio（%）	14.79	16.88	9.16	11.70

In general, from the above analysis, it can be concluded that with the gradual increase in temperature and the gradual decrease in annual rainfall from north to south in Italy, the area ratio of the city's negative body shape becomes smaller. The aspect ratio of the negative figure form and the aspect ratio of the street form become large, the average depth of the building becomes smaller, and the average floor space of the block becomes small. From north to south, these changes in urban form factors help reduce the absorption of solar radiation, increase the shadow area on the ground and promote natural ventilation of buildings.

2.3.4.2 Comparison of Thermal Adaptation Types between Traditional Italian cities and Chinese "courtyard" Buildings

The thermal adaptation type of Italian cities is similar to the thermal adaptation type of Chinese "courtyard" buildings. This section attempts to compare the similarities and differences in the changing patterns of the two types of enclosed fabric.

The "courtyard" building is the most stable and mature architectural system in traditional Chinese architecture. As the basic building unit, its gradual expansion creates traditional Chinese settlements connected by different courtyards in an orderly manner, thus forming a continuous courtyard type of urban texture. Therefore, the courtyard building can be a typical representative of the thermal adaptation type of Chinese settlement form.

The diagram of the relationship between the evolution of the plane space of typical Chinese courtyard houses and climate adaptability (Fig. 29), The ratio of Heat Reception Space, Heat Conditioning Space, and Outdoor Space in the courtyard varies with the climate zone where the building is located.[34] In the four different climatic zones from northeast to southwest China, the open space area decreases proportionally with the increase of the heat-receiving space, and the wide middle courtyard space gradually becomes a narrow patio for light and ventilation inside the building. In the cold and dry regions of North China and Northwest China, the enclosed courtyard open space helps to block the cold north wind while absorbing sufficient sunlight in winter so that the interior gets solar radiation. In the cold winter and mild summer regions of Central China, the proportion of Space under Eaves increases, and grille windows and grille doors with air conditioning are also used in large numbers. In the hot and humid summer and cold and dry winter regions of the southeastern region, the courtyard building becomes more compact, and the courtyard

[34] 刘巧. 夏热冬冷、夏热冬暖气候环境中的建筑热力学模型研究[D].东南大学,2019. 文中热受体空间主要指合院民居中的各个房间（Rooms），热调控空间主要指民居中的敞厅空间（Open-Hall Space）和檐下空间（Space under Eaves），露天空间主要指庭院空间（Courtyard Space）。

space is reduced in proportion to the northern one, while the gray space such as the gable porch is increased, thus blocking the sunlight from entering the house and promoting the ventilation effect of the building. In the Lingnan area, where the summer is hot and humid and the winter is mild and dry, the courtyard space in the courtyard building becomes a patio only for ventilation and lighting, closely integrated with the indoor under-eave space.

Typologically, the changes in the form of traditional villages result from the optimization of the settlement form according to the external climate. From the northwest to the southeast, the open space inside the courtyard keeps decreasing with the temperature and rainfall increase. The thermal control space formed by the corridors and open halls is getting larger and larger. The size of the thermal receptor space is continuously reduced to achieve a balance between the architectural form and the environment.

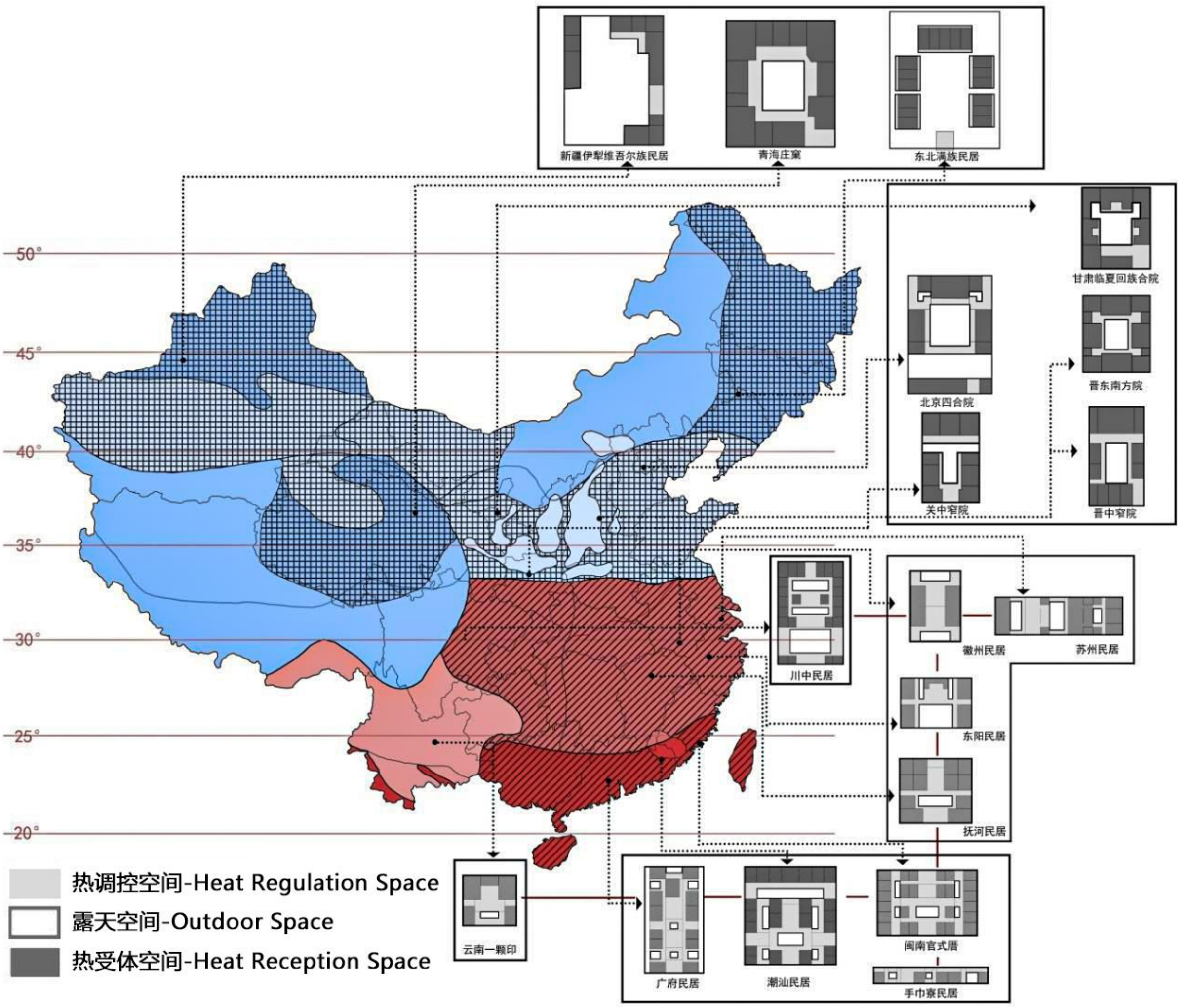


Fig. 29 Relationship between spatial evolution and climate adaptation of typical Chinese courtyard dwellings
Source: Prof. Zhang Tong's Studio of Geotechnical Architecture

Unlike Italian cities, where the courtyard texture is formed through the "concentration" and "merging" of units, traditional Chinese villages are formed through the "diffusion" and "spreading" of courtyard building units. The courtyard "spreads" to the whole area in series and parallel and increases the rest of the building area and courtyard area by adding annexes and walls, which form a texture that is almost flat on the whole site and connected to the road. The density of the whole settlement is thus inextricably linked to the single buildings of the courtyard, while the courtyard space in the block is subdivided into each building, forming a more permeable structure of the settlement than in the Italian towns.

The above analysis shows that whether it is a traditional Italian courtyard-style city or a traditional Chinese courtyard building, it is closely related to the external climate environment. Both countries span a relatively large latitudinal direction, and both countries have a wide variety of climate types within the country. Their traditional cities and traditional villages, from north to south, show an obvious variation of thermal adaptation type characteristics.

However, due to the differences in specific climate types and environments between Italy and China, some differences in the urban and architectural forms characterize their thermal adaptability. The traditional courtyard buildings in northern China tend to have a large courtyard area, while the cities in northern Italy located in the colder parts of the mountains do not have this morphological characteristic. I speculate that this is because the area around central and northern China has a semi-humid and semi-arid monsoon climate with hot and rainy summers and cold and dry winters, while the mountains in northern Italy are accompanied by high humidity throughout the year. In addition, the hotter regions of the two countries have the opposite situation: the Mediterranean coast and the southern peninsula of Italy have hot and dry summers and mild and rainy winters, unlike the year-round humid climate of the Lingnan region of China. Therefore, the negative shape area of the two climatic zones is relatively low, but the buildings in the Lingnan region of China focus more on ventilation to cool down the humidity, while the cities in southern Italy tend to form tight urban structures and thus block each other from the sun to cool down the temperature.

Even in the subtropical humid climatic zone of Italy's Po River Plain and parts of southern China, due to the differences in the specific climate and environment of the regions, the forms of towns or villages are also different. Taking Alba in Italy and Hongcun in China as examples, the average annual rainfall in Alba is 948mm, while the average annual rainfall in Hongcun is 2395mm. Therefore, Hongcun presents the morphological characteristics of summer ventilation, dehumidification, and cooling, while the urban form of Alba tends to obtain solar radiation in winter.

Overall, the architectural form of Chinese "co-yards" changes with the changes of the two climatic factors of temperature and humidity, while the urban form of Italian cities changes more with temperature changes. From the Chinese "courtyard" and Italian urban morphological types, we can see that the courtyard morphological characteristics have very strong thermal adaptation characteristics, and the settlement form formed by the enclosed architectural texture presents either loose or compact characteristics under different climatic conditions, thus playing a role in regulating the microclimate of the settlement and improving the comfort of the residents' life.

2.3.4.3 Extraction of Typical Cities Cases in Northern Italy

Italy has more mountains and less relatively flat land, and the Po River Plain in northern Italy is one of the few plain areas in the country. Due to the superior geographical environment and fertile land, the Po River Plain has become the most economically developed area in all of Italy and the most concentrated and concentrated area of Italian towns. At the same time, most of the towns in the Po Plain area are located in the subtropical humid climate zone. Therefore, to study the thermal adaptability of urban morphology in a Humid Temperate climate, the towns in the Po Plain of Italy are representative.

The distribution of towns in the Po Plain area is related to the Po River and closely related to the roads of the ancient Roman period. Originating from the Alps, the Po River is the largest in Italy. The land on both sides of it is fertile, and the river itself can be used for the transportation of goods. There are many towns around the river, such as Torino, Pavia, Ferrara, Piacenza, Cremona. However, because the Po River valley area is often threatened by flooding, other towns in the Po River Plain are also set up off the main river channel of the Po River, which is widely distributed in various areas of the plain.[35] On the other hand, some towns in the Po Plain area are located on both sides of the urban arterial roads built during the ancient Roman period. Via Aemilia is an ancient Roman road on the plains of northern Italy. It starts in the coastal city of Rimini on the Adriatic Sea in the southeast and ends at the Po River in the northwest. Piacenza, a small town on the river. It was an important road connecting various colonial cities in ancient Rome. Parma, Modena, Bologna, Cesena, and other towns are located along this road. (Fig. 30)

[35] 徐好好.波河平原城市的分布形态和历史的种子[J].新建筑,2010(03):97-101.

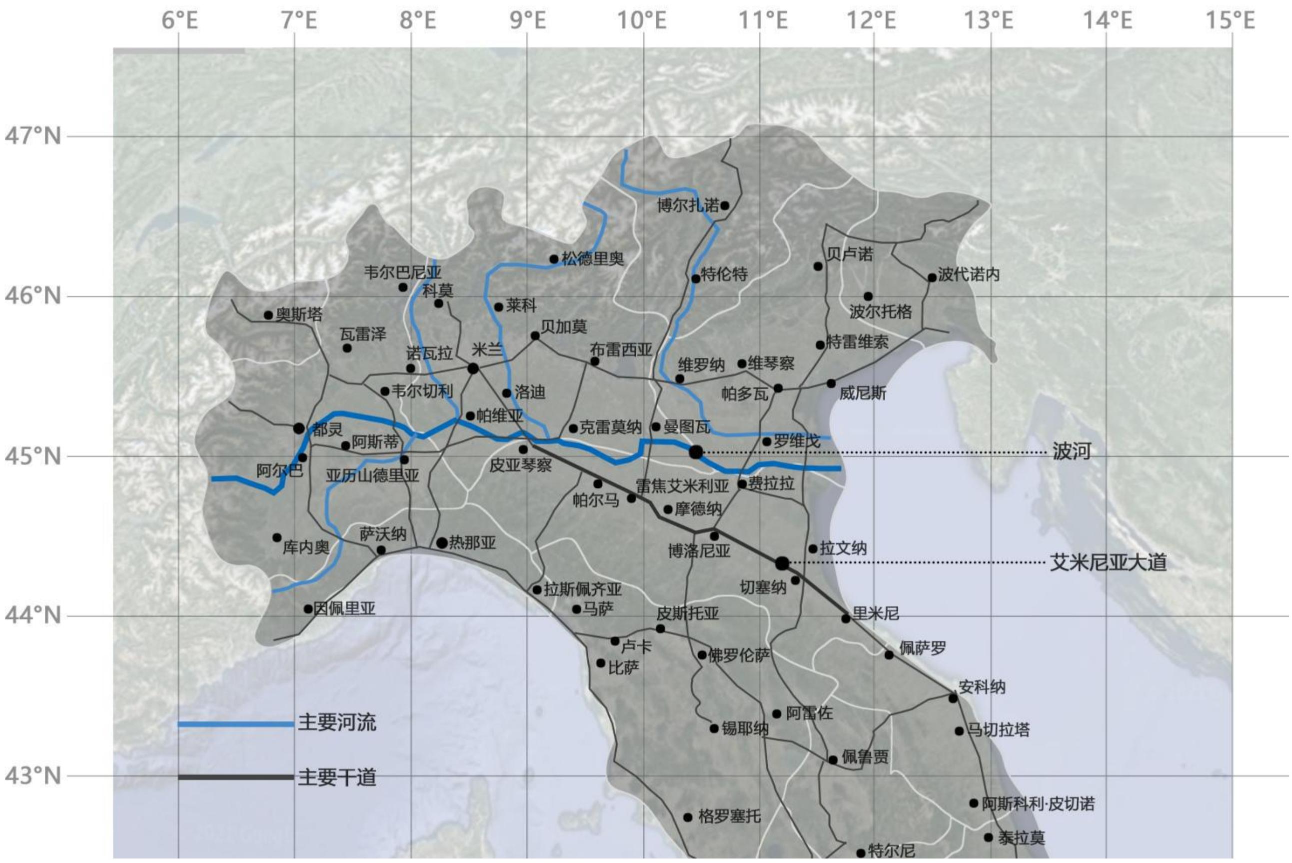


Fig. 30 Distribution map of cities in the Po plain area of northern Italy. Source: The author's drawing based on satellite map

The towns in the Po Plain area in northern Italy are mainly located in the subtropical humid climate zone, a sub-category of Cfa in the Köppen climate classification. In winter, the average temperature is between 0°C and 5°C, cold and humid, and foggy weather. In summer, the average temperature is between 22°C and 25°C, hot and humid, often accompanied by thunderstorms and hail weather. The climate is pleasant during the transitional seasons of spring and autumn. The annual rainfall in this area varies from 700 mm to 1200 mm, and it is more evenly distributed throughout the year, with relatively high amounts in autumn and spring. Insufficient natural air volume and wind speed are common features throughout the Po River Plain. This climatic feature makes the daytime hotter in summer. At the same time, a windless environment cannot discharge air pollutants in cities and towns, which in general aggravates air pollution levels. Therefore, the Po River Plain has become one of the most polluted areas in Europe. Except for the Humid Temperate climate, parts of the Alps and Apennines in northern Italy are located in a temperate continental humid climate, but the towns in the area are smaller and sparsely distributed.

Among Italian cities and towns located in a Humid Temperate climate zone, they can be divided into three main categories according to the size of the city. (Fig. 31) The first category is cities with more than 200,000, represented by Torino, Milano, and Bologna. The city-scale and development level of such cities are relatively high, and the scale of historic districts is also larger than that of other cities and towns. Due to urban development and expansion, the historic urban area and the new urban area are connected as a whole, forming a continuous urban area. The second category is cities with populations between 150,000 and 200,000, represented by Vicenza, Parma, and Pavia. They are generally regional central cities in Italian administrative divisions. The scale and size of historic districts are not much different from those of cities with more than 200,000. The construction of new districts is carried out around the historic districts, thus forming a larger city. The third category is towns with less than 150,000, represented by Asti, Brescia, and Ferrara. Together with other smaller towns (not shown in the figure), they constitute the basic unit of the Italian urban system. The historical urban areas of these towns are smaller than other regional central cities but larger than the historical urban areas of other small towns and have a certain urban scale.

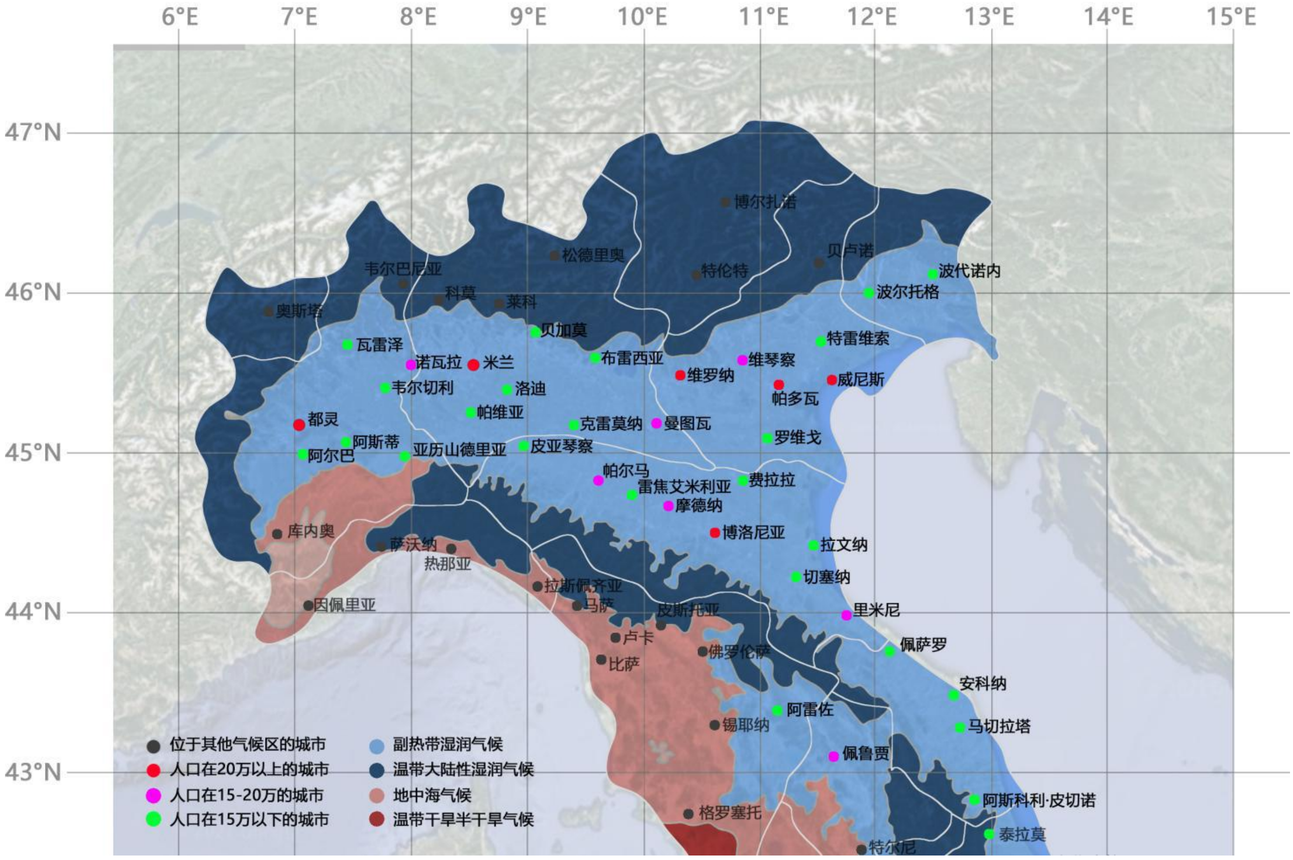


Fig. 31 Major towns in the Humid Temperate Climate zone of northern Italy and their urban population size.
Source: The author's drawing based on satellite and realative data

Among the towns with less than 150,000, Alba, Pavia, and Treviso were selected for specific comparative analysis. Selecting the 300m*300m range of the historical center of the three cities for analysis (Table 5), the author found that the building area of the three towns is about 50% to 60%, and the area of the block is 75% to 80%. There are similarities. Pavia and Treviso have higher building floors than Alba, with an average of 4 to 5 floors, so they have a higher density of built blocks and total urban density. In terms of the negative figure area ratio, Alba and Pavia have similar data, while Treviso's negative figure area is relatively low, only 16.82%. The reason is that in the urban negative shape space of Treviso, a large number of one-story buildings such as indoor parking lots and supermarkets cover the area of the courtyard, resulting in a relatively low area of the negative shape. If the area of this part is subtracted, its negative figure area ratio rises to about 28.15%.

In other respects, it can be found that the road grids of the three cities are inclined to a certain degree from north to south. The roads of Alba and Treviso are relatively curved, while Pavia maintains an orthogonal road system with Romanesque neighborhoods. In addition, both Alba and Pavia have relatively complete continuous courtyard-style urban texture features, which have a greater relationship with their unit-style architectural features. On the other hand, Treviso has a relatively compact architectural layout, and multiple buildings enclose the negative shape space of the block.

Table 5 Morphological analysis of cities and towns in northern Italy. Source: the author’s drawing

Cities and towns	Alba	Pavia	Treviso
Selected area	300m * 300m	300m * 300m	300m * 300m
Block types	Closed block	Compact block	Compact block
Architecture Construction Ratio （%)	51	54	62
Block Construction Ratio（%)	77	79	75
Floors	3-4	4-5	4-5
Built Block Density	2.33	2.73	2.94
Gross Density of City	1.79	2.17	2.43
Negative shape area ratio（%）	33.38	31.66	16.82

In the comparison of Alba, Pavia, and Treviso, it can be found that the main differences between the three towns are the density of built-up blocks and the type of urban texture. In the historic districts of Pavia and Treviso, there are many buildings with a relatively late construction period and a higher number of floors, and therefore have a higher density of built blocks. In terms of the urban fabric, Pavia's urban fabric maintains the Romanesque and orthogonal block morphology, while Alba and Treviso maintain the medieval complex and diverse block morphology.

Based on the comparative analysis of the three towns of Alba, Pavia, and Treviso, this paper selects the small town, Alba, as a typical case for detailed analysis and research by horizontally comparing the specific conditions of small and medium-sized towns in northern Italy with a population of less than 150,000 under subtropical humid climate conditions. In general, Alba has the following characteristics compared with other towns:

Firstly, compared with towns such as Piacenza and Pavia, Alba has a medieval urban texture. The towns formed in the Middle Ages have a certain Self-Organization. In the Middle Ages, merchants and artisans gathered to form independent communities and build houses to form towns. Compared with the towns planned and built by the town leaders with strong ruling power during the Roman period, the towns in the Middle Ages showed more characteristics of being integrated with the town's natural environment. In the Roman period, Alba Pompeia, a Roman colonial city, already existed in the location of the town of Alba. However, after the Roman ruling, the city was invaded and destroyed, and it was not until the Middle Ages that a new city was built on the original site. It can be seen from the comparison of the urban plan between the Roman period and the present (Fig. 32) that there are various characteristics of the relationship between the urban form and the topography, climate, and other factors that have been inherited from the medieval city. The influencing factors of the urban form in the Roman period were relatively single, mainly related to military deployment and religious beliefs.

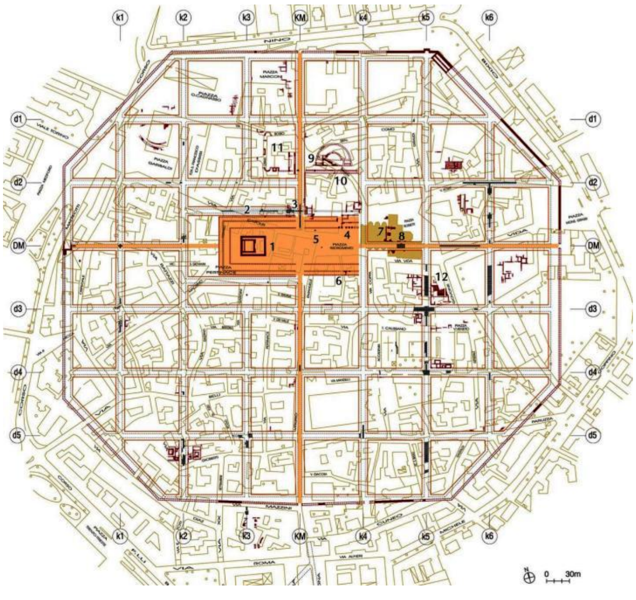


Fig. 32 Comparison of the urban plan between the Roman period Alba and the current Alba. Source: *"RACCONTARE LA CITTÀ DI ALBA"*

Fig. 33 The urban form of Alba in 17th century. Source: *"RACCONTARE LA CITTÀ DI ALBA"*

Secondly, The period when Alba's urban form changed greatly was between the 17th century and the 19th century. Since the end of the 19th century, the change of urban form has been relatively small. Therefore, the historical elements of the urban form of Alba are more. From the urban plan of Alba today, the aerial view of Alba drawn by Giovanni Borgonio in the 17th century(Fig. 33), the plan of Napoleon's reign in the early 19th century(Fig. 34), and the plan of the city plan of Alba in 1898(Fig. 35), it can be found that at the end of the 19th century, Alba had formed a stable urban form. Today's Alba historical city only has newly built buildings where the walls were demolished in the Middle Ages, and the original urban morphological features are still retained in the core area.

Fig. 34 Alba's plan during the Napoleon's reign (early 19th century. Source: "RACCONTARE LA CITTÀ DI ALBA"

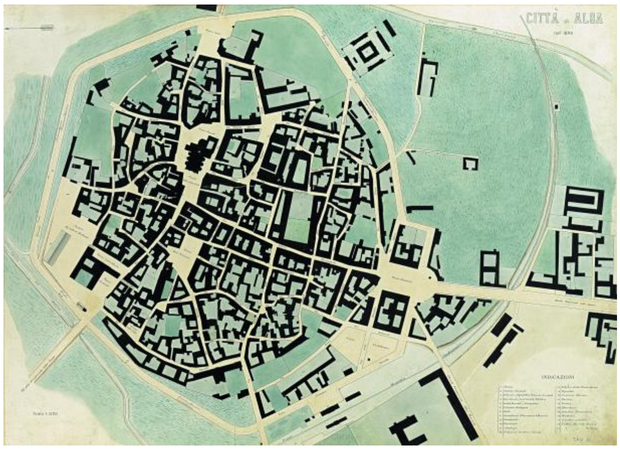


Fig. 35 Alba's urban planning plan in 1898. Source: "RACCONTARE LA CITTÀ DI ALBA"

Thirdly, the size and scale of Alba's historic district are smaller than that of other towns, which is conducive to the overall analysis and research on the urban form of its historic district. The historic district of Alba has an area of approximately 46 hectares, with approximately 50 blocks inside. Although the scale is small, the urban structure of Alba's historic district is complete. It has churches, city halls, and other common public buildings in Italian towns and continuous residential buildings with complete textures, with typical characteristics of traditional Italian towns.

Alba is a town in the province of Cuneo in Piedmont, Italy. Its geographic coordinates are 8° 01′ east longitude and 44° 41′ north latitude. Its climate belongs to the subtropical humid climate type of the Bataan Plain in Italy, with hot summers and cold winters. The average temperature in January is 1.6℃, the lowest temperature in January and December is less than 0℃, the average temperature in July is 23.2℃, and the highest temperature is 28.8℃. The annual average temperature is 12.8℃. In terms of rainfall, the average annual rainfall in Alba is 948mm, which is mainly distributed in April, May, June, and September, October, and other months- that is, the rainfall in spring and autumn is high, and the rainfall in summer and winter is low. (Table 6)

Table 6 Distribution of temperature and rainfall by month in Alba Source: The author's drawing

Month	January	February	March	April	May	June	July	August	September	October	November	December
Average high	5.2	8.0	13.6	18.0	22.8	26.6	28.8	27.4	23.6	18.2	11.8	6.4

temperature (℃)												
Daily average temperature (℃)	1.6	3.6	8.6	12.9	17.2	21.3	23.2	22.1	18.6	13.5	8.2	3.0
Average low temperature (℃)	-2.0	-0.8	3.6	7.8	11.6	16.0	17.6	16.8	13.6	8.9	4.6	-0.3
Average rainfall(mm)	53	51	86	113	124	87	43	51	76	107	93	64

Based on the analysis of the climatic data of Alba, the winter and summer enthalpy and humidity maps (Fig. 36, Fig. 37) of the Po River Plain region (Turin) show that the climate in Alba is more comfortable throughout the year, and the problem of cold winters is prominent. Natural ventilation and increasing the thermal mass effect in summer can effectively increase the comfort zone range, and direct evaporation cooling can also achieve some effect. In winter, increasing thermal mass effect and passive solar heating can effectively increase the comfort zone range, while evaporation cooling and natural ventilation have limited effects.

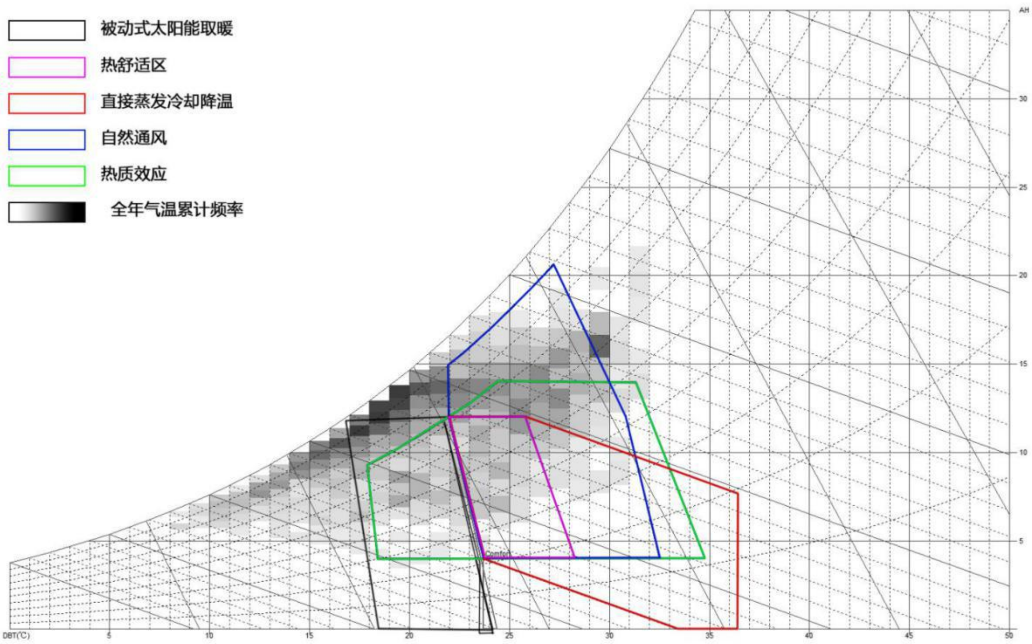


Fig. 36 Summer enthalpy and humidity map and building design strategy for the Po river plain region (Turin)

Source: weather tool output

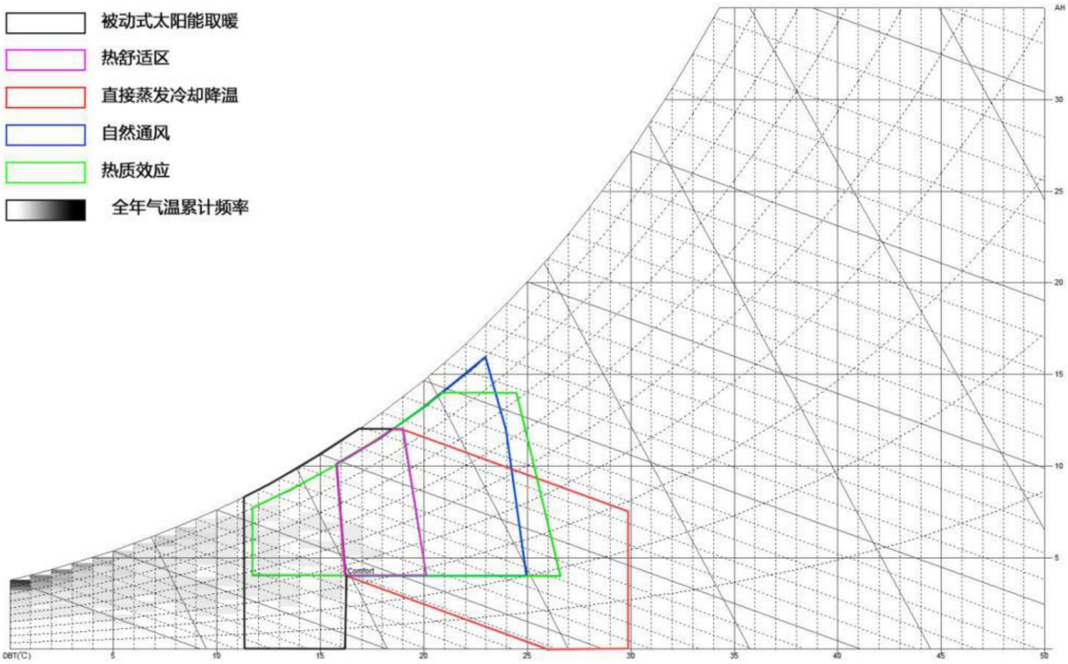


Fig. 37 Winter enthalpy and humidity map and building design strategy for the Po river plain region (Turin)
Source: weather tool output

2.4 **Chapter Conclusion**

This chapter serves as the theoretical basis for analyzing the thermal adaptative Model of Urban Morphology under temperate humid conditions. Firstly, it explains the ternary model of the urban environment with climate, city, and the human body as elements and explores the interactive relationship between external climate environment, urban morphology, and human thermal comfort, which provides the basis for the analysis and simulation of the research cases later on. Through the investigation of thermal comfort theory, the influencing factors of urban thermal environment and the evaluation index of thermal comfort are determined. By introducing climate and climate zones, the distribution of Humid Temperate Climate in the world is illustrated, and the division of Italian climate zones is elaborated. By investigating and comparing the types of thermal adaptation in Italian cities, the ratio of negative shape area of courtyard, the height-to-width ratio of negative shape space, and buildings' depth are used as an index to establish the relationship between cities and climate in different Italian regions. Finally, the author selects Alba, a small town located in the Humid Temperate Climate zone, a typical city from many towns in northern Italy, and analyzes the morphological characteristics and internal laws formed during the evolution of its thermal adaptability in the next chapter.

3. Thermal Adaptation Research of Urban Morphology in Alba, Italy

3.1 Thermal Adaptation of Block Morphology

3.1.1 Overview of the Characteristics of the Alba block

Fig. 38 Satellite view of Alba block morphology Source: the The author's drawing

The Alba block form (Fig. 38) is dominated by courtyard and perimeter enclosed blocks, where the external interface of the block is a continuous street interface. In contrast, the interior courtyard is mainly a living courtyard, accessible only to those who live and reside in the neighborhood. The internal courtyards are generally used only for parking and as entrances to buildings, without much greenery or public activity.

The morphological texture of Alba's present blocks has been gradually formed mainly from the original medieval neighborhood texture since the mid-19th century. From the 1840s onwards, under the mayor's administration, Giorgio Busca, who was also an architect, Alba's economy and society gradually became more prosperous, and the city's construction was on track. Alba's urban construction expanded to the south, and many important public buildings within the city, such as the Alba Cathedral and the City Hall, were renovated under Busca's direction. There was also a significant increase in private residential building construction in the city; third- or fourth-floor buildings gradually replaced the original medieval building. Throughout the 19th century, Alba gradually developed a relatively complete urban texture, thus laying the foundations of the present urban texture.

Fig. 39 The closed block in Alba. Source: Photo by the author

Fig. 40 The closed block in Alba. Source: Photo by the author

According to the comparison of Alba's city cadastral maps since the 19th century, it can see the changes in Alba's urban texture from 1848 to 1898 and then to today (Fig. 41). The changes in the city's block morphology have the following two characteristics. First of all, with the increase of new buildings, the texture characteristics of the closed urban blocks are more prominent, and the size and distribution of the inner courtyards of the blocks have become more regular. Secondly, in the city's central area, when the building's coverage and density reach a certain level, a relatively stable block shape is formed and no longer changes over time.

Fig. 41 Map of urban texture changes in Alba since 1848 Source: The The author's drawing

3.1.2 Analysis of Block Density and Block Shape

The density of built-up blocks was calculated for each plot within the historic district of Alba and differentiated by shades of color (Fig. 42). The analysis shows that the density distribution of built-up blocks in Alba has several characteristics.

First, the plots with high-density blocks are mainly located in the center of the city around the plaza of Alba's church. Via Vittorio Emanuele and Via Camillo (two streets in this plaza) constitute a T-shape street, which together with the public square form the city's infrastructure. These are also the oldest plots of land in Alba, with many public buildings such as the Chiesa Della Maddalena, the Museo di Alba, and the Alba City Hall.

Secondly, the density of built-up blocks tends to decrease from the center to the city periphery, which corresponds to the city blocks' historical order. The density of the built-up blocks in the central part of the city can range from 2.4 to 2.7, with the largest residential neighborhood reaching 2.71 and the adjacent neighborhoods reaching 1.5. In the periphery of Alba's central city, where there are larger green areas, urban parks, and parking lots, the density of the built-up blocks is lower, at about 0.5. As a result, the density of the neighborhoods in Alba tends to increase as time goes on, replacing the existing buildings with higher buildings and forming a stable neighborhood morphology, with a density of about 2.7.

Third, in terms of block morphological characteristics, the courtyards within the higher density plots are divided into several courtyards of similar size, surrounded by 3 to 4-story buildings. In contrast, in the interior of some block courtyards, buildings such as one-story residential service buildings and parking lots are built, which increase the density of the completed blocks to a certain extent.

Fig. 42 Density analysis of built-up blocks in the Alba district Source: The The author's drawing

Based on the analysis of the density of the built-up blocks of each plot, the block shape coefficients were obtained by calculating the surface area and shape of the buildings in the blocks, distinguished by different shades of color (Fig. 43). It shows that the shape coefficients of the Alba blocks have several characteristics.

First, except for the main church of Alba, which occupies a single plot, and the plots with small buildings and scattered distribution, the distribution of the shape coefficients of the other plots is more even, mainly ranging from 0.35 to 0.43. It indicates that although the degree of development of each plot is different, the shape coefficients of the plots remain at similar levels. For one thing, the shape coefficients are related to the characteristics of Alba's courtyard urban texture. For another, it shows that the urban form has formed a stable relationship with the external environment in terms of energy and material exchange over a long period, which indicates the solid thermal adaptability of the urban form.

Secondly, the buildings that make up the urban texture of Alba have a high degree of similarity, with residential buildings of 10 to 12 meters in depth and 3 to 4 stories in height lining up around the blocks as the main body, forming a block morphology characterized by similar shape factors. Except for the main church, all the public buildings in Alba are combined with residential buildings and the enclosed neighborhoods. This pattern of public building placement plays a vital role in maintaining the continuity of urban form and increasing the permeability of urban blocks.

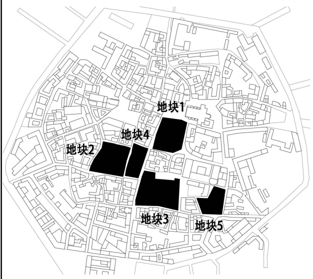
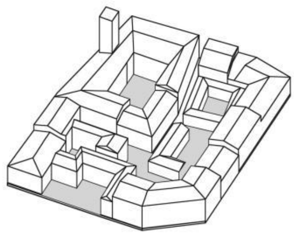
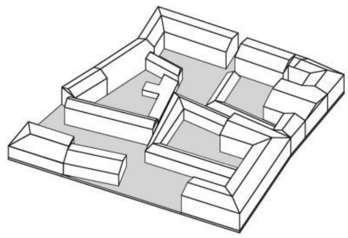
Thirdly, the living service houses on the first floor inside the block combined with residential construction increase the building area on the first floor, which increases the density of the built-up block while reducing the block's shape coefficient to a certain extent.

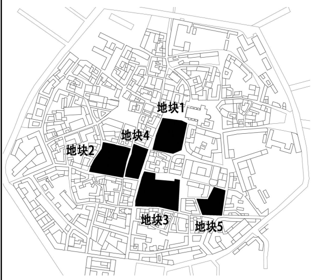
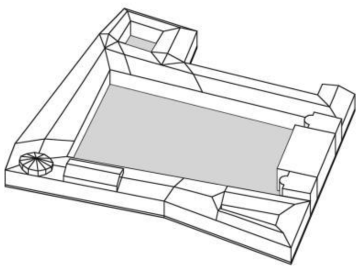
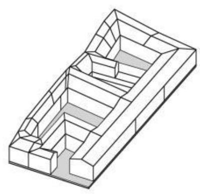
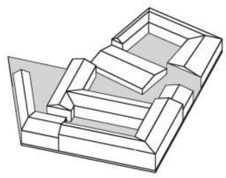
Fig. 43 Analysis of block shape coefficients across Alba Source: The The author's drawing

Typical plots are taken from the city limits for analysis(Table 7). Plot 1, 2, 4, and 5 are mainly residential buildings, while plot 3 is mainly public buildings. Plots 1 and 4 are located on both sides of the main street of Alba, with 3 to 4 stories of buildings. The building coverage can reach about 70%, and the density of built-up blocks is relatively high, 2.42 and 2.10. Moreover, the block shape coefficients are 0.31 and 0.36. For another, plots 2 and 5 are located in the more peripheral blocks. The number of buildings on the periphery is relatively high, while the number of buildings inside the courtyard is relatively low. The building coverage rate in these two plots is respectively 59% and 65%. The block shape coefficients are respectively 0.41 and 0.43, higher than those of plots 1 and 4. Moreover, plot 3 has a building coverage of 57%, and with a lower building coverage and building density, its shape coefficient is 0.37, and the overall building form is more compact (Table 7).

As for the courtyard space of the plots, Plot 3 (public building) has the largest and most complete courtyard space, with a long side of about 75 meters and a short side of about 42 meters. Except for Plot 3, the courtyards of other plots are mainly divided into different parts by enclosed buildings. The courtyards of Plots 2 and 5 are divided into different parts by buildings with lower floors and irregular shapes. In contrast, the courtyards of Plots 1 and 4 are roughly rectangular, with a long side size of about 20 meters and a short side size of 10 to 15 meters. (Table 7)

Table 7 Analysis of density and shape coefficients across Alba Source: The The author's drawing

Plot location	Plot 1	Plot 2
		
Block area (㎡)	6369	6828
Number of building floors	3-4	1-3
Building coverage (%)	70	59
The density of built-up blocks	2.42	1.45
Block shape coefficients	0.31	0.41

Plot location	Plot 3	Plot 4	Plot 5
			
Block area (㎡)	8865	3359	3751
Number of building floors	3	3-4	1-3
Building coverage (%)	57	73	65
Density of built-up blocks	1.27	2.10	1.21
Block shape coefficients	0.37	0.36	0.43

Plot 1,2, and 4 are mainly for the resident. The author analyzes the solar radiation in winter and summer(Fig. 44) and the sunshine hours on summer and winter solstices(Fig. 45) to investigate the relationship between the built-up block density, building coverage and shape coefficient, and the block solar radiation heat gain. Since the density index of each plot is different, the solar radiation absorbed per unit building area Q (Wh/㎡) and sunshine hours are used as the main evaluation index.

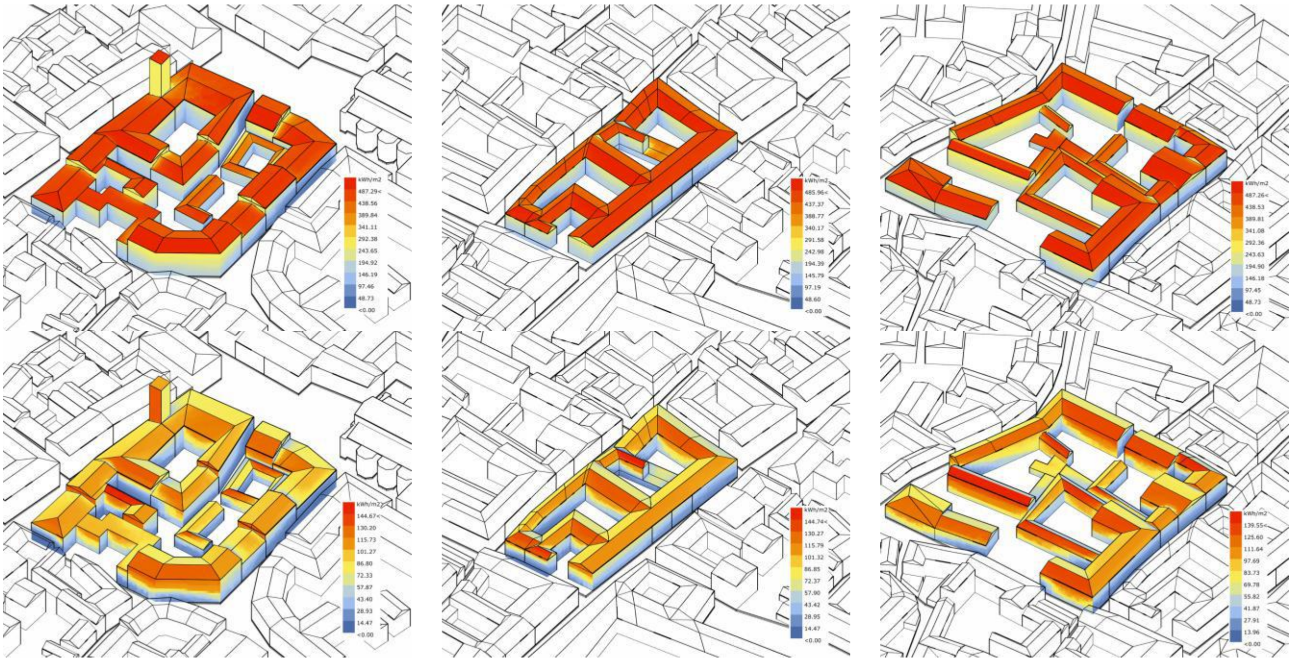


Fig. 44 Analysis of solar radiation in summer and winter for buildings on Plots 1, 4 and 2 of Alba Source: The author’s drawing

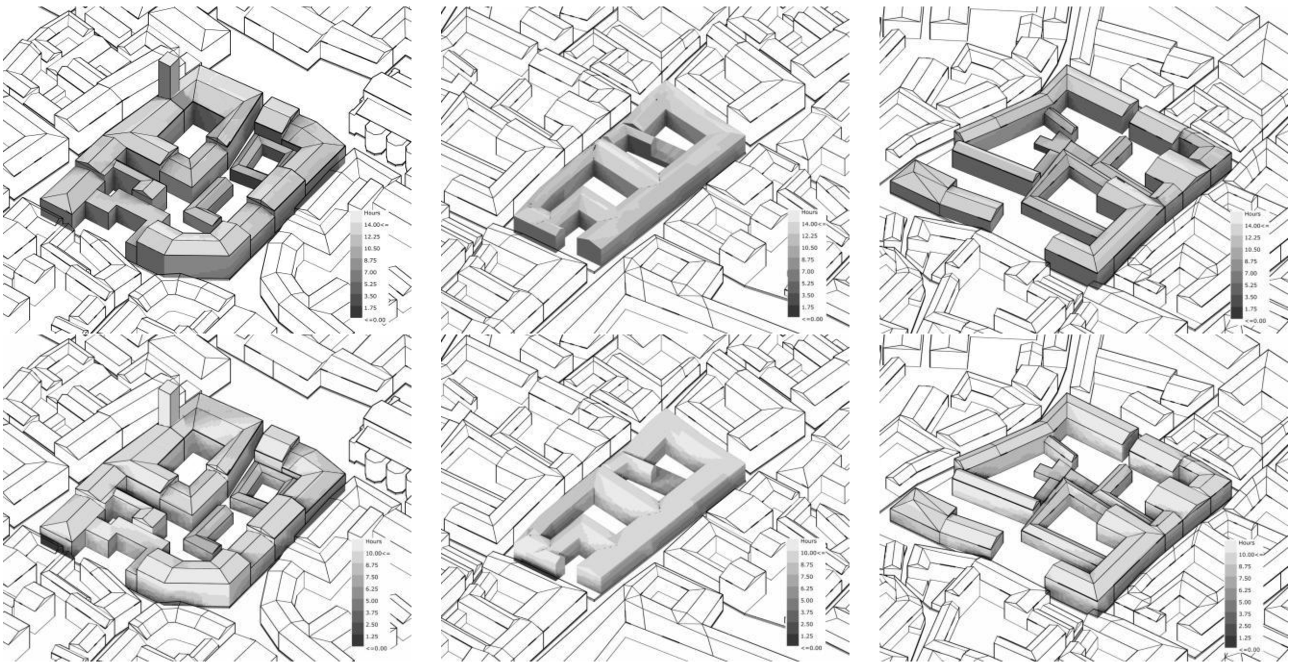


Fig. 45 Simulation of summer and winter sunshine hours for buildings on Plots 1, 4, and 2 of Alba Source: The The author's drawing

Table 8 Simulated data of solar radiation and sunshine hours in various regions

Plot Number	1	4	2
Building coverage (%)	70	73	59
Density of built-up blocks	2.42	2.10	1.45
Block shape coefficients	0.31	0.36	0.41
Solar radiation per unit area in summer (Wh/㎡)	192.45	227.28	262.25
Solar radiation per unit area in winter (Wh/㎡)	42.90	49.08	60.55
Sunshine hours per unit area on the summer solstice (h/㎡)	5.71	6.79	8.18
Sunshine hours per unit area on the winter solstice (h/㎡)	3.98	4.99	5.75

From the above simulation results(Table 8), in summer, plot1 and plot4 have lower solar radiation per unit building area and lower sunshine hours per unit building area on the summer solstice. Moreover, they have higher building coverage and built-up block density, and lower block shape coefficient than Plot2. Therefore, in summer, appropriately increasing the block density can increase the shading between buildings and reduce solar radiation absorption. Furthermore, in winter, compared with Plot 2, Plot 1 and Plot 4 have lower solar radiation and sunshine hours per unit building area, which will impact the utilization of sunlight and indoor lighting in winter.

3.1.3 Analysis of the Ratio of Passive Space

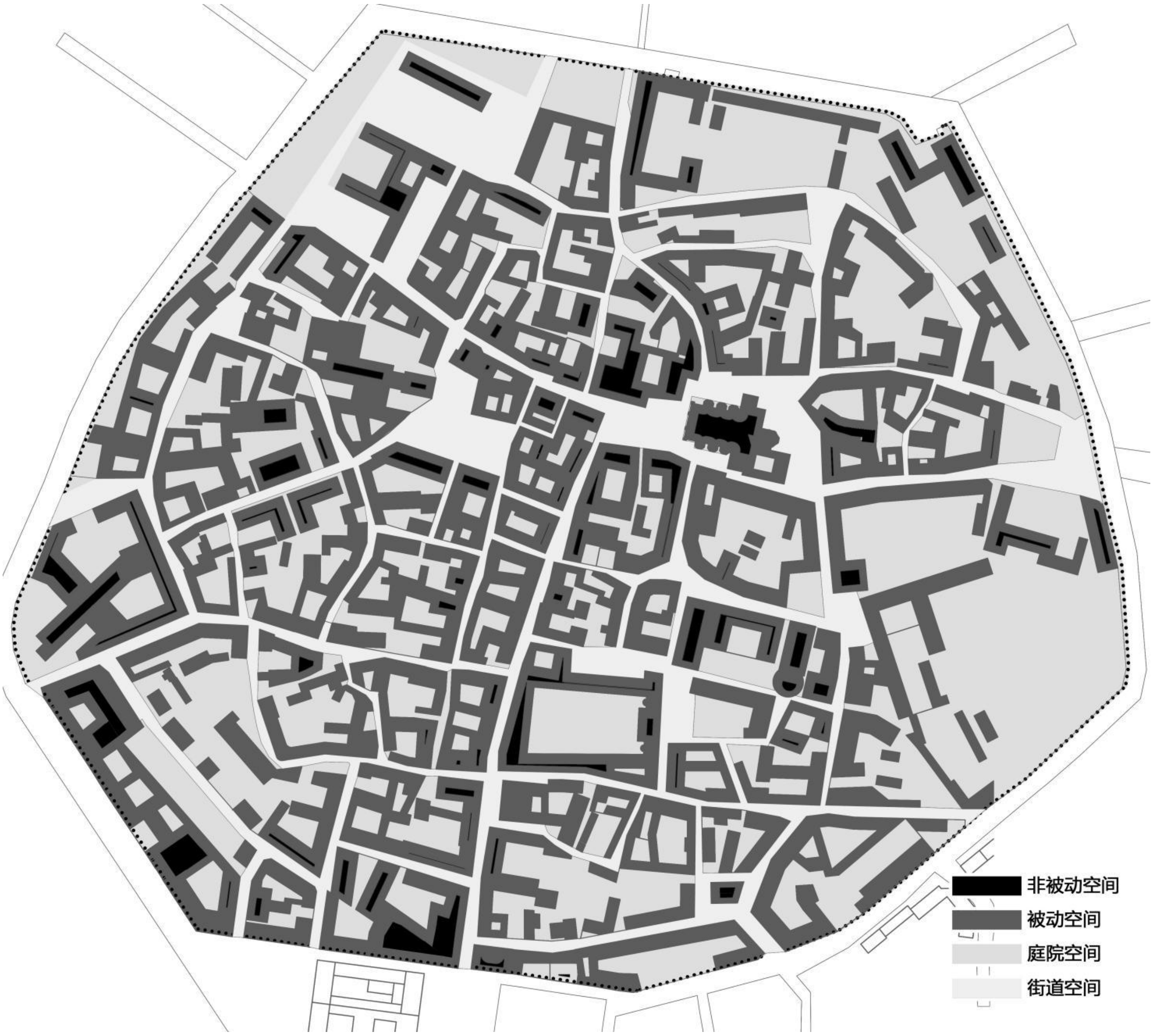


Fig. 46 Passive space analysis of Alba's urban form Source: The The author's drawing

From the definition, the ratio of passive space refers to the ratio of floor area within 6 meters from the building's external envelope to the building's total area. For the analysis of urban space in Alba, on the first-floor plan of Alba, the area more than 6 meters away from the external envelope is non-passive space, which is less efficient in exchanging energy with the external environment and is represented in black. The area within 6 meters away from the external envelope is passive space represented in gray.

From the analysis of Fig. 46, it can be concluded that the non-passive space in Alba is relatively tiny, and most of the building space is passive space. Four main aspects characterize the distribution of non-passive spaces. Firstly, the ratio of passive space is relatively small in important public buildings such as churches, theaters, city halls, and museums. These buildings may have relatively open indoor spaces with higher story height, where people can hold activities. Second, in some new buildings and factory buildings, where the passive space is tiny, modern mechanical ventilation and lighting increase the indoor thermal comfort of the building, but the energy consumption also increases exponentially. Thirdly, in the interior of each block plot, indoor parking, utility rooms, and other service rooms connected to the residences are built on the first floor. These spaces have less passive space and do not cause much impact because residents do not usually occupy them. Fourthly, most of the residential buildings along the main street of Alba have 100% passive space, but there is also a tiny percentage of non-passive space.

Excluding the public buildings and the new modern buildings in Alba, the percentage of passive space in the urban texture of Alba ranges from 95% to 100%, which indicates that almost all of the residential spaces can be improved by natural ventilation and lighting to improve the indoor thermal and light environment. It is because of the generally shallow building depths and the evenly distributed courtyards within the blocks in Alba. The appropriate proportion of courtyards and buildings allows the buildings to be naturally ventilated to improve indoor comfort during the hotter summer months and in the spring and autumn when temperatures are favorable and ensure sufficient natural light to enter and improve the indoor light environment in winter.

3.1.4 Summary

From the above analysis, it can be seen that the building coverage in the central area of Alba can reach about 70%, the density of the built-up blocks can reach 2.6 to 2.8, and the block shape coefficient is between 0.31 and 0.35. Alba's urban texture of 3 to 4-story buildings increases the building density while effectively reducing the block shape coefficient, reducing heat loss in the city during colder winter conditions. At the same time, the relatively high density of the block can reduce the absorption of solar radiation in summer through the shading effect between buildings, which can reduce the temperature and improve indoor comfort. Although the block form impacts the amount of solar radiation and sunshine hours in winter, in blocks where fireplace heating is the primary heat gain method, the loss of these external heat gains is negligible.

Although Alba's blocks have a high building coverage and density of built-up blocks in passive space share, the passive space ratio can reach more than 95%. In general, increasing the amount of non-passive space in the city leads to a lower block shape factor, further reducing the heat loss in the block in winter. However, in the hotter summer months and the warmer spring and fall months, a higher percentage of passive space helps the city be naturally ventilated and lit, thus increasing indoor comfort.

The density, shape factor, and passive space ratio of Alba blocks have a complex relationship with the external environment. In general, the block form has a more decisive influence on the thermal environment than the wind environment. The block characteristics are mainly regulated by insulation in winter, shading, cooling in summer, and natural ventilation and lighting.

3.2 **Thermal Adaptation of Street Morphology**

3.2.1 Overview of the Characteristics of Alba Street Space

Alba has a very typical medieval street texture. The Baroque urban renewal did not affect the layout and appearance of the city but only intervene in some of the buildings, such as the municipal hospital built in the area of the old castle and the churches of Dalla Maddalena and San Giuseppe. In the drawings of the city's municipal administration signed by the architect Giacomo Isnardi in 1752 (Fig. 47), the main built-up area of the city at that time was limited to the main north-south streets of the city and the area around the Alba Cathedral, with large areas of unbuilt-up land and rural housing in the rest of the city. However, it is already possible to see a fabric characterized by an exemplary network of urban streets, irregular streets extending from the gated entrances around the city into the city's interior, dividing the different plots of land. At the beginning of the 19th century, Alba was still surrounded by abandoned walls. The entire city pattern was not very different from the medieval period. However, with the demolition of the walls and other urban fortifications, the city regularized the medieval winding streets, widening the original streets and installing new city squares in the place of the original gates, expanding the city area.

The street texture of Alba (Fig. 48) is now basically a continuation of the medieval and 19th-century street texture, with the outer ring road of the city formed at the location of the original city walls. In contrast, in the inner part of the city, the narrow roads were widened, and the original block space was re-cut to become a public square, making the whole street space more permeable. Street space is an essential urban public space in Alba, especially in the city's main streets and some small squares, where cafe operators place tables and chairs outside, forming a place for people to interact and move around with each other high spatial vitality. In addition, the squares in the city are also places for important events and gatherings and have a large flow of people.

Fig. 47 Street texture of Alba in 1752. Source: "RACCONTARE LA CITTÀ DI ALBA"

Fig. 48 Street texture of the current Alba. Source: The author's drawing

Fig. 49 Shop and street scenes along the main street of Alba. Source: The author's drawing

Fig. 50 Small squares all over the streets of Alba. Source: Photo by the author

3.2.2 Analysis of Street Morphology and Environmental Physical Properties

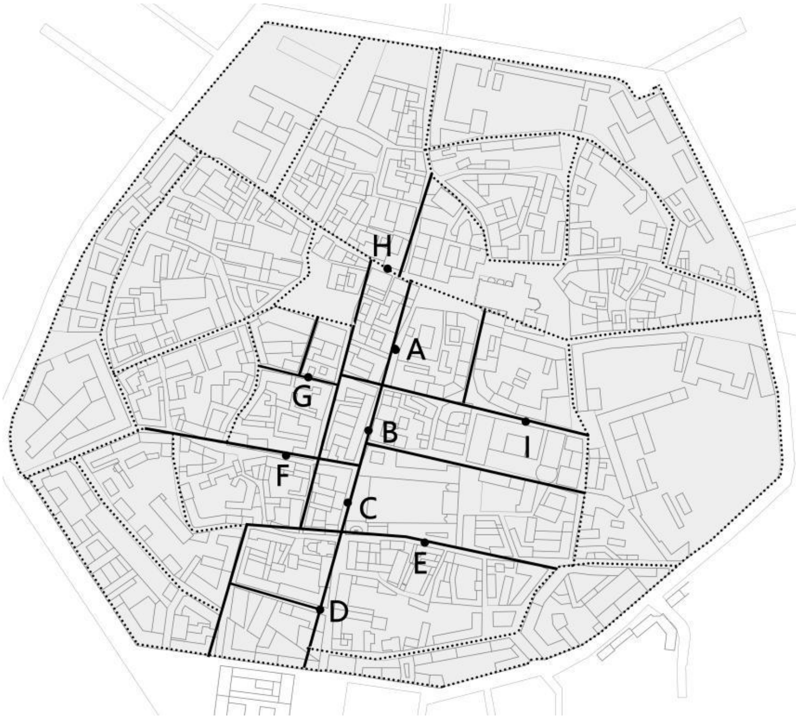


Fig. 51 Alba's street system and street height to width ratio measurement selection points

Street selection points	Street height to width ratio
A	1.55
B	1.48
C	1.25
D	1.38
E	1.58
F	1.80
G	1.89
H	1.67
I	1.65

The twisting streets of Alba are distributed throughout the city in a seemingly irregular manner, but in essence, consist of two interconnected systems. The first one is an orthogonal street network consisting of the main street leading from the city's south square to the city center and the cathedral and its perpendicular east-west streets. The second is a radial road system extending from the east-west streets to the original gates around the city and the circular streets along the city walls.

In the orthogonal street system, the angle between the main north-south street and the south direction is about 15 degrees, and the angle between the east-west street and the east direction is between 15 and 20 degrees (Fig. 51). In the orthogonal street system, nine points from A to I were selected to analyze the height to width ratio of the streets, and it can be found that the height to width ratio of the north-south main streets is lower at 1.3 and 1.6. In contrast, the height to width ratio of the east-west streets ranges from 1.6 to 1.8. Since the building heights are similar in Alba, the east-west streets are narrower than the north-south streets.

Fig. 52 Space insolation analysis of a typical street area on the summer solstice in the street canyon 图例

Source: The author’s drawing

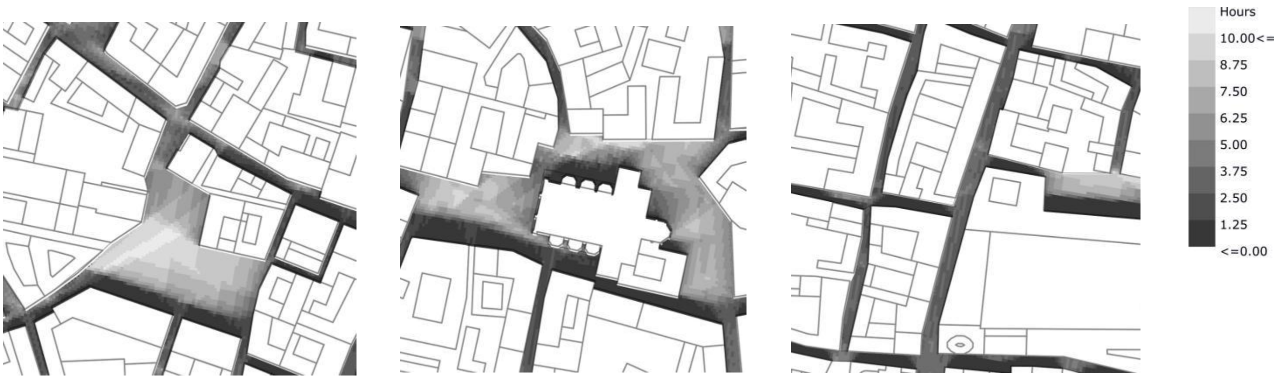


Fig. 53 Space insolation analysis of a typical street area on the winter solstice in the street canyon 图例

Source: The author’s drawing

The shadow analysis of the streets shows a small shadow area on the east side of the north-south streets, with the shadow area occupying about one-third of the street area on the summer solstice. In contrast, the south side of the east-west streets has a larger shadow area, occupying about two-thirds of the street area. On the winter solstice, there are no large sunless areas on the north-south streets, and most of the streets have between 3 and 5 hours of sunlight, while the east-west streets have fewer hours of sunlight on the south side, but some areas still get sunlight in winter. In addition, the square along the east-west direction has longer sunshine hours in winter, and the ground of the square can receive sufficient solar radiation to improve the comfort of outdoor activities (Fig. 52, Fig. 53).

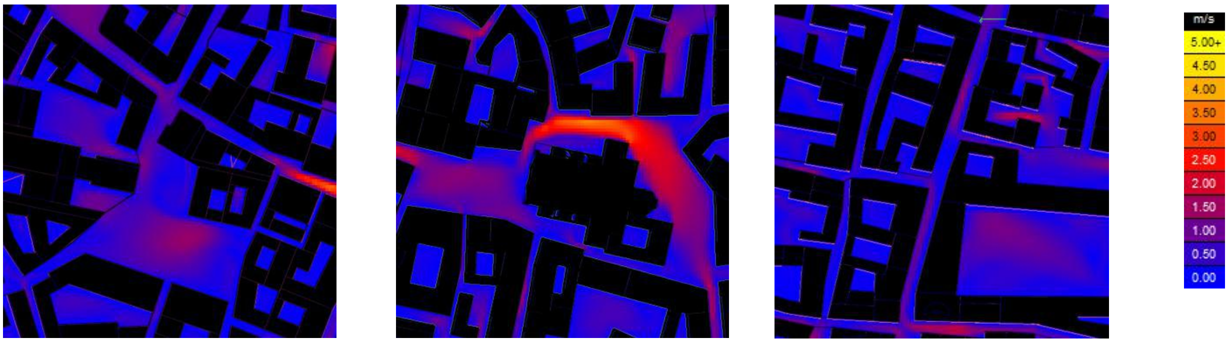


Fig. 54 Analysis of the dominant winter wind speed in a typical street area Source: The author's drawing Illustrations

The wind environment of the street space in Alba was simulated with the expanded area of the selected street area as the simulation area. The dominant wind direction of southeast wind and wind speed of 4m/s in winter in Alba as the input conditions. From the simulation analysis, it can be seen that in the wind speed distribution at 1.5m pedestrian height, there is no excessive wind speed in the street space except for the wind turbulence effect formed by the taller Alba Cathedral. The wind speed of the main streets in the north-south and east-west directions of the city is high and can reach up to about 2m/s, while the wind speed of the other east-west streets is low and almost in a windless state in winter. In addition, due to the large area of the city square, the surrounding taller buildings may play a role in blocking the wind flow, which then leads to a larger wind field in the downwind direction of the square near the dominant wind, and the average wind speed can reach about 2m/s (Fig. 54).

3.2.3 Summary

Alba's leading street network has an angle of about 10 to 15 degrees to the north-south direction and an angle of about 30 to 35 degrees to the dominant wind direction in winter, with a street height to width ratio between 1.3 and 1.8. In summer, the street can form a continuous shadow on one side to provide shade for pedestrians and increase walking comfort. In contrast, in east-west streets with fewer pedestrians and a higher height to width ratio, buildings can shade each other to reduce the amount of solar radiation absorbed in summer. In winter, the shadow area on the street is smaller, and there will not be an area without sunlight all day long, while a certain amount of solar radiation can be guaranteed to be received. In addition, the twisting road network around the city helps to reduce the wind speed in winter and brings a rich variation to the physical environment of the city streets.

In terms of wind environment, the high height to width ratio of the streets makes it less likely for winter winds to penetrate to the bottom of the streets. At the same time, the angle formed with the direction of the dominant winter wind also helps to shield the streets from cold air currents and reduce the heat loss to buildings from convection. In summer, the wind speed in the city is also maintained at a low level. However, due to the relatively low humidity of the air in Alba in summer, the convection and evaporation effects of summer winds bring a slight cooling effect to the city and have less impact on the thermal environment.

3.3 Thermal Adaptation of Negative Shape Morphology

3.3.1 Overview of Alba Negative Shape Space

The negative space in Alba is mainly composed of inner courtyard space and the porch space in enclosed blocks. The morphology of the negative space in Alba is complex. There are two primary forms: "convex" and "concave" (Fig. 55). The "convex" shaped negative space is composed of the courtyard space and the ground-floor arcade. In contrast, the "concave" shaped negative space is enclosed by the main building and the additional buildings inside the courtyard. The "convex" shaped negative space increases the permeability of the space by forming gray space inside the solid space. In contrast, the "concave" shaped negative space divides the existing courtyard space inside the courtyard to increase the contact area between the building and the external environment. The two seem to be different methods of operation, but in essence, they have the same approach.

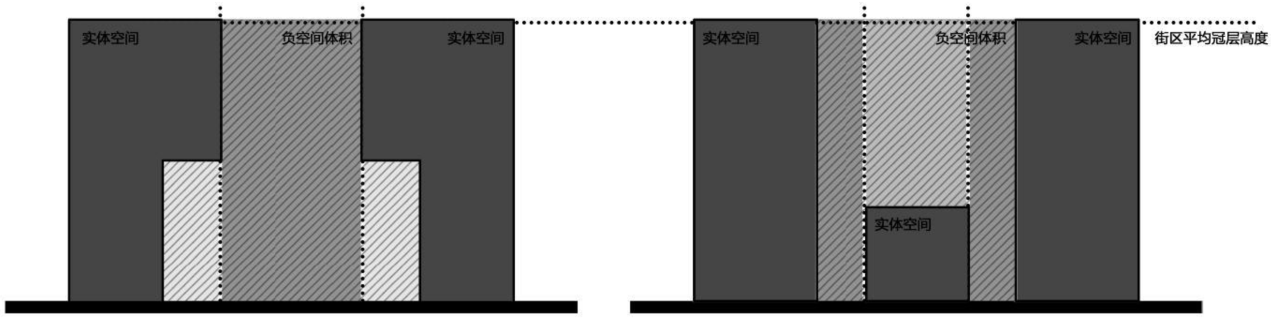


Fig. 55 llustration of the basic types of negative space in Alba Source: The author’s drawing

Using the height of negative shape space in Alba as a grayscale indicator, we can map the distribution of negative space in Alba (Fig. 56). From the analysis of the figure, we can see that the negative space form in Alba has the following main characteristics.

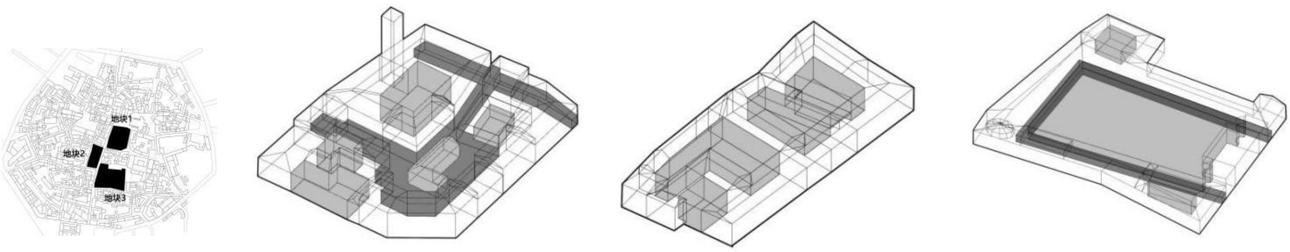
First, the negative space form in Alba blocks is mainly divided by internal buildings, forming several different internal courtyards and varying in height. Some of the negative spaces in the blocks are entirely divided into different courtyard spaces by buildings of the same height. In contrast, others are divided by shorter buildings with their top spaces still connected, becoming "concave" negative spaces. Secondly, the negative space form in the city of Alba is fractal in two hierarchical scales. One is the large courtyard with green space or square space enclosed by public buildings, and the other is the small courtyard in private houses. There are few large courtyards, the representative ones being the Cortile Della Maddalena in the center of the city and the interior courtyards of the Alba parish. At the same time, there are a large number of small courtyards, which are scattered in various blocks of the city. Finally, there is a big difference in the use of the negative space function. The courtyards in private houses are generally used as access spaces and parking spaces for houses and do not have public properties. In contrast, large courtyards have large hard floor and greenery areas and are generally used for large-scale public events in the city.

Fig. 56 Negative space morphology expressed in grayscale in Alba Source: The author's drawing

Fig. 57 The arcade space in Alba. Source: Photo by the author

Fig. 58 The courtyard interior in Alba's public space. Source: www.google.com

3.3.2 Negative Shape Morphology and Environmental Physical Properties Analysis



	Plot 1	Plot 2	Plot 3
Negative space ratio /%	30	27	43
Buildings floor	3-4	3	2

Fig. 59 Negative space shape in Alba's typical blocks and relative data. Source: The author's drawing

Three typical plots 1, 2, and 3 in Alba were selected to analyze the Negative space morphology (Fig. 59). The negative shape space presents very complex morphological characteristics in the plots, with three different states of the full enclosure, semi-enclosure, and independence between the buildings, resulting in the division and encroachment of the Negative shape morphology. It is worth mentioning that the inner courtyard of Plot 3 has a continuous circle of arcade space around the first floor, which is connected to the courtyard.

Using the typical plots as a reference and counting the other plots, we can learn the leading indicators of negative shape space in the city of Alba: the area ratio of negative shape space in the plots ranges from 25% to 35% for private residences represented by Plot 1 and Plot 2. In comparison, the area ratio of negative shape space in public buildings represented by Plot 3 is around 45%. The number of floors in private residences is generally 4. The size of the height to width ratio of negative space is around 1.3, and the height to width ratio in some of the more compact blocks can reach around 2, while the number of floors in Plot 3 is less than other blocks and the height is higher than other blocks, with a height to width ratio of around 0.19.

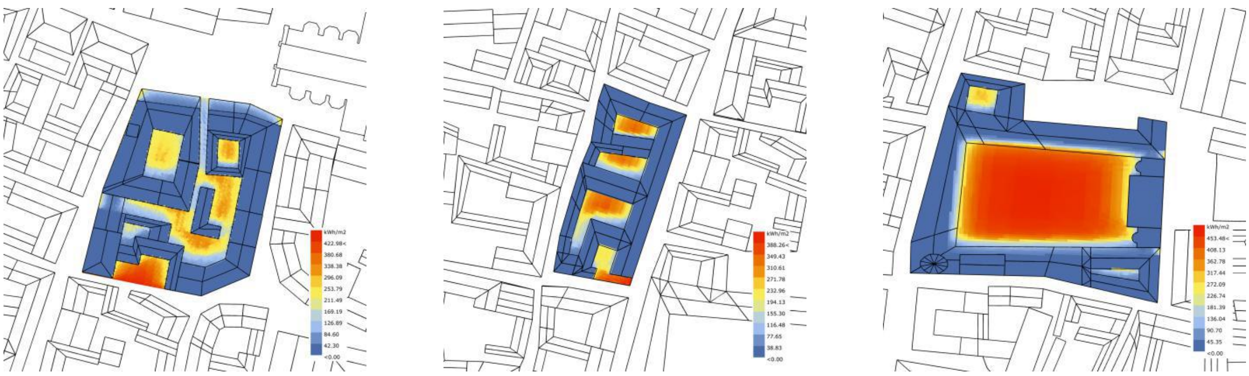


Fig. 60 Analysis of summer solar radiation in typical Plots 1, 2, and 3 (from left to right) Source: The author's drawing

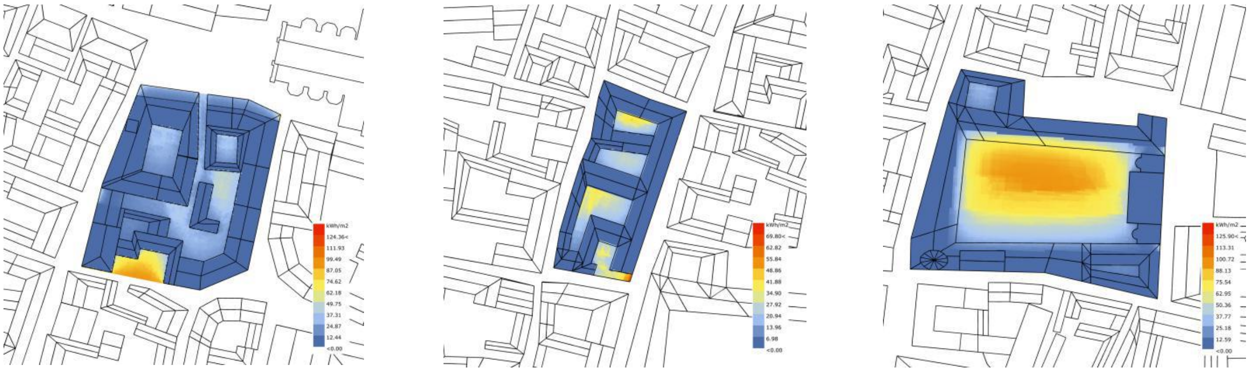


Fig. 61 Analysis of winter solar radiation in typical Plots 1, 2, and 3 (from left to right). Source: The author’s drawing

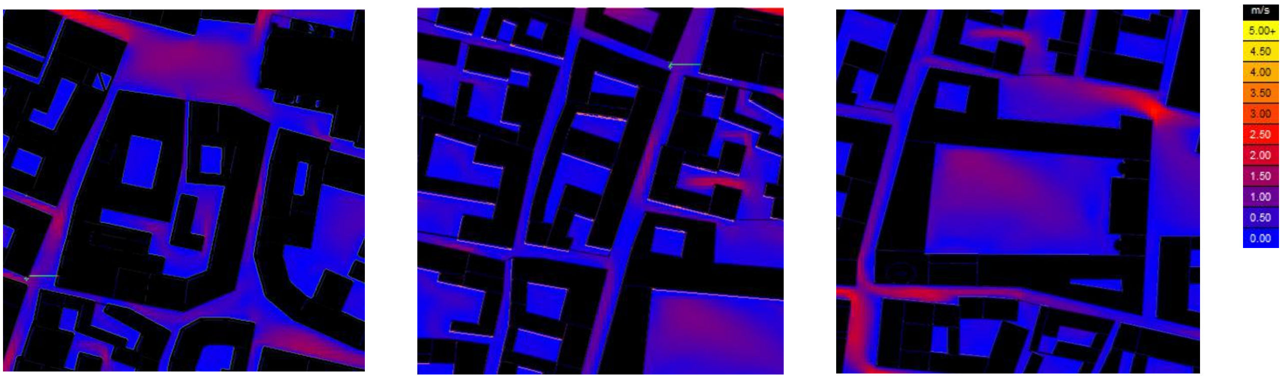


Fig. 62 Analysis of the dominant winter wind speed for typical Plots 1, 2, and 3 (from left to right) Source: The author’s drawing

The solar radiation analysis of the three plots in summer and winter (Fig. 60, Fig. 61) shows that: in summer, the courtyard space of Plot 3 receives the most solar radiation, and most of the ground inside the courtyard receives more than 400kWh/㎡, but the solar radiation of the arcade around the courtyard drops to less than 200kWh/㎡, which can effectively shade the summer solar light. In contrast, Plot 1 receives less solar radiation in summer because of the high number of floors and the buildings blocking each other's sunlight. In winter, the open courtyard of Plot 3 is conducive to receiving solar radiation, and the northern part of the courtyard receives more than 100kWh/㎡ of solar radiation. The rest of the courtyard space and arcade space can also receive a certain amount of solar radiation. The courtyards of Plot 1 and Plot 2 receive less solar radiation than other plots.

Analysis of the dominant winter wind direction for the three plots (Fig. 62) shows that the courtyard space of Plot 2 is basically in a wind-free environment. Plot 1 has some wind turbulence influence inside the irregularly enclosed courtyard, and the low buildings inside affect the wind flow direction. Plot 3 has a high wind speed in the downwind area of the courtyard, reaching about 2m/s. This form of wind turbulence harms winter protection against cold. In addition, in summer, the higher ratio of the courtyard’s height to width inside the Alba block and the higher ratio of the window area to the wall area are conducive to the formation of thermal pressure ventilation, which takes away the excess heat from the interior, thus achieving a cooling effect.

3.3.3 Summary

The types of negative space in Alba cities can be divided into two main types. One is the ample courtyard space enclosed by public buildings used to hold regular public events in the city and often has tall arcades around the courtyard for people to walk and rest. The area of the courtyard is relatively large, and the height and width ratio is relatively small. The other type of courtyard is an internal courtyard space enclosed by private residences used for ventilation and light and access and living space. The area of the courtyard is small, and the height to width ratio is high.

In terms of environmental physical performance, the spacious courtyard space is conducive to maximizing utilization of winter sunlight and creating a comfortable outdoor space inside the courtyard, which is conducive to the holding of public events. At the same time, attention should be paid to the penetration of cold winds in winter, and the lower courtyard height to width ratio tends to create faster wind speed inside the courtyard, reducing human comfort. In summer, taller arcade spaces can shade the sun's rays and create gray spaces conducive to walking and sitting. For residential interior courtyards, a small courtyard area ratio and a higher height ratio to width are not conducive to solar gain in winter. However, they have less impact because they are not the primary place for people to move around.

3.4 **Chapter Conclusion**

This chapter summarizes and analyzes the thermal adaptability from three levels- Alba’s block form, the streets from, and the Negative Form. In general, the urban form of Alba takes winter daylighting and heat preservation as the primary control target, which contains three aspects. The first one is that a low block shape factor is conducive to the warmth of the block buildings in winter. The second is that the streets with relatively high height and width and a certain angle with the dominant wind are conducive to preventing the penetration of the winter wind. The third is that the spacious courtyard space can absorb much solar radiation in winter. Although it focuses on the conditioning of the cold winter environment, the shape of Alba also takes into account the conditioning of the hot summer weather. Appropriate street aspect ratio and azimuth angle can provide shading to the street in summer. The passive space ratio close to 100% is conducive to natural ventilation and lighting in summer. Consequently, the urban form of Alba has the characteristics of Environmental Conditioning in both winter and summer.

This chapter provides a realistic case basis for the following construction of a Thermal Adaptive Model of Urban Morphology under Humid Temperate Climate through a detailed analysis of the thermal adaptability of the urban form of Alba. It provides a preliminary analysis of the mechanism of various urban form factors and the urban environment and judgment.

4. An Thermal Adaptive Model of Urban Morphology in Humid Temperate Climate

4.1 Analysis of the Relationship between Climate, Form and Environmental Factors

In Alba, Italy, to cope with the external climatic environment in different seasons under Humid Temperate Climate, different sub-factors of urban morphology act synergistically and interact with each other to form the thermal and wind environments in the city. Any one of the climate, morphological, and environmental factors changes. The other variables will be affected and eventually affect the thermal comfort of the residents. As shown in the bioclimatic function diagram (Fig. 63), the comfort zone of the human body is strongly correlated with each of the elements of the external climatic environment, such as temperature, humidity, wind speed, solar radiation, and shadows. For example, if the external temperature is in the region above the comfort temperature, increasing the wind speed, decreasing the solar radiation, and decreasing the relative humidity can restore the comfort zone. While if the external temperature is in the region below the comfort temperature, increasing the solar radiation can effectively increase the human comfort level. The thermal adaptive urban morphology model in Humid Temperate Climate studies the interaction between external climate and urban morphological factors and between urban morphological and environmental physical performance factors in this climate zone and reveals the model's mechanism in this climate zone.

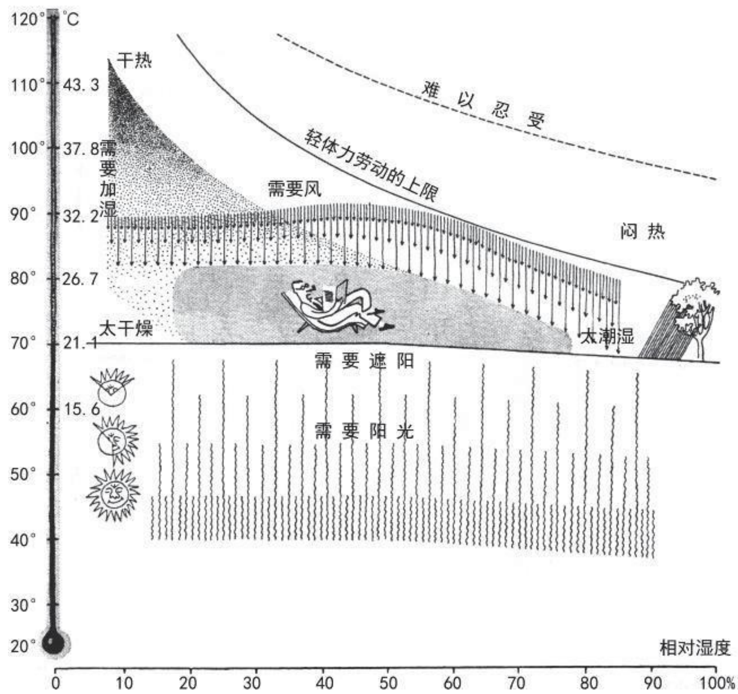


Fig. 63 Bioclimatic function diagram Source: Olgyay V.《Design with Climate》

The city's physical environment contains the thermal environment, wind environment, light environment, sound environment, the air quality of the urban and the wind environment, light environment, thermal environment of urban buildings, etc. They discussed that environmental physical factors could be classified into three types of thermal and wind environments by cluster analysis. At the city level, the environmental physical factors composing the thermal environment are solar radiation and shadow density, and the environmental physical factors composing the wind environment are airflow velocity. At the architectural level, the environmental physical performance factors that make up the thermal environment include air temperature and air velocity. The environmental physical properties that make up the wind environment include air velocity and air temperature.

Explicitly analyzing the relationship between the existing urban form factors and the urban environment (Fig. 64), the factors that affect the thermal environment are: block shape coefficient (S), street thermal azimuth (α), street height, and width ratio (A), negative space area ratio (B) and negative space height and width ratio (C); the factors affecting the wind environment are: block passive space occupancy ratio (D), street wind azimuth (β), negative space area ratio (B), negative space height to width ratio (C) street height to width ratio (A); factors affecting the light environment are passive space occupancy ratio (D), street height to width ratio (A), street thermal azimuth (α), and negative space height to width ratio (C).

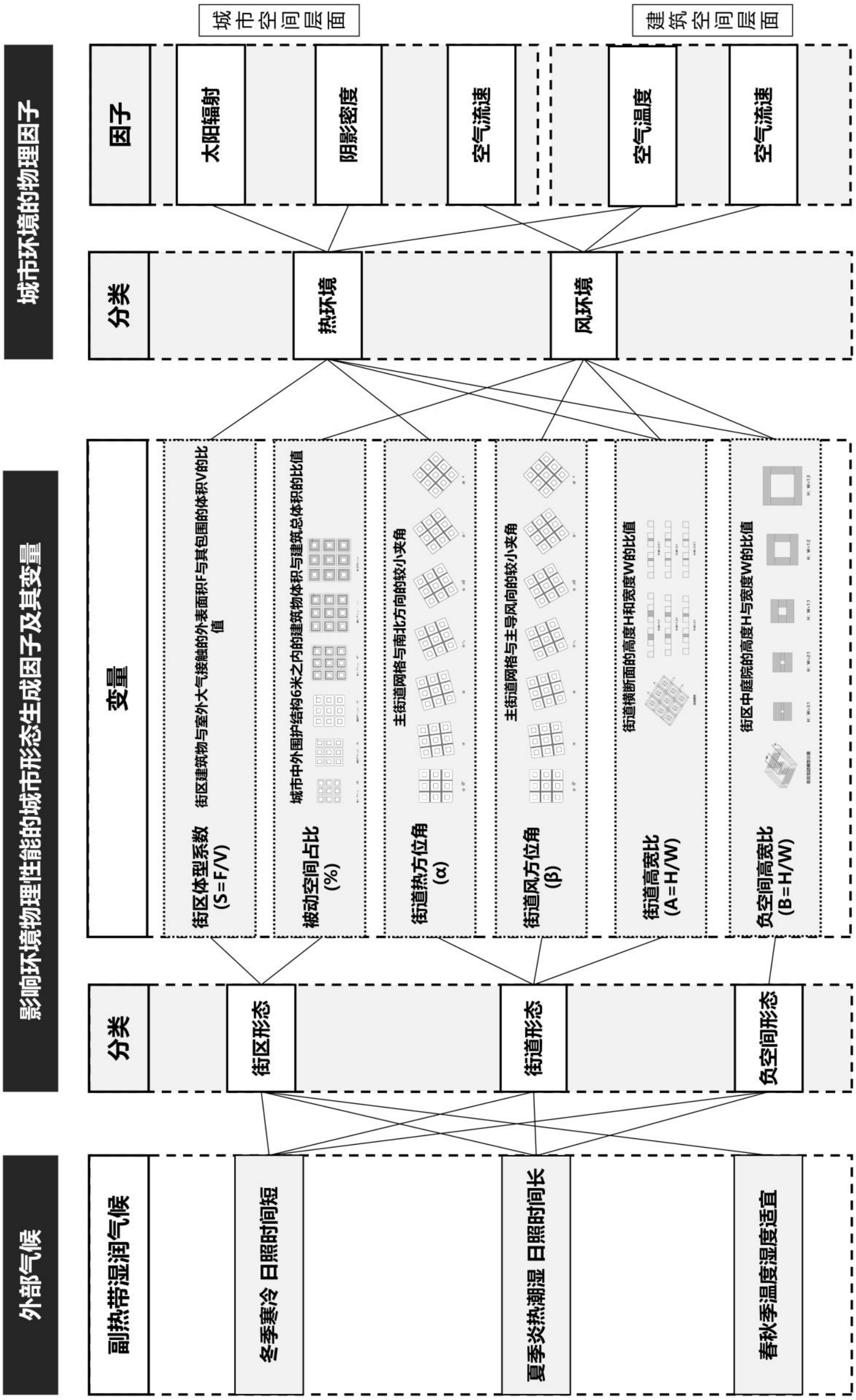


Fig. 64 The analysis of effective relationship physical factors of the urban environment and urban morphological factors in Humid Temperate Climate. Source: The author’s drawing

4.2 Extraction of Urban Morphology of the Thermal Adaptive Alba-model

Through the Thermal Adaptive analysis of Alba’s urban morphology, urban form presents a multi-layer, organic complexity condition because of the interactive effects and influences between different climates, politics, economies, and humanities long-term development process. As a result, it produces various types of urban public spaces and architectural spaces.

Based on Alba’s urban form analysis, this article extracts the Alba-Model of urban form according to the representative data of Alba. The shape data of the basic model is divided into three aspects: block shape, street shape, and Negative form. There are indicators such as building stories, height, depth, and window ratio in block shape. There are indicators such as street height, width, wind azimuth, and heat azimuth in street shape. There are indicators such as negative body width, height, and area ratio in terms of the Negative Form. The specific data of the various indicators of Alba’s urban morphology are shown in Table 9. According to the specific data of each indicator, the typical data of the various urban morphological factors discussed in Chapter 2 can be calculated (Table 10).

Table 9 Typical data extraction of various specific indicators of Alba’s urban form

Block form					Street form						Negative shape form				
Floors	Floor height（m）		Building depth（m）	Opening ratio（%）	Street height（m）	Street width（m）		Wind azimuth（°）		Thermal azimuth（°）	Negative shape width（m）		Negative shape length（m）		Negative shape height（m）
3-4	1	3.5	10-12	0.4	9-12	Main street	5-8	winter	30-35	15-20	houses	8-12	houses	20-25	9-12
	2-4	2.5-2.8				Others	3.5-5	summer	-[36]		Public space	48	Public space	78	

Table 10 Typical data extraction of Urban Morphological Factors in Alba

Block form		Street form					Negative shape form		
Block shape coefficient	Negative space ratio（%）	Street aspect ratio		Wind azimuth（°）		Thermal azimuth（°）	Negative shape aspect ratio		Negative shape area ratio
0.35-0.43	95%-100%	Main street	1.3-1.6	winter	30-35	15-20	houses	1.3-2	30
		Others	1.6-1.8	summer	-		Public space	0.19	

[36] 阿尔巴中夏季风的方向分布较为均匀，不存在主导风方向，因而没有夏季的街道风方位角数据。

In addition to the index parameters mentioned above, other parameters such as block length and shape, the bending of the street, and the number and distribution of the negative shapes space are more complex in Alba-Model than others. The large block in Alba is more than 100 meters long, and the smallest block is only 40 meters long, and the shapes of the blocks are different and have no apparent characteristics. The length and shape of the block have a low degree of correlation with the climate, mainly determined by the management unit of the town and the division of streets. There are more curved streets in Alba, which affects the wind speed and solar radiation on the streets. In addition, there are many negative shape spaces in a single block in Alba, and multiple groups of buildings often combine the interior of a single block to form a whole. The distribution of negative shape spaces is relatively uniform.

The Alba-Model of urban form takes the grid-like street layout and enclosed block texture as the basic form characteristics. The heights of the buildings in the blocks in the model remain the same, responding to the average urban canopy height in Alba. The block units in the model are combined to form a larger block, responding to the longer length and more complex inner block in Alba. The city square in the model can be regarded as a negative body space enclosed by surrounding blocks.

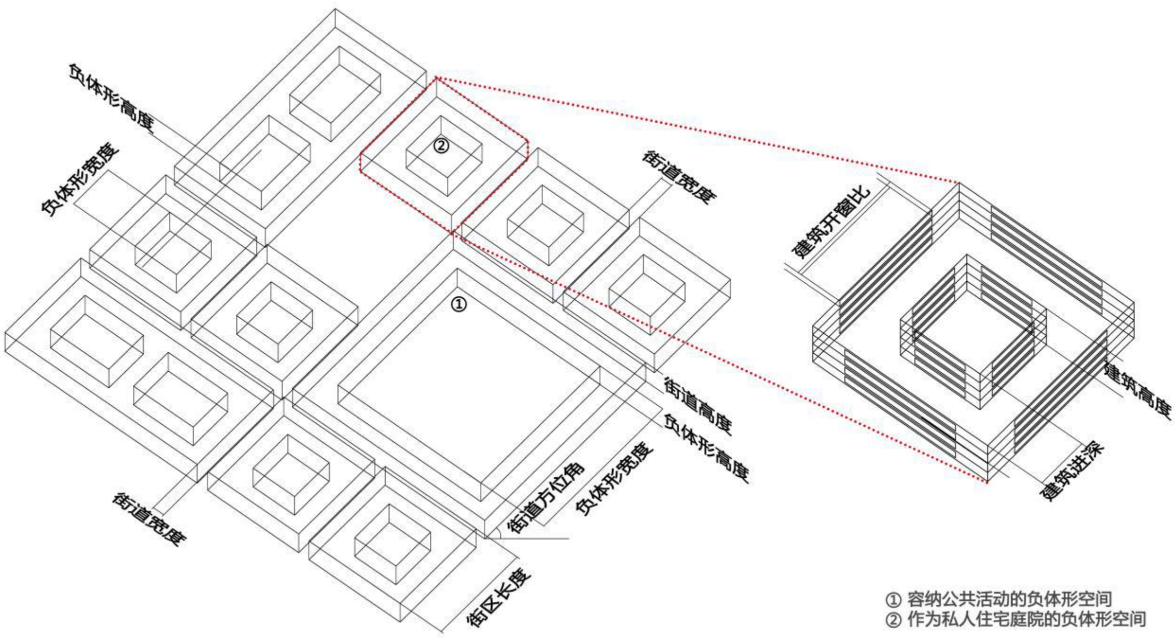


Fig. 65 Extraction of Alba-Model of urban morphology. Source: The author’s drawing

Based on the extracted basic model of the Alba model of urban morphology, this article discusses the relationship between each urban morphology factor in the model and the thermal environment and wind environment. In the specific analysis of each item, except for the set independent variables, the other model data are the typical urban morphology data in the Alba case.

4.3 **The Mechanism of Action of Urban Morphological Factors in Humid Temperate Climate**

4.3.1 Mechanisms of Action of Urban Morphological Factors Affecting the Urban Thermal Environment

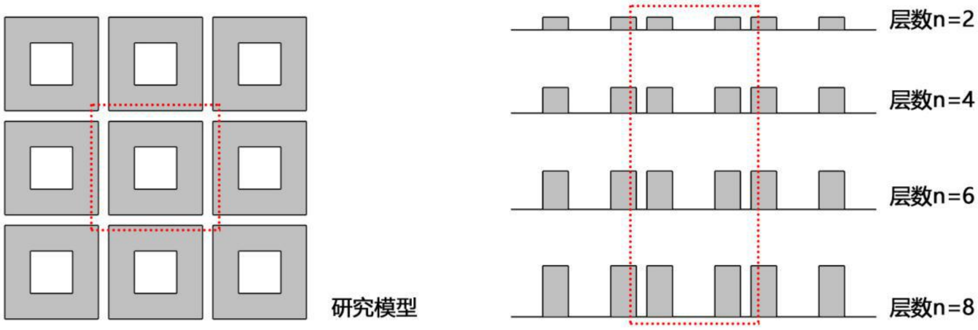
4.3.1.1 Block shape coefficients (S) and thermal environment

The block shape coefficient (S) has a complex relationship with the density of the built-up block and the building coverage of the block. The increase in the number of building floors and the building coverage will reduce the block shape coefficient should be explored separately.

The basic block type is the enclosed block with a square grid layout. The relationship between the two indexes and urban heat and cold load is investigated by keeping the building coverage constant and increasing the number of floors of the buildings. In the model, the length of the enclosed block is 44 m, the depth of the building is 12m, the height of the building is 2.8m, the width of the street is 5m, and the occupancy rate of the buildings in the block is 79.3%. As shown in Table 8, the number of building floors in the block, the density of the built-up block, the shape coefficient, and the height to width ratio of the street all change as the number of building floors increases. The block's shape coefficient decreases rapidly from 0.345 to 0.238 between 2 and 5 floors, and then the decrease in shape coefficient becomes flat as the number of floors increases. At the same time, the street height to width ratio and the density of the built-up blocks show a linear increase.

Table 11 Model analysis and urban morphology schematic with the number of building floors as the leading indicator

Research Case	Number of floors n	Building area (㎡)	The density of built-up blocks	Building surface area F (㎡)	Total building shape V (m^3)	Block shape coefficient S	Building height H (m)	Block height to width Ratio H/W
1	2	3072	1.587	2969.6	8601.6	0.345	5.6	1.12
2	3	4608	2.380	3686.4	12902.4	0.286	84	1.68
3	4	6144	3.174	4403.2	17203.2	0.256	11.2	2.24
4	5	7680	3.967	5120	21504	0.238	14	2.8
5	6	9216	4.760	5836.8	25804.8	0.226	16.8	3.36
6	7	10752	5.554	6553.6	30105.6	0.218	19.6	3.92
7	8	12288	6.347	7270.4	34406.4	0.211	22.4	4.48



The experimental model was imported into the building load simulation software, and the climate of Alba was used as the climate condition for the test. The window-to-wall ratio of each direction of the block building was set to 0.4. In summer, the cooling load value in summer and the heat load value in winter were obtained for each experimental object by taking a single block as the calculation object and its adjacent blocks as the influence object. It can be seen from Fig. 66 that in the winter heat load index, the heat load per unit building area decreases rapidly from 37.52kWh/㎡ to 23.96kWh/㎡ when the number of building floors increases from 2 to 4. While the decrease of the heat load value slows down significantly when the number of building floors exceeds 5, and the heat load per unit building area only decreases from 21.31kWh/㎡ to 17.44kWh/㎡ when the number of building floors increases from 5 to 8. Therefore, the built-up block density corresponding to the turning point of the decreasing rate of cold load in winter is between 3.1 and 3.9, while the shape coefficient is between 0.238 and 0.256. While in summer, the cold load per unit area shows a decreasing trend as the number of floors increases, and the decreasing rate of cold load in summer is faster when the number of building floors rises from 2 to 5. When the number of building floors exceeds 5, the decreasing rate of the cold load becomes slower.

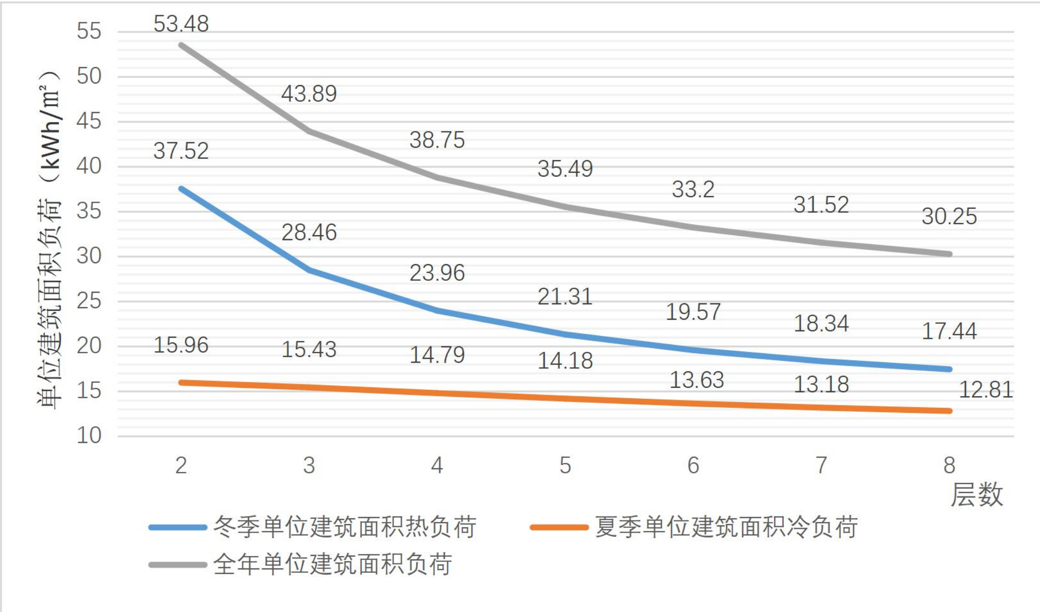
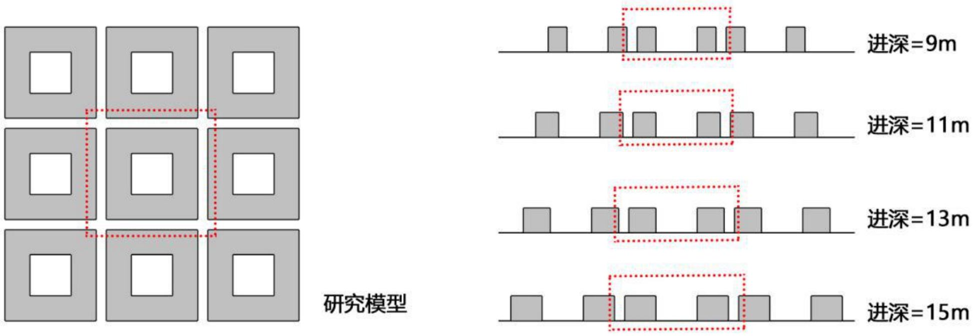


Fig. 66 Relationship between the number of experimental model floors and unit floor area load

The second group of experiments also uses the enclosed block as the basic block type, keeping the size of the internal courtyard and the number of floors of the buildings unchanged and increases the block shape coefficient by changing the depth of the buildings. The height of the buildings is 2.8 m, and the width of the street is 5m. From Table 12, we can see that the block shape coefficient decreases as the depth of the buildings increases, but the rate of decline decreases. The density of the built-up blocks shows the same trend while the number of building floors, building height, and street height to width ratio remains the same.

Table 12 Model analysis and urban form illustration with building depth as the leading indicator

Research Case	Building Depth	Building area (㎡)	The density of built-up blocks	Building surface area F (㎡)	Total building shape V (m^3)	Block shape coefficient S	Building height H (m)	Block height to width Ratio H/W
1	9	4176	2.892	3642.4	11692.8	0.312	11.2	2.24
2	10	4800	3.000	3888	13440	0.289	11.2	2.24
3	11	5456	3.093	4141.6	15276.8	0.271	11.2	2.24
4	12	6144	3.174	4403.2	17203.2	0.256	11.2	2.24
5	13	6864	3.244	4672.8	19219.2	0.243	11.2	2.24
6	14	7616	3.306	4950.4	21324.8	0.232	11.2	2.24
7	15	8400	3.360	5236	23520	0.223	11.2	2.24



Analyzing the experimental results (Fig. 67), it can be concluded that, for one thing, when the building depth rises from 9 to 12 meters, the heat load per unit floor area of the block decreases faster in winter, from 31.54 kWh/㎡ to 23.96 kWh/㎡. For another, when the building depth rises from 12 to 15 meters, the heat load decreases begin to slow down, from 23.96 kWh/㎡ to 19.46 kWh/㎡. The turning point of the heat load decline in winter corresponds to a building depth of about 12 meters, and the shape coefficient of the block is about 0.25. The heat load per unit building area in summer shows a similar pattern, but the absolute value and the declining value are less than the heat load in winter.

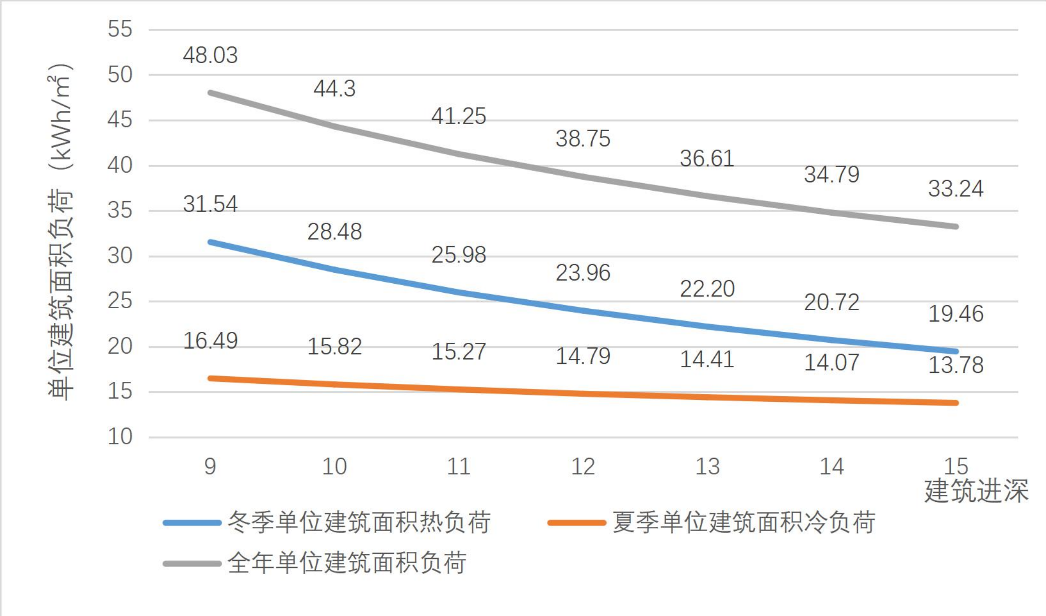


Fig. 67 Relationship between building depth and unit floor area load

From the above simulation results, it can be seen that under the Humid Temperature Climate, increasing the building's shape coefficient has a significant effect on reducing the heat loss and heat load of the building in winter. The turning point of the rate change of heat load reduction in winter corresponds to a shape coefficient of about 0.25. It indicates that the enclosed block form with a building depth of 12 m and four floors has high efficiency in preventing the cold and keeping warm. In the center of the Alba block, the shape coefficient is between 0.31 and 0.35, similar to the ideal block shape coefficient. Excluding the influence of the buildings attached to the block. Furthermore, increasing the building height and depth can further reduce the block shape coefficient, reducing the absolute value of heat loss in buildings. Therefore, in Humid Temperature Climate, compact enclosed blocks with 4 to 7 floors and 10 to 14 meters of building depth are better adapted to the external climate.

4.3.1.2 Street thermal azimuth (α) and thermal environment

The thermal azimuth of the street has a close relationship with the amount of solar radiation received by the street plane. When the external wind environment is lacking, the thermal environment of the street is mainly influenced by solar radiation. The thermal azimuth of the street affects the amount of solar radiation absorption. It affects the distribution of the shadow of the street plane, causing subtle differences in the thermal environment of the street space.

In order to explore the specific relationship between street thermal azimuth and thermal environment, seven sets of simulation conditions are set for street thermal azimuth α of 0°, 7.5°, 15°, 22.5°, 30°, 37.5°, and 45°. The solar radiation heat gain received by the street plane and the shadow density of the street are simulated respectively (Fig. 68), the width of the street in the simulation model is set to 5m, the number of floors of the building is 4, the depth is

12m. The simulated climatic conditions are those of Alba, and the simulated dates are the winter solstice (December 22) and the summer solstice (June 22).

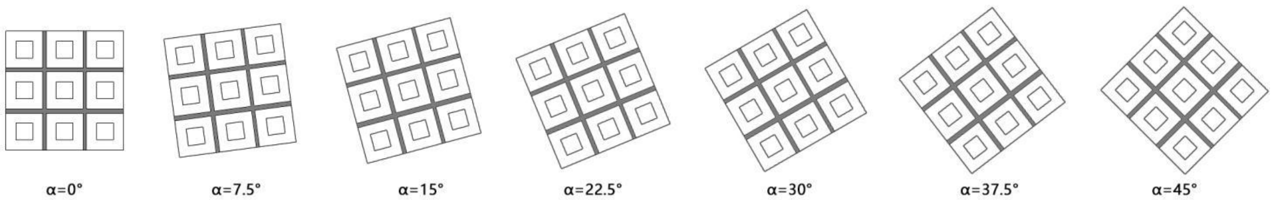


Fig. 68 Experimental model of thermal azimuth Source: The author’s drawing

The simulation results of solar radiation and shadow density at different street thermal azimuths on the winter solstice are as follows(Fig. 69, Table 13)：

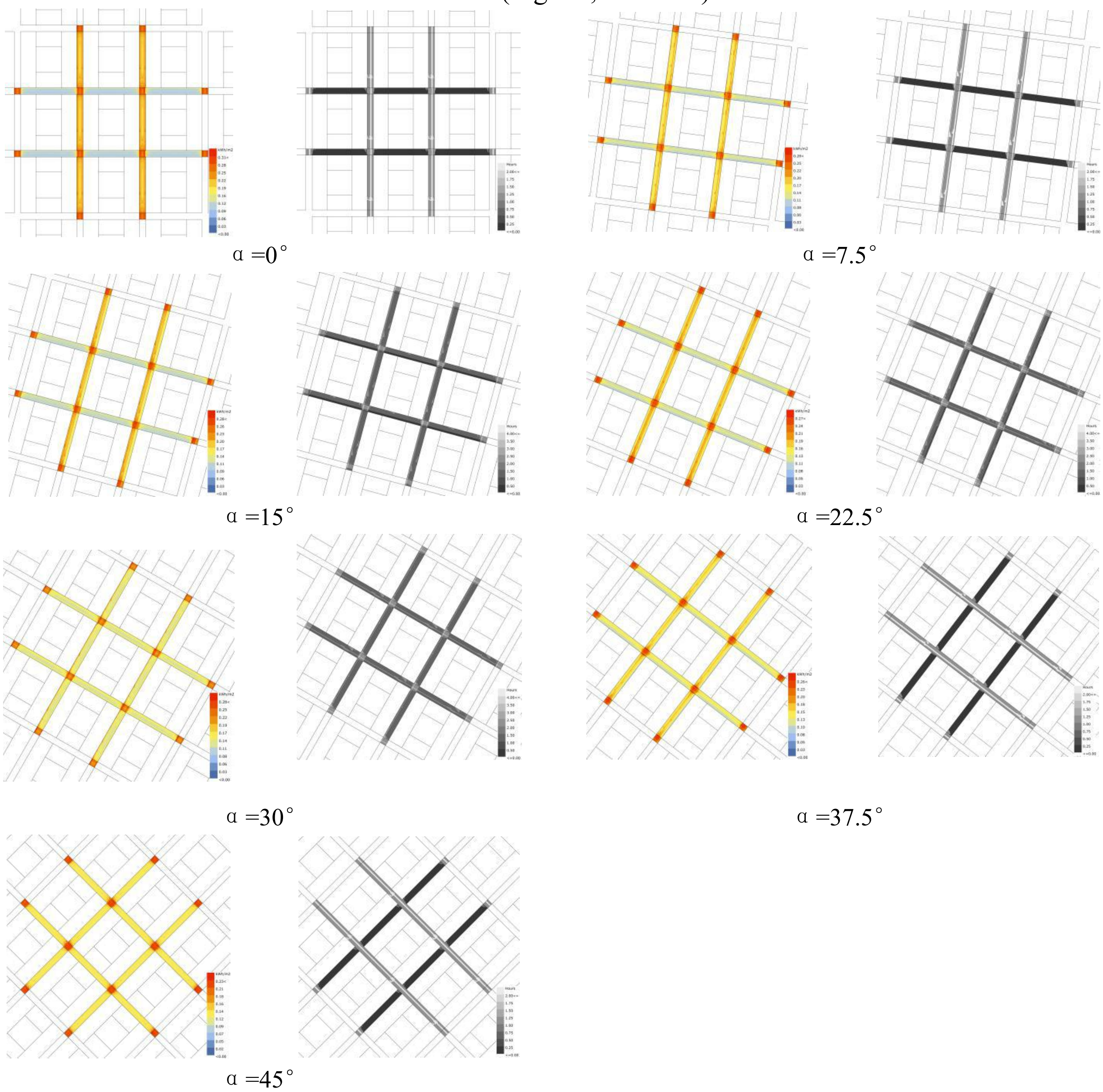


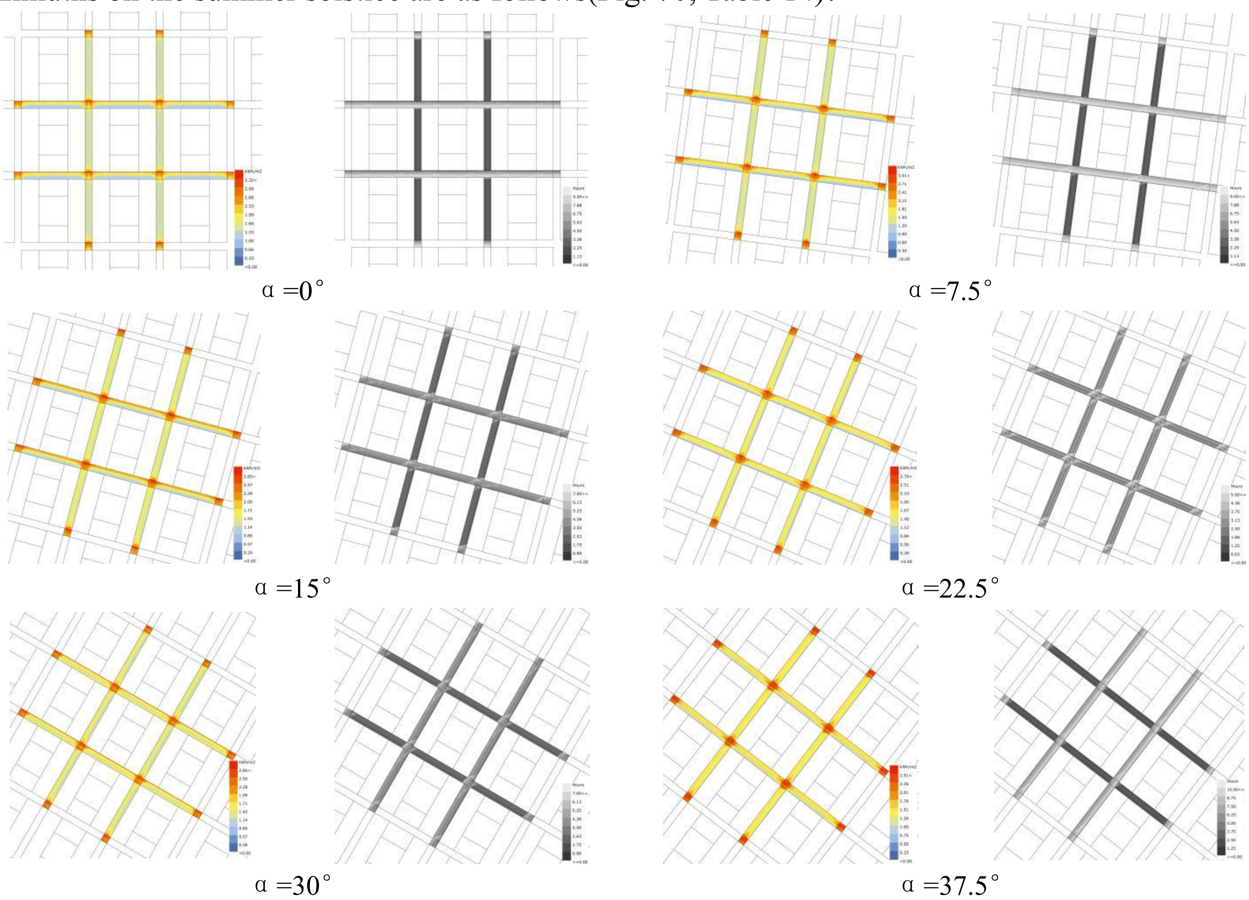
Fig. 69 Simulation of solar radiation and shadow density at different street thermal azimuths on the winter solstice Source: The author’s drawing

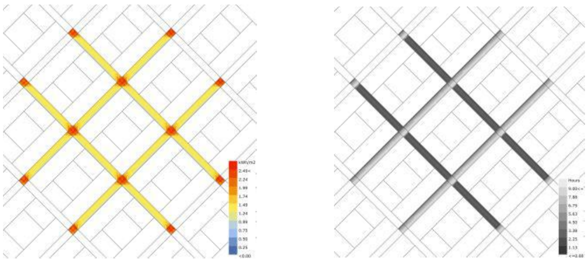
Table 13 Solar radiation and sunshine hours at different street thermal azimuths on the winter solstice Source: The author’s drawing

	α =0°	α =7.5°	α =15°	α =22.5°	α =30°	α =37.5°	α =45°
Solar radiation value (kWh)	478.2	418.9	426.7	413.2	400.6	393.6	380.2
Sunshine hours (h)	1757.6	1785.5	3371.1	3732.6	3987.2	2020.5	1728.7

Comparing the simulation results of each model (Fig. 69, Table 13), it can be found that with the increase of the street’s thermal azimuth, the solar radiation received by the street in the winter solstice shows a decreasing trend. In contrast, the sunshine hours show a trend of first increasing and then decreasing. When the thermal azimuth angle is 0° , the solar radiation received by the street on the winter solstice is the largest, 478.2kWh. Moreover, the sunshine hours of the street are small, only 1757.6h and the east-west street is entirely in shadow. When the thermal azimuth angle is 45, the street's solar radiation value and sunshine hours are less, and the street from southwest to northeast is entirely in shadow. When the thermal azimuth is 15° to 30° , the solar radiation received by the street is higher, and the number of sunshine hours on the street plane is also higher, the sunshine of the street is uniform, and almost no area is in shadow for one day.

The simulation results of solar radiation and shadow density at different street thermal azimuths on the summer solstice are as follows(Fig. 70, Table 14)：





α =45°

Fig. 70 Simulation of solar radiation and shadow density at different street thermal azimuths on the summer solstice Source: The author's drawing

Table 14 Solar radiation and sunshine hours at different street thermal azimuths on the summer solstice Source: The author's drawing

	α =0°	α =7.5°	α =15°	α =22.5°	α =30°	α =37.5°	α =45°
Solar radiation value (kWh)	4265.3	4115.4	4110.1	4045.3	4002.3	3978.0	3946.6
Sunshine hours (h)	12323.1	12798.8	8387.4	7426.7	8647.8	12980.9	12338.9

Comparing the simulation results of each model (Fig. 70, Table 14), it can be found that the solar radiation received by the street on the summer solstice tends to decrease as the thermal azimuth of the street increases. In contrast, the number of sunshine hours tends to decrease first and then increase. When the thermal azimuth angle is 0, although the north-south streets are in the solar shadow, almost all the sunshine is located on the east-west streets. The streets have no shade throughout the day, and the outdoor comfort is shallow. When the thermal azimuth angle is 45°, the solar radiation received by the streets is at the minimum. However, the shaded area of the north-south streets is small, which is not conducive to pedestrian comfort in summer. When the thermal azimuth angle is 22.5 and 30, the sunshine hours of the streets are more evenly distributed, and the streets are shaded all day on the summer solstice. The sunshine hours are small, which is favorable to the outdoor walking comfort.

In summary, under Humid Temperate Climate conditions, if shading is the primary conditioning goal in summer, a street thermal azimuth between 20 and 30 can produce more urban shaded areas and reduce solar radiation absorption from streets and plots. If the light is the primary conditioning goal in winter, a street thermal azimuth between 15 and 30 can increase the solar radiation value and increase the comfort of streets.

4.3.1.3 Street height to width ratio (A) and thermal environment

The height to width ratio of urban streets has a close relationship with the heat gain of block buildings surface along the street, the street's heat gain, and the sunshine hours of the street. Generally speaking, the deeper the street level canyon is, the better the shading relationship between buildings, which is conducive to producing a larger shaded area on the street and suitable for public activities on the street in summer. The shallower the street level canyon is, the more solar radiation can be obtained on the surface of buildings and streets, which is conducive to increasing the heat gain in winter.

In order to explore the specific relationship between urban street height to width ratio and thermal environment, the street height to width ratio of Alba is used as a reference. A total of six sets of simulation conditions with street height to width ratio A of 1:1, 1.5:1, 2:1, 2.5:1, 3:1, and 3.5:1 are set to simulate the solar radiation heat gain of each indoor floor of the building and the surface of the street respectively. In contrast, the sunshine hours of the street are simulated and calculated. In the simulation model, the number of floors of the building is 4, the depth is 12m, the window to wall ratio is set to 0.4, and the wind azimuth and thermal azimuth of the street are set to 30° . The width of the street is 12m, 8m, 6m, 4.8m, 4m, and 3.43m under each set of height to width ratio data. The simulated climatic conditions are those of Alba, and the calculation time is two days for the winter and summer solstice.

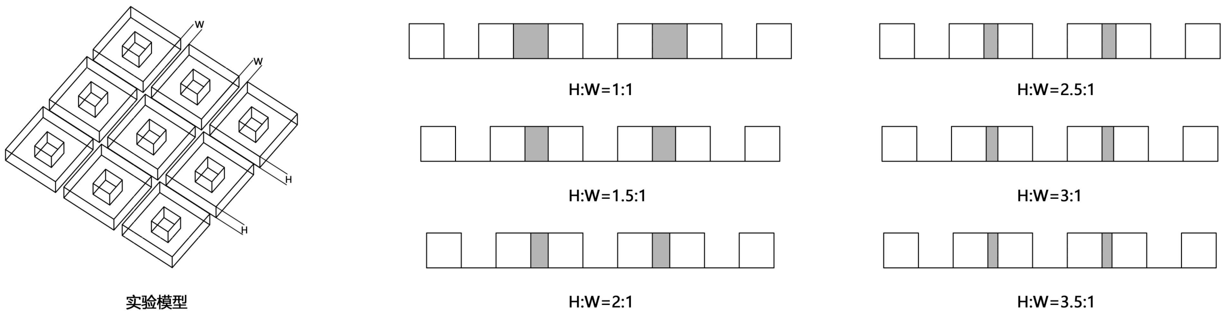


Fig. 71 Schematic diagram of the basic model of street aspect ratio and thermal environment simulation. Source: The author's drawing

The simulation results of each model are organized as follows：

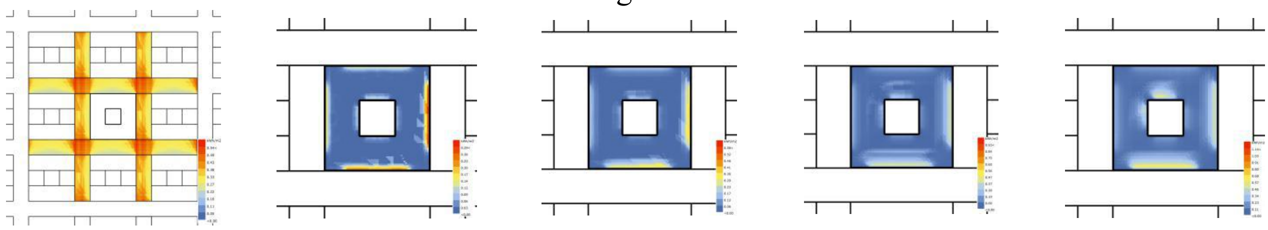


Fig. 72 Simulation of solar radiation for the building from 1st to 4th floor and street surface at A=1:1 on the winter solstice Source: The author's drawing

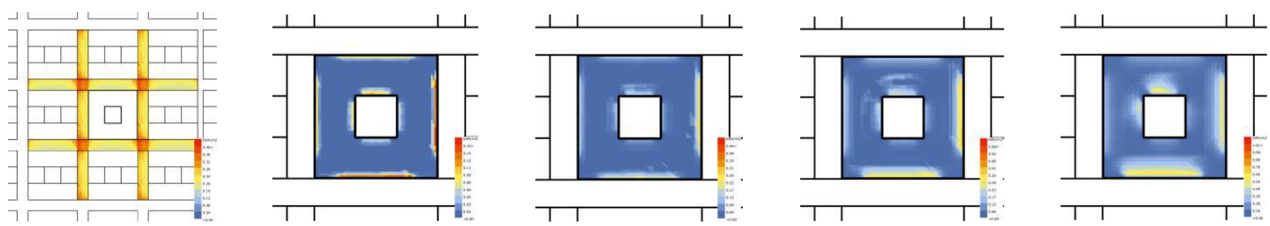


Fig. 73 Simulation of solar radiation for the building from 1st to 4th floor and street surface at A=1.5:1 on the

winter solstice Source: The author’s drawing

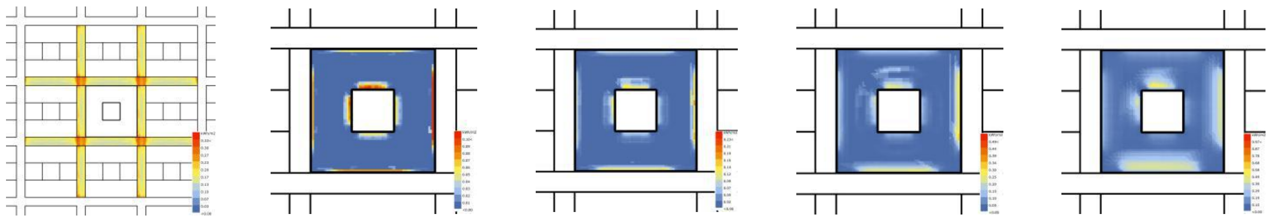


Fig. 74 Simulation of solar radiation for the building from 1st to 4th floor and street surface at A=2:1 on the winter solstice Source: The author’s drawing

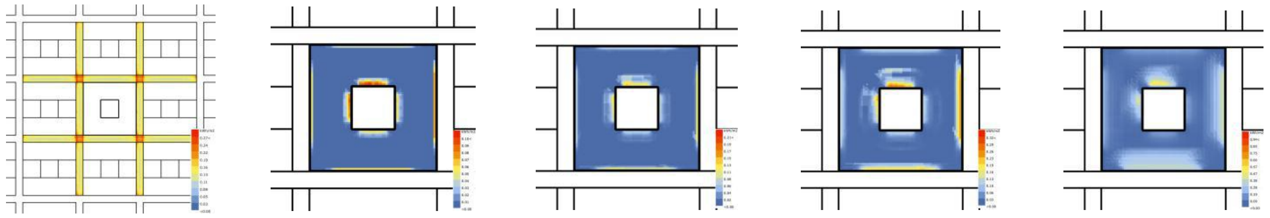


Fig. 75 Simulation of solar radiation for the building from 1st to 4th floor and street surface at A=2.5:1 on the winter solstice Source: The author’s drawing

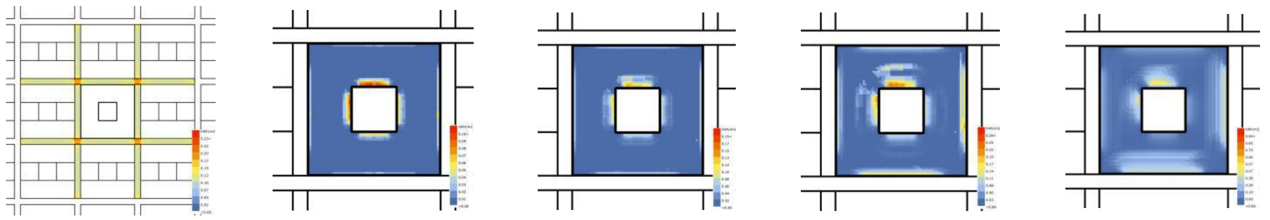


Fig. 76 Simulation of solar radiation for the building from 1st to 4th floor and street surface at A=3:1 on the winter solstice Source: The author’s drawing

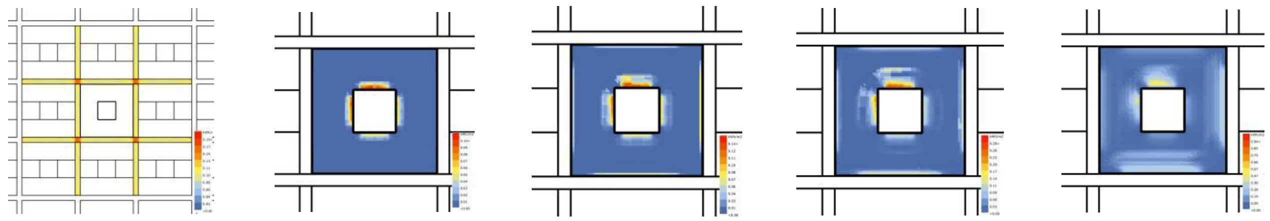


Fig. 77 Simulation of solar radiation for the building from 1st to 4th floor and street surface at A=3.5:1 on the winter solstice Source: The author’s drawing

Table 15 Solar heat gain from indoor on all floors of block buildings and street surfaces on the winter solstice (in kWh) Source: The author’s drawing

	1F	2F	3F	4F	Street surface
A=1:1	23.0	47.7	84.6	143.4	1803.6
A=1.5:1	9.8	24.7	56.5	132.6	789.8
A=2:1	5.8	15.0	40.3	121.0	439.2
A=2.5:1	4.8	10.8	30.0	108.8	279.2
A=3:1	3.5	8.6	24.8	99.1	189.2
A=3.5:1	2.7	8.1	21.1	90.1	140.1

The simulation results for the winter solstice show that, in general, the amount of solar radiation received by each surface tends to decrease as the height to width ratio of the street increases, but the magnitude of the decrease varies. The solar radiation on the street surface shows a turning point of slowing down between A of 1.5 and 2. The building's first floor shows turning point A from 1 to 1.5, and the second and third floors show turning point A from 1.5 to 2. In contrast, the 4th floor never shows a significant turning point.

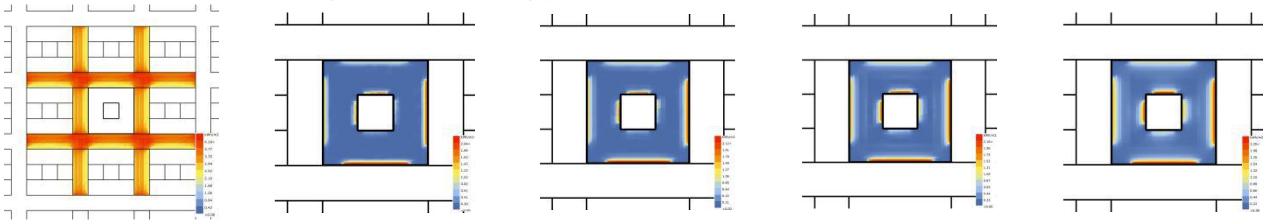


Fig. 78 Simulation of solar radiation for the building from 1st to 4th floor and street surface at A=1:1 on the summer solstice Source: The author's drawing

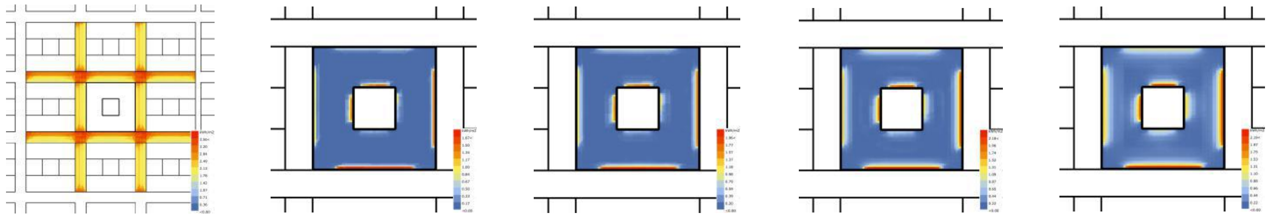


Fig. 79 Simulation of solar radiation for the building from 1st to 4th floor and street surface at A=1.5:1 on the summer solstice Source: The author's drawing

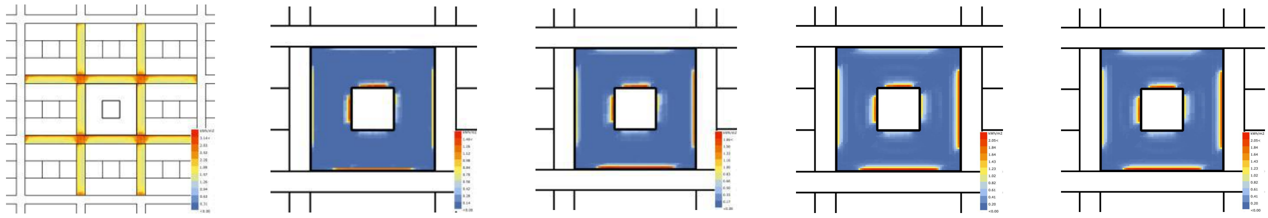


Fig. 80 Simulation of solar radiation for the building from 1st to 4th floor and street surface at A=2:1 on the summer solstice Source: The author's drawing

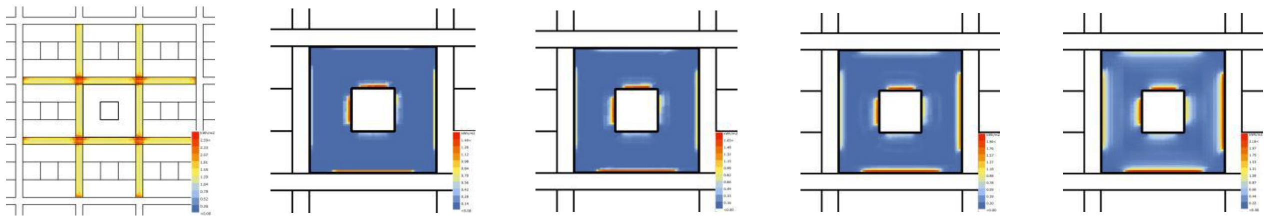


Fig. 81 Simulation of solar radiation for the building from 1st to 4th floor and street surface at A=2.5:1 on the summer solstice Source: The author's drawing

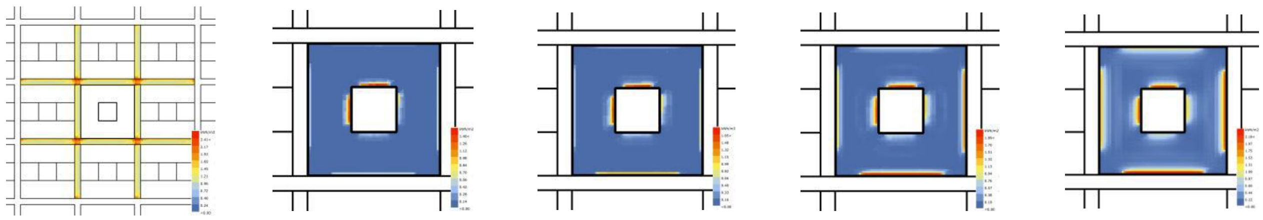


Fig. 82 Simulation of solar radiation for the building from 1st to 4th floor and street surface at A=3:1 on the summer solstice Source: The author's drawing

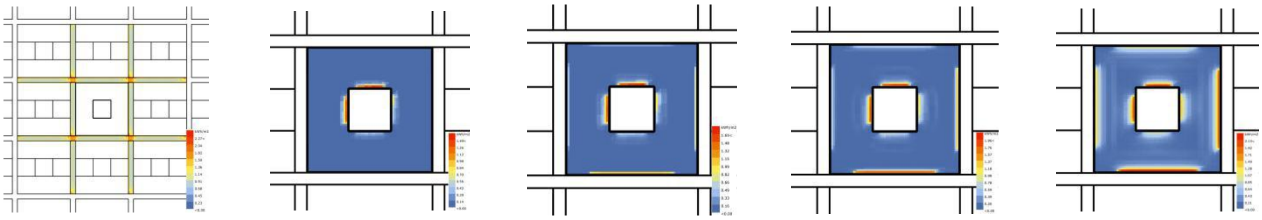
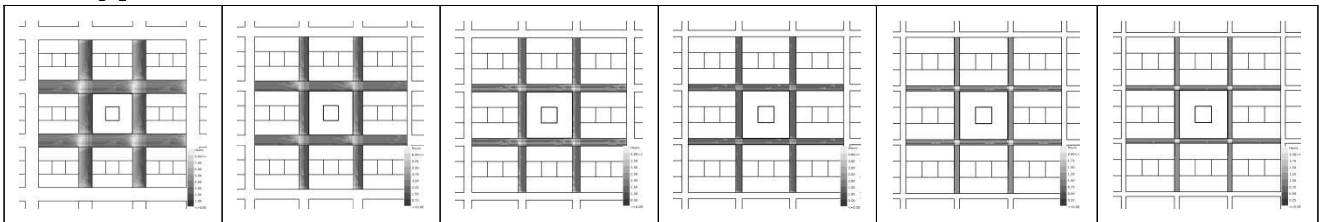


Fig. 83 Simulation of solar radiation for the building from 1st to 4th floor and street surface at A=3.5:1 on the summer solstice Source: The author’s drawing

Table 16 Solar heat gain from indoor on all floors of block buildings and street surfaces on the winter solstice (in kWh) Source: The author’s drawing

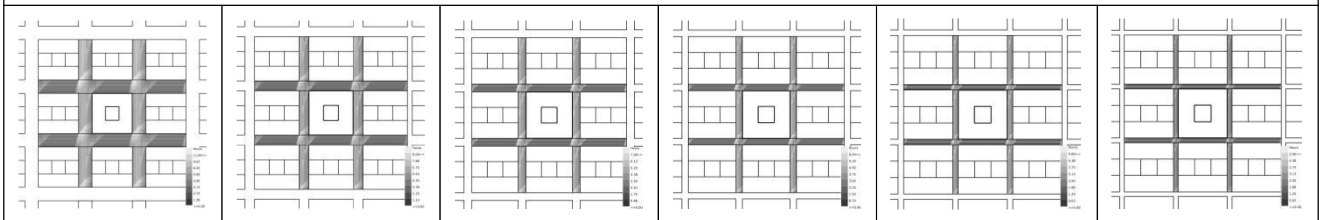
	1F	2F	3F	4F	Street surface
A=1:1	146.9	237.9	310.2	403.0	16618.7
A=1.5:1	92.4	171.9	267.2	384.0	7894.6
A=2:1	58.5	129.2	224.0	366.8	4552.9
A=2.5:1	51.1	97.4	209.2	347.4	2853.6
A=3:1	39.8	77.2	164.4	332.3	2037.8
A=3.5:1	25.8	72.0	161.9	316.3	1477.3

The simulation results for the summer solstice have roughly the same trend as the winter solstice. The solar radiation received by the street surface has a turning point where the decline rate slows down between A of 2 and 2.5, a turning point at the 1st floor of the building between A of 1.5 and 2, a turning point at the second and third floors between A of 2.5 and 3, and no significant turning point at the 4th floor.



A=1：1	A=1.5:1	A=2:1	A=2.5:1	A=3:1	A=3.5:1

Fig. 84 Number of hours of sunlight on the surface of each street in the model of the height to width ratio on the winter solstice Source: The author’s drawing



A=1：1	A=1.5:1	A=2:1	A=2.5:1	A=3:1	A=3.5:1

Fig. 85 Number of hours of sunlight on the surface of each street in the model of the height to width ratio on the summer solstice Source: The author’s drawing

Table 17 Statistics of sunshine hours on the street surface on the winter and summer solstices (unit: h)
Source: The author's drawing

	A=1:1	A=1.5:1	A=2:1	A=2.5:1	A=3:1	A=3.5:1
Sunshine hours on the winter solstice	19539.1	7937.1	4205.9	2539.4	1692.6	1364.5
Sunshine hours on the summer solstice	34786.7	16419.3	9360.3	6310.1	3991.9	2992.1

Comparing the sunshine hours on the street surface during the winter solstice and the summer solstice, we can find that the turning point of the decrease in sunshine hours on the winter solstice occurs when A is between 2 and 2.5. The turning point at which the decline rate slowed down during the summer solstice day occurred when A was between 2.5 and 3. In addition, when the height to width ratio gradually increases, the difference between the sunshine hours on the summer solstice and the sunshine hours on the winter solstice decreases continuously, which indicates that with a suitable thermal azimuth of the street. The height to width ratio has a negligible effect on the sunshine hours on the winter solstice. Even at a height to width ratio of 3.5, the absorption of a certain amount of solar radiation in winter can still be guaranteed on the street. While the effect on the summer sunshine hours is large and at a height to width ratio of 3.5, the solar radiation on the street in summer is only 2992.1h.

Overall, under the Humid temperate Climate, when shading to cooling in summer is the main control target, the street height to width ratio of 3 can effectively reduce the value of solar radiation received by the street and the interior of the building, and will not affect too much the solar radiation of the street in winter. When solar heating in winter is the main control target, the street height to width ratio of 1.5 can effectively ensure the solar radiation absorption of the top floor of the building and the street while creating enough street shadows in summer to increase the thermal comfort of the street.

4.3.1.4 Negative shape height to width ratio (B) and thermal environment

The height-to-width ratio of the negative shape in the block is closely related to the building's heat gain and the heat gain of the bottom surface of the negative shape. The negative shape with a small height to width ratio and a larger area can receive a large amount of solar radiation. In comparison, the negative shape with a large height to width ratio and a smaller area can form a shading relationship between buildings and buildings, and at the same time, provide shading for the internal courtyard space to avoid receiving too much solar radiation.

In order to explore the specific relationship between the height to width ratio of negative shape and the thermal environment, five sets of simulation conditions are set for the height to width ratio H/W of negative shape as 3:1, 2:1, 1:1, 1:2, and 1:3. The solar radiation heat gain of the interior of each floor of the building and the solar radiation heat gain of the bottom of the negative shape is simulated, respectively. The width of the street in the simulation model is set to 5m, the number of floors of the building is 4, the depth is 12m, the window to wall ratio is set to 0.4, the simulated climate conditions are those of Alba, Italy. Moreover, the simulation time is set to the whole year. The calculation time is from 7:00 to 19:00 to realize the calculation of solar radiation throughout the year.

Fig. 86 Schematic diagram of the basic model of thermal environment simulation for negative body shape aspect ratio. Source: The author’s drawing

The simulation results of each model are organized as follows：

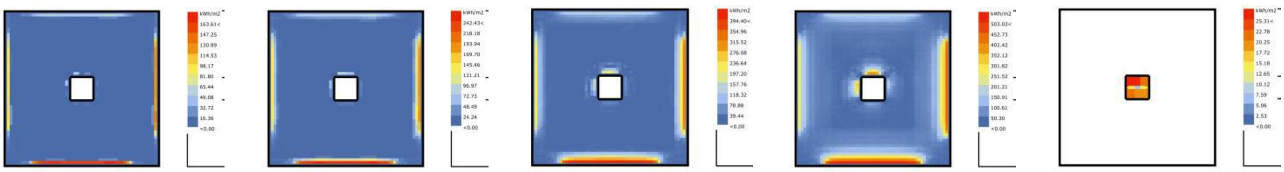


Fig. 87 Simulation of solar radiation for each floor and courtyard at height to width ratio B=3:1 Source: The author’s drawing

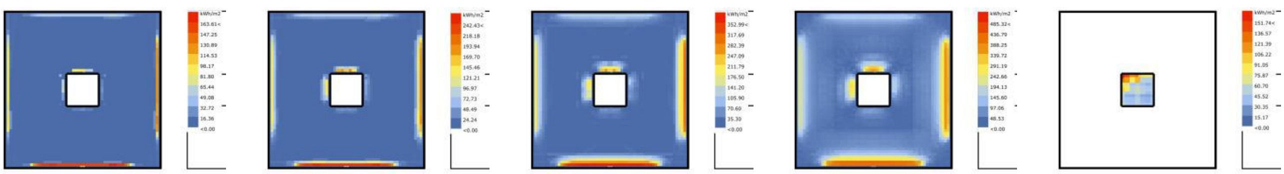


Fig. 88 Simulation of solar radiation for each floor and courtyard at height to width ratio B=2:1 Source: The author’s drawing

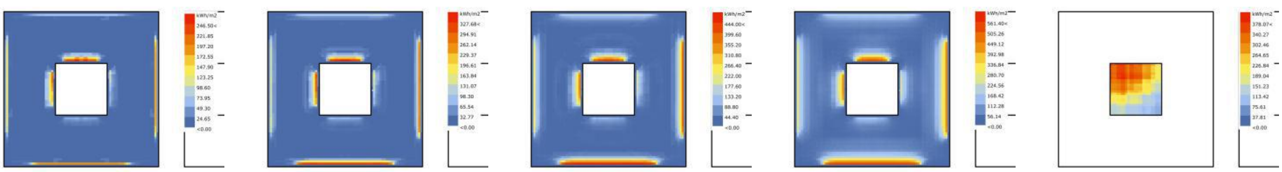


Fig. 89 Simulation of solar radiation for each floor and courtyard at height to width ratio B=1:1 Source: The author’s drawing

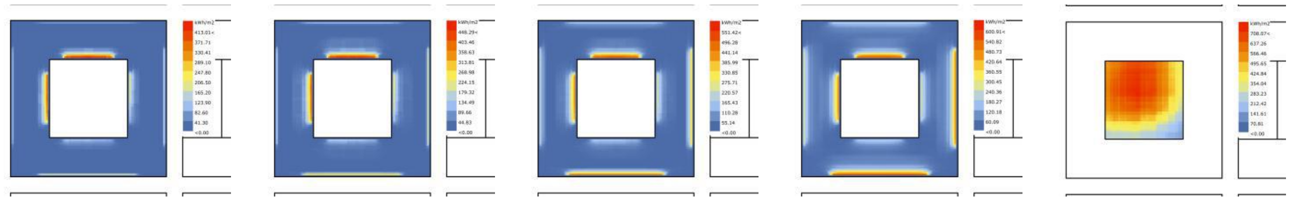


Fig. 90 Simulation of solar radiation for each floor and courtyard at height to width ratio B=1:2 Source: The author’s drawing

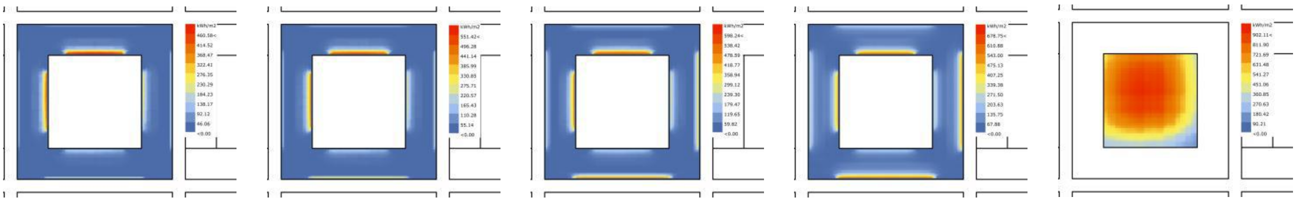


Fig. 91 Simulation of solar radiation for each floor and courtyard at height to width ratio B=1:3 Source: Author’s drawing

Table 18 Annual solar heat gain for each negative shape height to width ratio model (unit: kWh) Source: The author’s drawing

	1F	2F	3F	4F	Courtyard surface
B=3：1	4788	9753	24025	53373	313
B=2：1	5297	11526	28062	61032	1873
B=1：1	12848	25531	49589	88333	29252
B=1：2	28497	47029	79943	133254	265928
B=1：3	56167	78930	114808	184294	788258

According to the simulation results of each model, it can be found that the higher the number of floors, the better the heat gain inside the building is for any block with a negative shape height-to-width ratio. As the negative height to width ratio decreases, each floor's average solar radiation area gradually increases. When the negative shape height to width ratio is less than 1, the growth of solar radiation is slow. In contrast, when the height to width ratio is greater than 1, there is a sudden increase in solar radiation. The growth rate is faster, especially the solar radiation received by the courtyard ground. In addition, with the decrease of the aspect ratio of the negative body shape, the growth of the solar radiation reception value from layer1 to layer4 tends to be gentle, indicating that the radiation uniformity of each layer is gradually improving.

Overall, under the Humid Temperate Climate, when the negative shape space takes shading to cool in summer as the main regulation goal, the negative shape space with the height-to-width ratio greater than 1 is beneficial to shield the solar radiation reduce the indoor temperature. When the heating in winter is the main regulation goal, the height to width ratio less than 1 is beneficial to obtain a large amount of solar radiation on the ground inside the building and in the courtyard, thus increasing the indoor and outdoor comfort.

4.3.2 The Action Mechanism of Urban Morphological Factors Affecting Urban Wind Environment

4.3.2.1 Street wind azimuth (β) and wind environment

The orientation of urban streets and the wind environment have a close relationship with the external wind environment. The wind from the external nature enters the urban environment mainly through the mechanism of wind pressure ventilation. Under the condition of suitable street height and width ratio, when the prevailing wind direction of the city is the same as the direction of the city's main street, the wind flow will be smoother. In contrast, with the change of the wind azimuth of the street, the wind environment in the street will be very different. In general, urban spaces oriented to natural ventilation are conducive to increasing the wind speed in the streets, improving the natural ventilation efficiency of buildings, and enhancing human thermal comfort. However, in a Humid, Temperate Climate, high wind speeds, and low winter temperatures will carry away human heat and reduce human comfort. Therefore, the orientation of the street should be aimed at introducing summer wind and shielding winter wind.

In order to explore the inner relationship between street wind azimuth and wind environment, further simulation studies are conducted on the relationship between street wind azimuth and wind environment. A square grid-like enclosed block is set up, and the street in one direction is set as the main street of the city with a width of 6 m and a street height to width ratio of 2. The street in the other direction is set as a secondary street with a width of 4m and a height-to-width ratio of 3. The smaller angle between the direction of the main street and the dominant wind direction is used as the street wind azimuth angle β . The simulation is set up for seven conditions, and the street wind azimuth angles are 0° , 15° , 30° , 45° , 60° . 30° , 45° , 60° , 75° , and 90° , and the external wind speed is set to 2m/s.

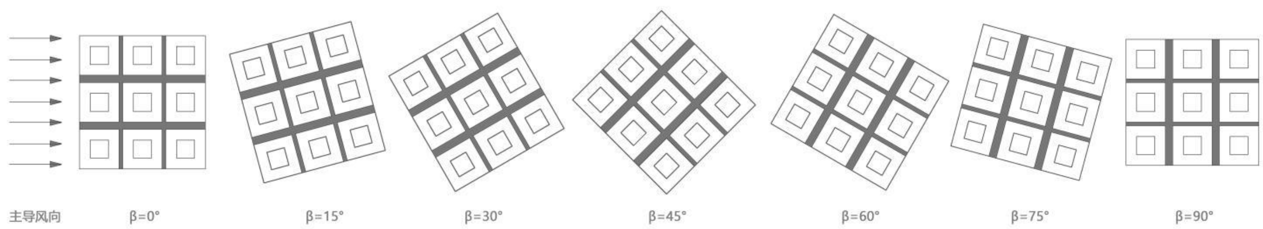


Fig. 92 Schematic diagram of wind simulation experiment model with different wind azimuth Source: The author’s drawing

The simulation results of each model are as follows：

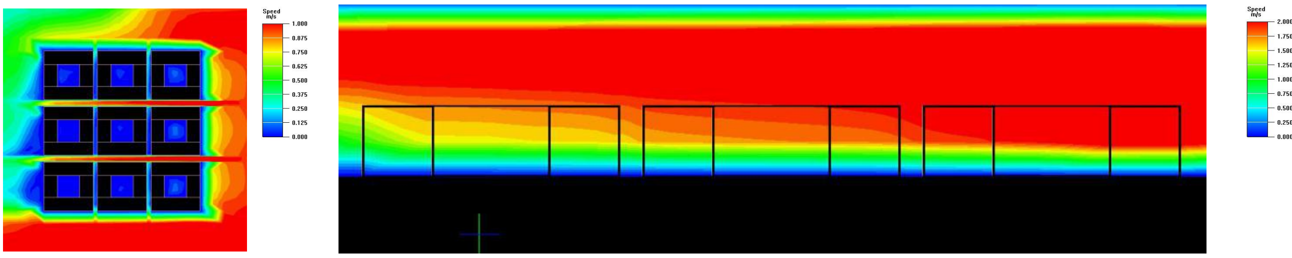


Fig. 93 Wind speed diagram for 1.5m street plane and main street profile at β=0° Source: The author's drawing

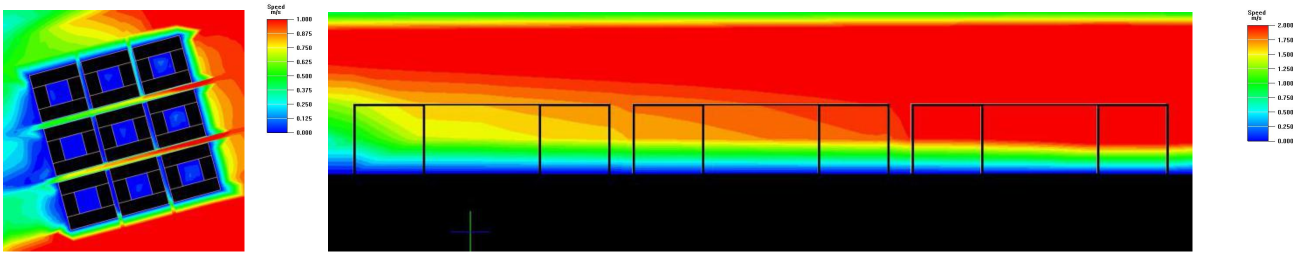


Fig. 94 Wind speed diagram for 1.5m street plane and main street profile at β=15° Source: The author's drawing

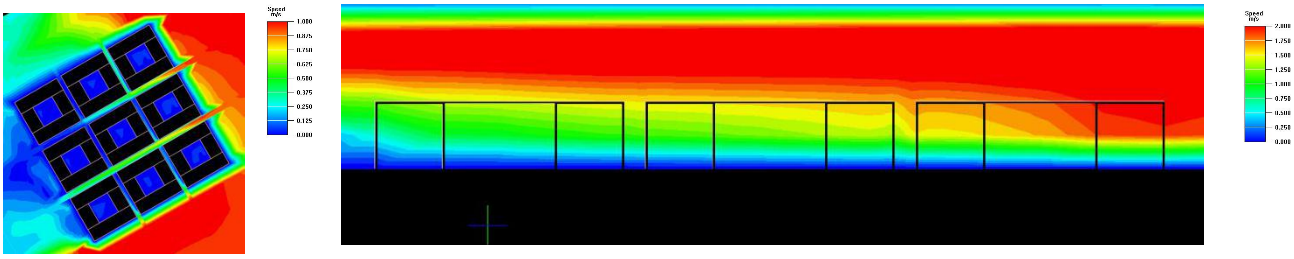


Fig. 95 Wind speed diagram for 1.5m street plane and main street profile at β=30° Source: The author's drawing

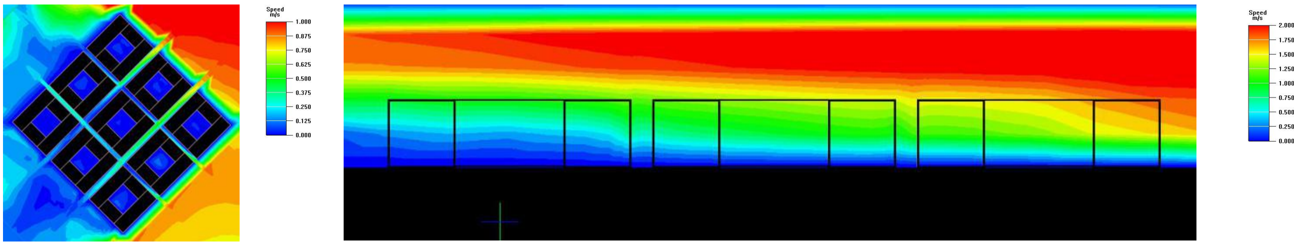


Fig. 96 Wind speed diagram for 1.5m street plane and main street profile at β=45° Source: The author's drawing

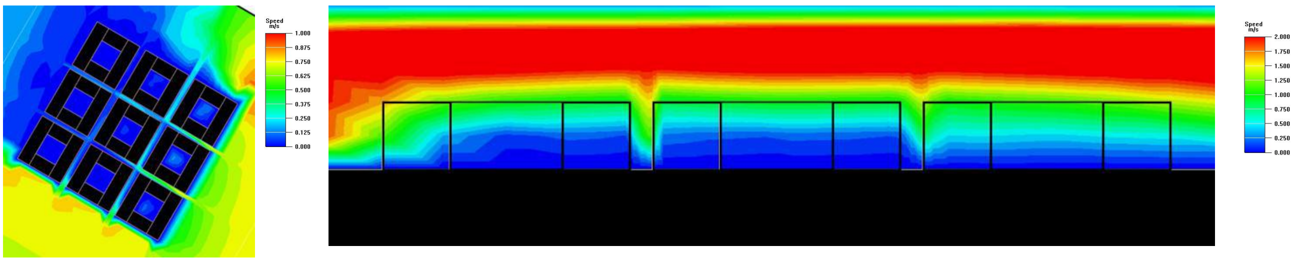


Fig. 97 Wind speed diagram for 1.5m street plane and main street profile at β=60° Source: The author's drawing

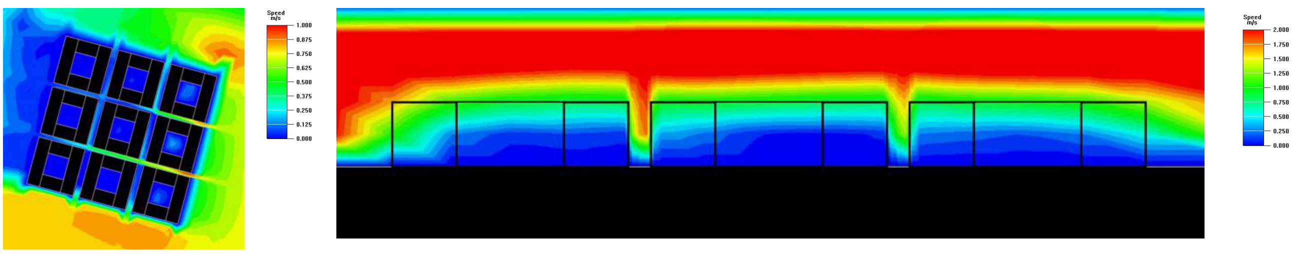


Fig. 98 Wind speed diagram for 1.5m street plane and main street profile at β=75° Source: The author's drawing

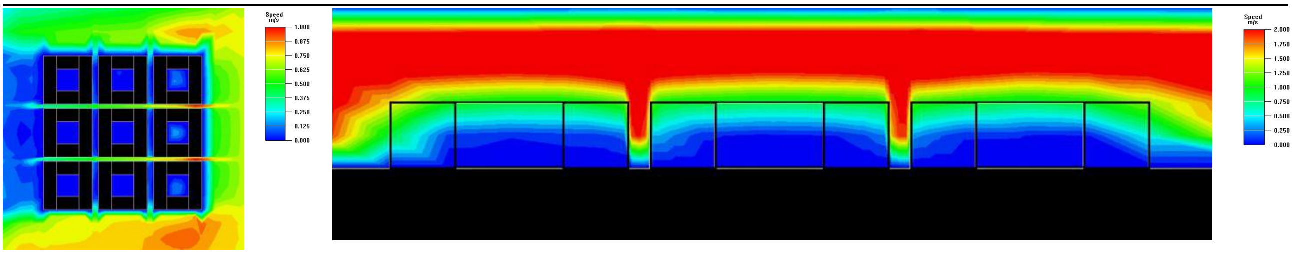


Fig. 99 Wind speed diagram for 1.5m street plane and main street profile at β=90° Source: The author's drawing

From the comparison of the wind speed maps of 1.5m street plane and east-west profile of the main street in different street wind azimuth models, it can be found that when the street wind azimuth angle β is less than 45, with the increase of β, the distance of wind penetration in the main street gradually becomes shorter, from three block lengths to one block length. In contrast, the average wind speed on the street shows a decreasing trend, from 2m/s to less than 1m/s. There is always no wind penetration on the secondary streets. When the wind azimuth angle β is 45, there is a certain wind speed on both the main street and the secondary streets. The wind speed on the streets is between 0.5m/s and 1m/s. When the wind azimuth angle β is greater than 45, the wind speed on the main streets keeps decreasing. The wind speed on the secondary streets keeps increasing. However, the growth of the wind speed on the secondary streets is slower, and when β is 90°, the wind speed on the streets averages is also only about 1m/s.

Collectively, the ventilation conditions on the streets are poor when β is between 45° and 75°, and better when β is between 0° and 45°.

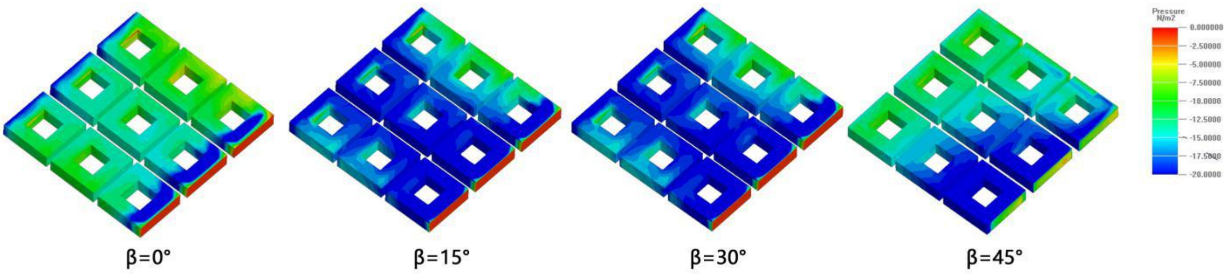


Fig. 100 Wind pressure on the surface of buildings in the block with different wind azimuths Source: The author's drawing

By analyzing the wind pressure (Fig. 100) on the surfaces of buildings with street wind azimuths of 0°, 15°, 30°, and 45°, it can be found that when β is 0°, the wind pressure difference between the surfaces of buildings located outside the city blocks is larger. In contrast, the wind pressure distribution on the surfaces of buildings located in the city center is more uniform all around -10N/㎡. When β is 15° and 30°, the wind pressure difference between the surfaces of blocks buildings located in the upwind direction of the city and downwind direction of the city becomes larger and exists in most of the blocks. When β is 45°, the blocks located in the upwind direction have a large wind pressure difference, while the blocks in the downwind direction are located in the negative pressure zone.

To sum up, in the Humid Temperate Climate, when shelter wind is the main control target in winter, the wind azimuth of the street should be more than 45 from the dominant wind direction in winter, effectively reducing the wind velocity on the city streets and improve the comfort of pedestrians. When natural ventilation is the main control target in summer and transitional season, the wind azimuth of the street should be 15 to 30 from the dominant wind direction in summer. It can increase the wind pressure difference on the building's surface and promote natural ventilation inside the building while ensuring the appropriate wind speed on the street.

4.3.2.2 Negative shape height to width ratio (H/W) and wind environment

Natural ventilation mechanisms in cities are mainly divided into wind pressure ventilation and thermal pressure ventilation. The wind-pressure ventilation is closely related to the building texture, the direction of the prevailing wind, and the street's angle in the city. The effect of wind-pressure ventilation in the city is very complex. There are various phenomena such as canyon effect, Wen effect, wind-pressure phase effect, pyramid effect, wind-blocking effect. It is easy to produce a large wind shadow area in the middle of the building group and produce acute wind and static wind areas in the street and courtyard space, thus causing a large impact on the wind-pressure ventilation in the city.

Thermal pressure ventilation is another main mechanism of natural ventilation in the urban environment. The urban environment has special subsurface materials, and the surface temperature of the urban ground, which is mainly hard ground, is higher, which together with the large amount of heat generated by human living and production activities, causes the temperature of the city to be higher than that of the surrounding environment, thus leading to changes in air density and the formation of positive and negative pressure differences, which provide the driving force for the thermal pressure ventilation of the city.

In the continuous enclosed urban texture represented by Alba with low-rise buildings, when the external wind environment is good, the windward side will generate a positive pressure difference due to the blockage of the block buildings, and the negative pressure difference will be generated on the backside of the buildings when the airflow bypasses the block. When the negative shape space is placed inside the block, the negative shape as the leeward side generally presents two negative pressures, promoting the block's wind pressure ventilation. In contrast, when the negative shape height to width ratio gradually decreases, the negative shape is transformed from two negative pressures to one positive pressure and one negative pressure. The direction of wind pressure ventilation may be changed.

When the negative shape height to width ratio gradually increases, the airflow inside the courtyard gradually decreases. The temperature of the negative shape of the top space increases under the influence of solar radiation, and the density of air decreases, while the temperature of the lower air is low and the density is great. The heat exchange between the upper and lower air forms a vertical airflow, which drives the natural ventilation inside the building, and this effect becomes the chimney effect. The thermal pressure ventilation in the negative shape of the block is closely related to the temperature difference between the upper and lower surfaces of the block. The height to width ratio shows a positive correlation with the temperature difference. When the height to width ratio of the negative shape rises to a certain value, thermal pressure ventilation occupies the leading mechanism of natural ventilation in the block.

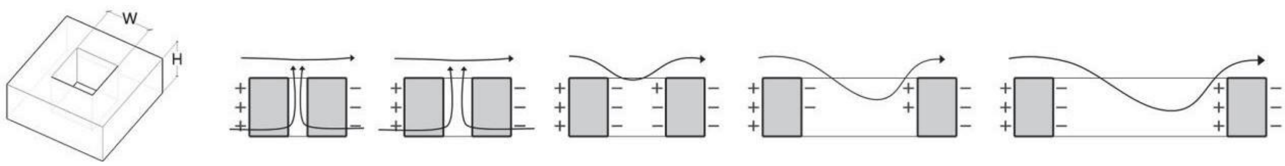


Fig. 101 Illustration of ventilation with different negative shape height to width ratio Source: Prof. Zhang Tong's Terroir Design Studio

In order to further research on the height to width ratio of negative shape space and wind environment in the city, a block in the city is extracted, and different negative shape height to width ratios are set and placed in the urban environment for wind environment simulation. Based on the characteristics of the height to width ratio of Alba negative shape, five sets of simulated conditions with the height to width ratio H/W of 3:1, 2:1, 1:1, 1:2, and 1:3 were set, respectively. The width of the street in the simulation model was set to 5m, the number of floors of the building was 4, the depth was 12m, and the window to wall ratio was set to 0.4.

Fig. 102 Illustration of the base model for wind environment simulation with negative shape height to width ratio Source: The author’s drawing

The simulation is carried out in two types: wind pressure alone (setting the wind speed outside the city without considering the influence of solar radiation) and thermal pressure alone (setting the solar radiation value without setting the wind speed outside the city). Under normal conditions, the natural ventilation of a city is usually the result of the combined effect of wind and thermal pressure, and one of the mechanisms dominates the other. During the simulation, separating the different ventilation mechanisms for the research facilitates a more detailed observation.

The solar radiation module of Airpak is used to simulate the solar irradiation, the latitude, and longitude values of Alba, Italy, are used for each model. The date and time are set to noon on the summer solstice. The initial temperature of walls and floors are set to 20 degrees C, the sunshine factor is set to 0.75, the wind direction is from southwest to northeast, the windows of the neighborhood buildings are fully open, and the wind speed is set to 1m/day, other basic parameters were set according to the software default.

The wind speed simulation results of each model are organized as follows：

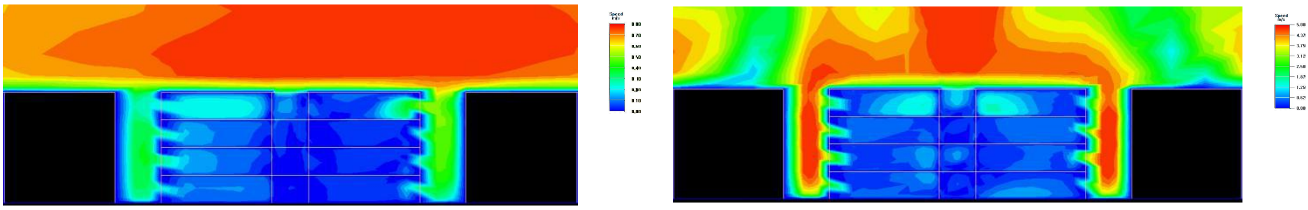


Fig. 103 B=3:1　4.5m plan and south-north section in wind pressure simulation Source: The author’s drawing

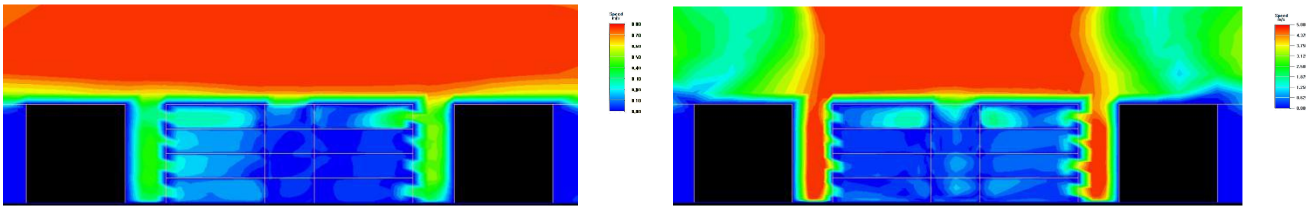


Fig. 104 B=3:1　4.5m plan and south-north section in thermal pressure simulation Source: The author’s drawing

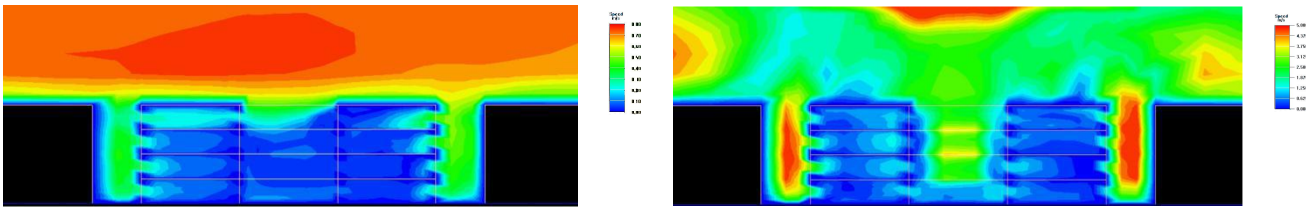


Fig. 105 B=2:1　4.5m plan and south-north section in wind pressure simulation　Source: The author’s drawing

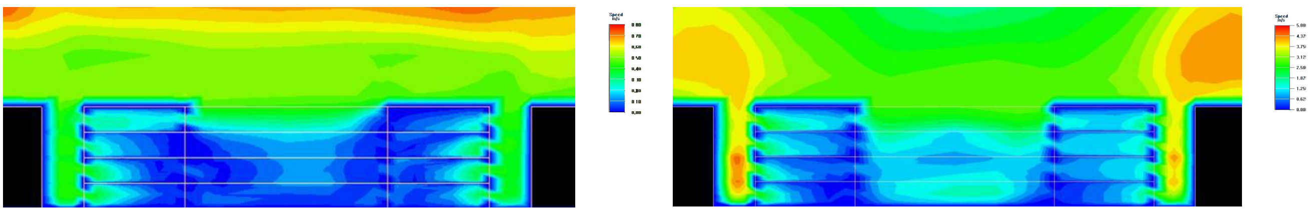


Fig. 106 B=2:1　4.5m plan and south-north section in thermal pressure simulation Source: The author’s drawing

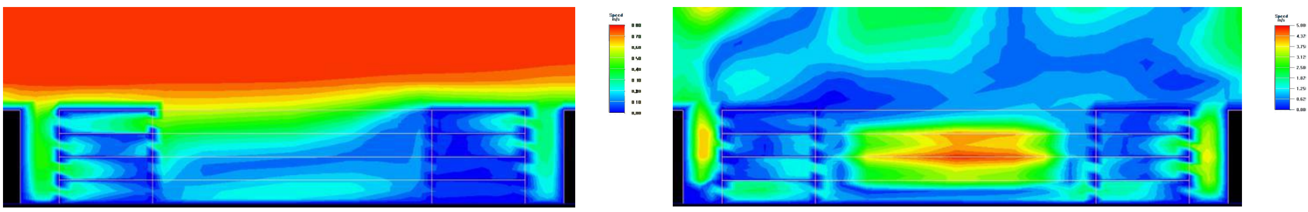


Fig. 107 B=1:1　4.5m plan and south-north section in wind pressure simulation Source: The author’s drawing

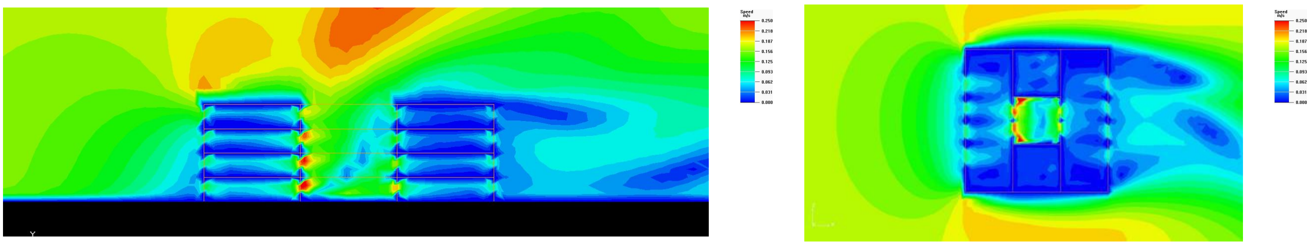


Fig. 108 B=1:1　4.5m plan and south-north section in thermal pressure simulation Source: The author's drawing

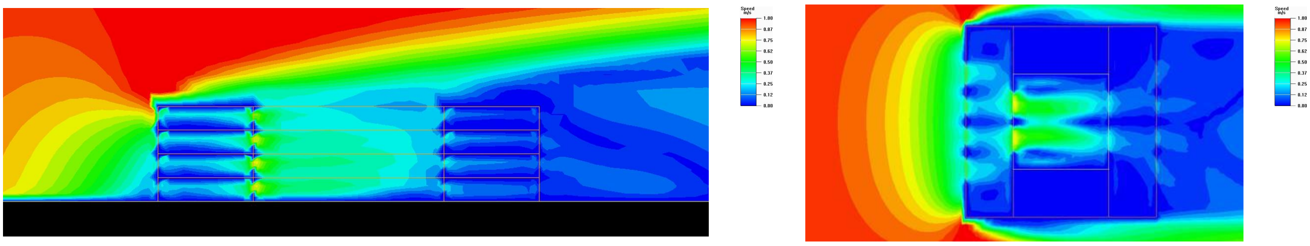


Fig. 109　B=1:2　4.5m plan and south-north section in wind pressure simulation Source: The author's drawing

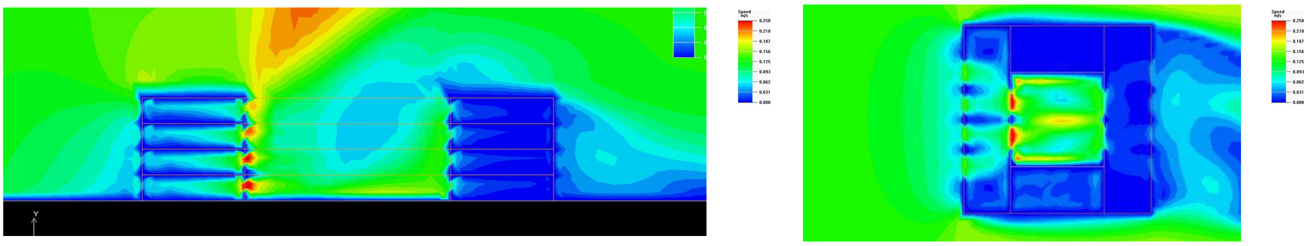


Fig. 110　B=1:2　4.5m plan and south-north section in thermal pressure simulation Source: The author's drawing

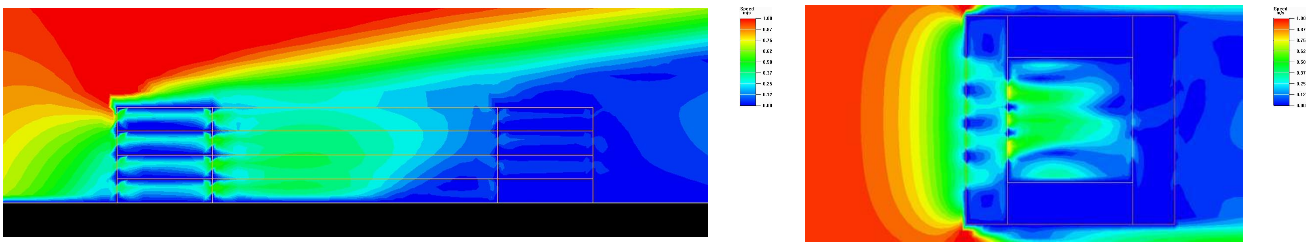


Fig. 111　B=1:3　4.5m plan and south-north section in wind pressure simulation Source: The author's drawing

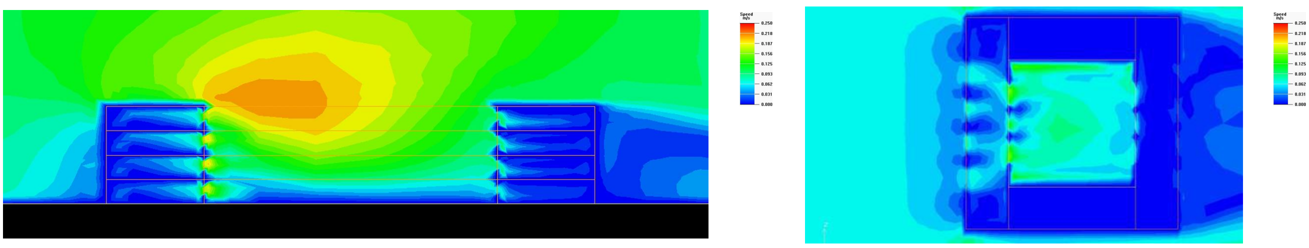


Fig. 112　B=1:3　4.5m plan and south-north section in thermal pressure simulation Source: The author's drawing

Since wind and thermal pressure simulations are carried out separately, there are many simulation conditions.

Observe the wind pressure ventilation of the model with B=1:1. It is found that the wind direction inside the negative shape is horizontal. Moreover, the wind pressure is not affected by the vortex inside the block. Furthermore, it does not occur updraft condition. The wind direction is mostly horizontal on each floor of the building interior, and the wind speed is uniformly distributed in the interior.

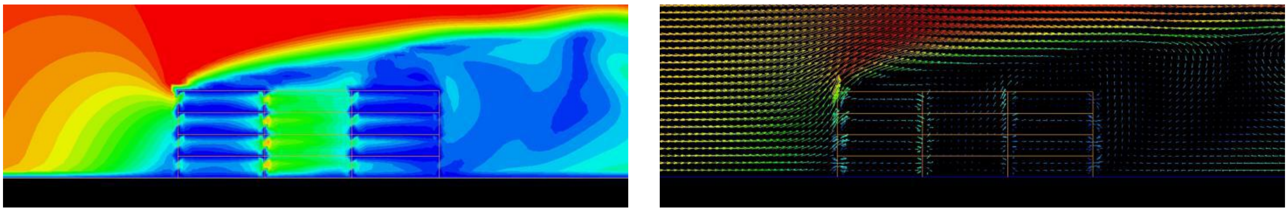


Fig. 113 Wind speed cloud diagram and vector diagram of the north-south section of wind pressure ventilation at B=3:1 Source: The author’s drawing

Observe the wind pressure ventilation of each group of models with B>1:1. The wind is horizontal in the interior of each floor of the building. The overall distribution of wind speed is uneven. Due to the blockage of the negative shape space inside the block, the wind direction inside the negative shape is transformed from horizontal to vertical. It is found that when B=3:1, the ventilation in the vertical direction inside the negative shape is more obvious than when B=2:1. Since the opening on the side of the negative body is small, the wind opening appears the Venturi effect, and the wind speed inside the building on the leeward side is faster than that on the windward side. The average wind speed inside the building and in the negative shape decreases continuously with the height-to-width ratio of the negative shape. The barrier effect of the narrow negative shape space on the air is obvious.

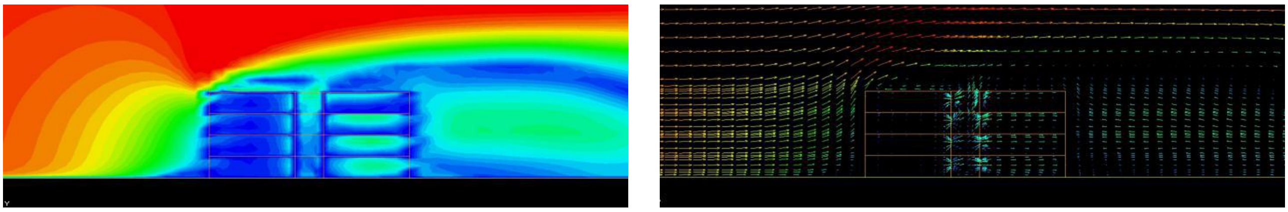


Fig. 114 Wind speed cloud diagram and vector diagram of the north-south section of wind pressure ventilation at B=3:1 Source: The author’s drawing

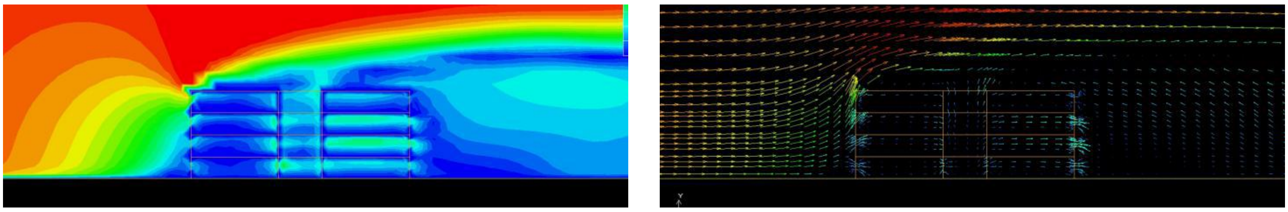


Fig. 115 Wind speed cloud diagram and vector diagram of the north-south section of wind pressure ventilation at B=2:1 Source: The author’s drawing

Observe the wind pressure ventilation of each group of models with B < 1. The wind is mostly horizontal on each floor. The negative shape of the building and the wind velocity distribution is more uniform in each floor and negative shape of the building, and there is a turbulent local area inside the negative shape without obvious vertical airflow. With the decrease of the negative shape height to width ratio, the wind of the external environment is more disturbing to the negative shape interior. The wind speed of the formed turbulent zone is larger, which is opposite to the wind pressure ventilation of the lower floors of the leeward side of the building, which is not conducive to natural ventilation. The wind condition inside the negative shape gradually tends to the external wind environment, decreasing the height-to-width ratio.

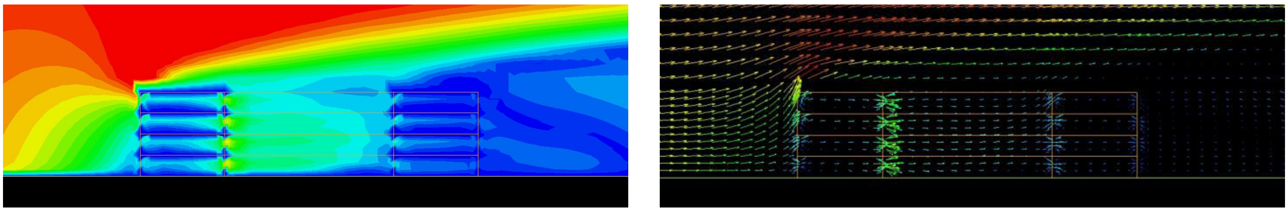


Fig. 116 Wind speed cloud diagram and vector diagram of the north-south section of wind pressure ventilation at B=2:1 Source: The author's drawing

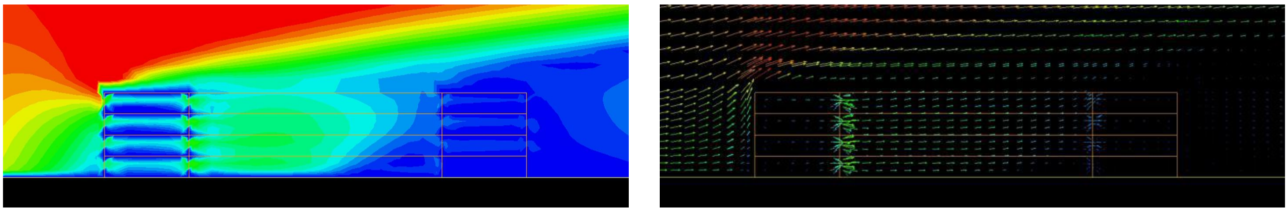


Fig. 117 Wind speed cloud diagram and vector diagram of the north-south section of wind pressure ventilation at B=3:1 Source: The author's drawing

Observe the situation of thermal pressure ventilation at B=1:1. Because the exterior façade of the block and negative shape façade receive various amounts of solar radiation, it forms a horizontal thermal pressure. There are horizontal winds on each floor, and the wind inside the negative figure is chaotic and turbulent.

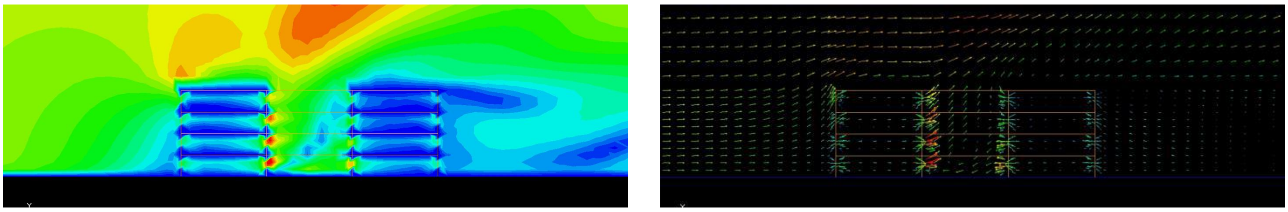


Fig. 118 Wind speed cloud diagram and vector diagram of the north-south section of thermal pressure ventilation at B=1:1 Source: The author's drawing

Observe the situation of thermal pressure ventilation at B>1:1. There is a more obvious vertical ventilation trend in the negative shape of each group of models, and there is a chimney effect. The effect is more obvious as the aspect ratio increases.

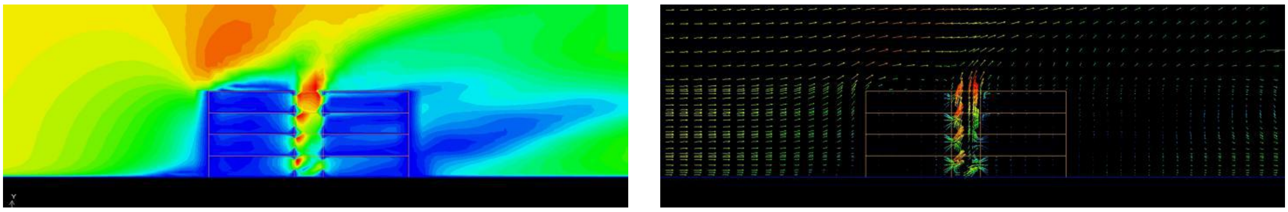


Fig. 119 Wind speed cloud diagram and vector diagram of the north-south section of thermal pressure ventilation at B=3:1 Source: The author’s drawing

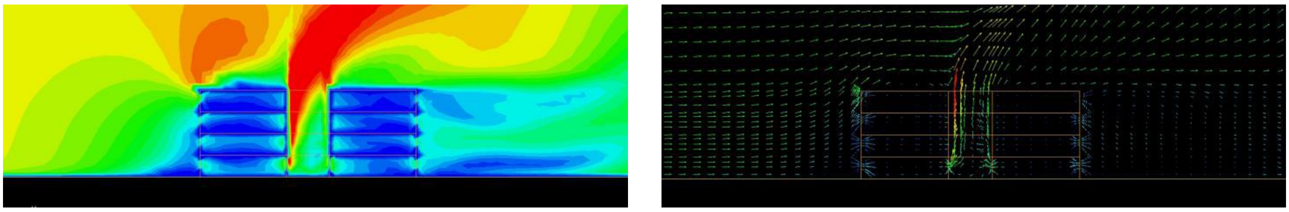


Fig. 120 Wind speed cloud diagram and vector diagram of the north-south section of thermal pressure ventilation at B=2:1 Source: The author’s drawing

Observe the situation of thermal pressure ventilation at B<1:1. It is found that there is no obvious vertical ventilation trend inside each model, and there is natural wind infiltration inside the negative figure. The vortex phenomenon is generated in the courtyard.

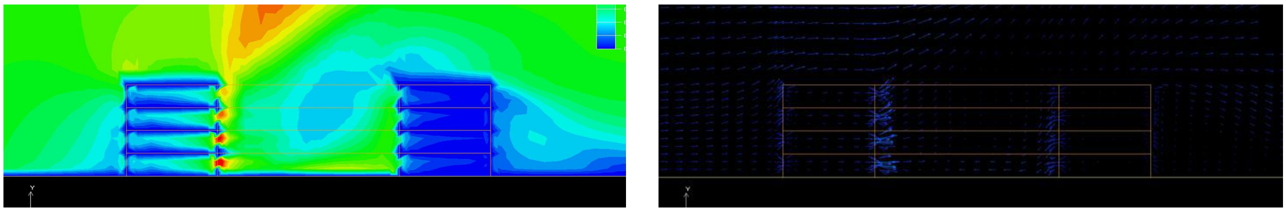


Fig. 121 Wind speed cloud diagram and vector diagram of the north-south section of thermal pressure ventilation at B=1:2 Source: The author’s drawing

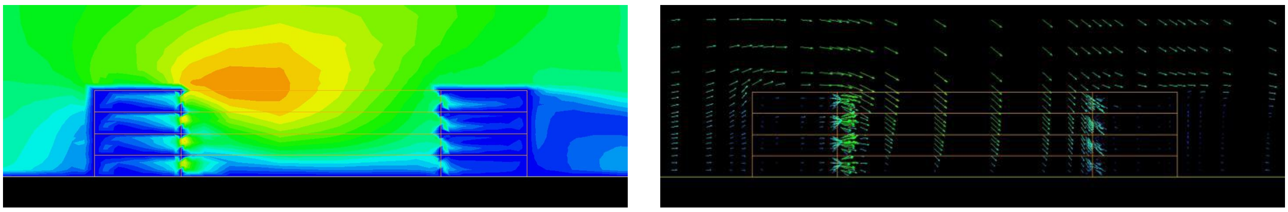


Fig. 122 Wind speed cloud diagram and vector diagram of the north-south section of thermal pressure ventilation at B=1:3 Source: The author’s drawing

After analyzing the five groups of working conditions set up, the following conclusions can be obtained: the trend of wind pressure ventilation inside the urban block decreases with the increase of the height to width ratio of the negative shape, while the trend of thermal pressure ventilation increases with the decrease of the negative shape, and when the height to width ratio of the negative shape is above 2, a strong chimney effect occurs inside the negative shape, and the effect is enhanced with the increase of the height to width ratio; when the height to width ratio is less than 2, the mechanism of wind pressure ventilation occupies a dominant position.

In summary, a Humid Temperate Climate can be divided into two summer and transitional seasons when the regulation objective is natural ventilation. When the external wind environment is poor, the wind pressure difference on the building's surface is small. The negative shape height to width ratio above two can effectively promote the thermal pressure ventilation effect in the city. The chimney effect is used to discharge the hot air inside the building from the negative shape space. Therefore improving the wind and thermal environment inside the room and the negative shape; while the external wind environment is good, the wind pressure ventilation effect is better when the negative shape height to width ratio is less than or equal to 1. The urban crossing wind passes through the interior of the building and takes away the indoor heat. For the important negative shape space used for public activities in the city, a height to width ratio of less than 0.5 can effectively increase the wind speed in the negative shape ground space and increase people's comfort in outdoor activities.

When preventing cold wind infiltration in winter is the regulation goal, the height-to-width ratio of a negative shape greater than or equal to 1 can effectively reduce the wind forming internal turbulence in the negative shape space. Therefore, reducing the amount of wind infiltrating the negative shape and the building interior and increasing the comfort of the indoor and outdoor spaces.

4.3.2.3 Street height to width ratio (A) and wind environment

The height to width ratio of urban streets has a corresponding relationship with the wind environment of the city. Generally speaking, while keeping the building height unchanged, increasing the street height to width ratio will make the street width narrower, compressing the passage of external wind into the city's interior and reducing the permeability of the urban space. In addition, with the change of the street height to width ratio in the street section, the form of turbulence formed inside the street will also change, thus affecting the wind environment on the street surface and the comfort of the street public space.

To further investigate the relationship between street height to width ratio and wind environment, six experimental models with street height to width ratios of 1:1, 1.5:1, 2:1, 2.5:1, 3:1, and 3.5:1 were set up for experiments. The number of floors of the buildings in the block group is 4, the height is 12m, the depth is 12m, the width of the street is 12m, 8m, 6m, 4.8m, 4m, and 3.43m, the width of the courtyard inside the block group is 20m, and the window to wall ratio is 0.4.

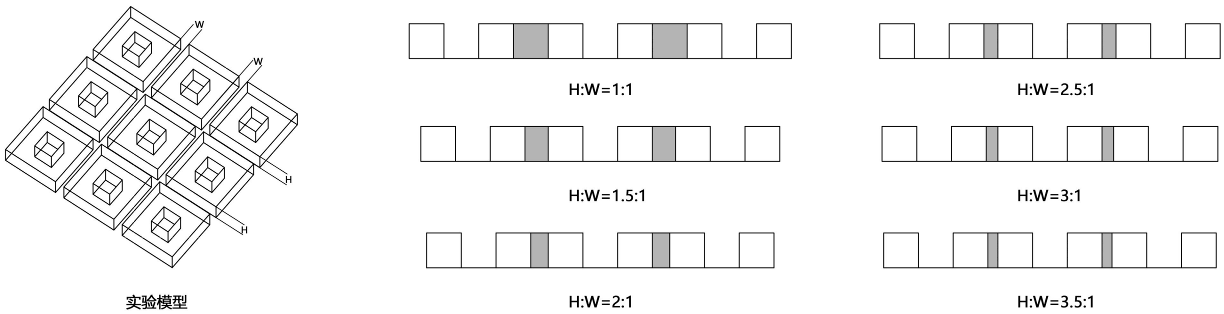


Fig. 123 Schematic diagram of the basic model of street aspect ratio and wind environment simulation. Source: The author's drawing

The results of the experimental models for each group are organized as follows：

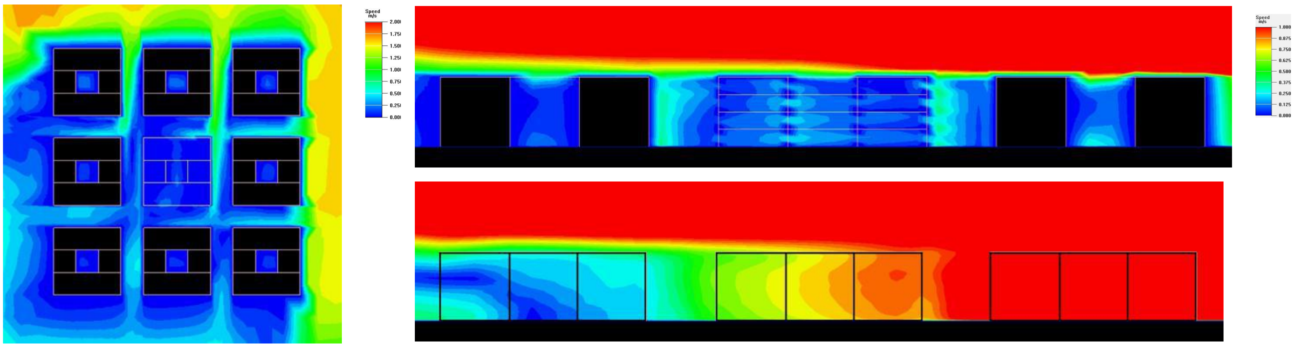


Fig. 124 Wind speed diagram of 1.5m plan and street profile for a street height to width ratio A of 1:1 Source: The author's drawing

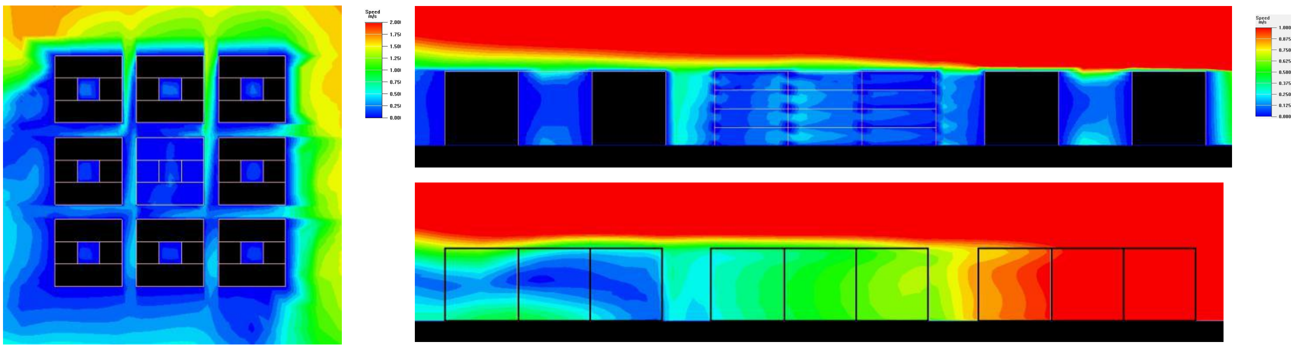


Fig. 125 Wind speed diagram of 1.5m plan and street profile for a street height to width ratio A of 1.5:1 Source: The author's drawing

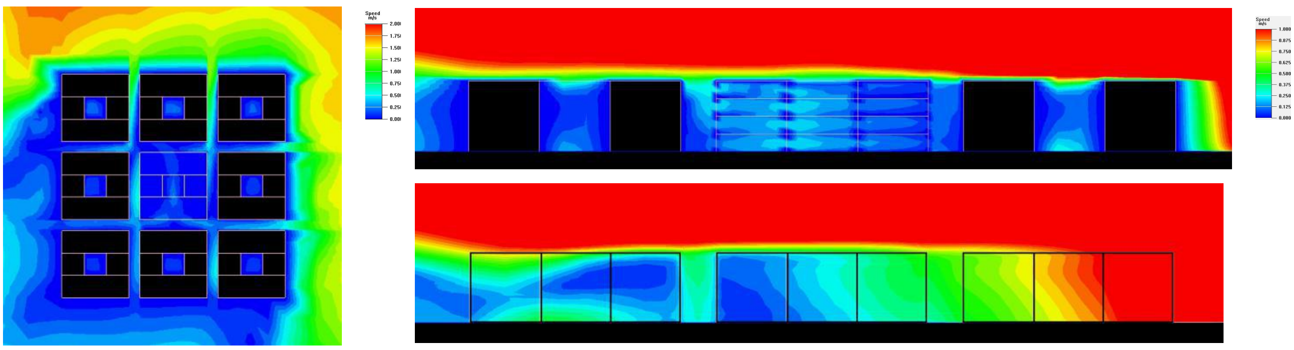


Fig. 126 Wind speed diagram of 1.5m plan and street profile for a street height to width ratio A of 2:1 Source: The

author’s drawing

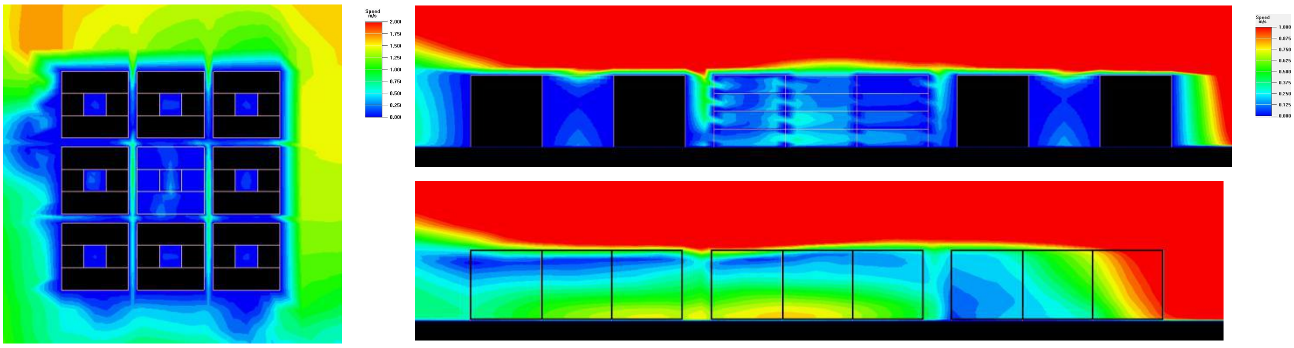


Fig. 127 Wind speed diagram of 1.5m plan and street profile for a street height to width ratio A of 2.5:1 Source: The author’s drawing

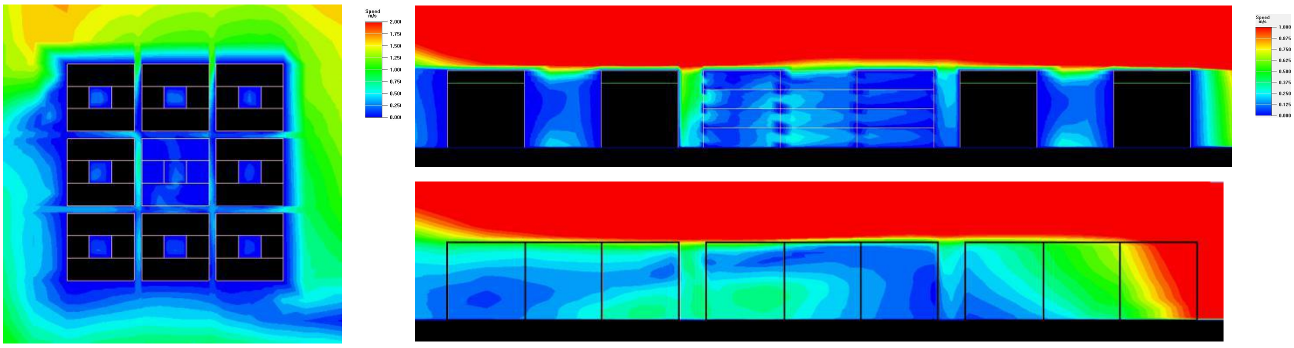


Fig. 128 Wind speed diagram of 1.5m plan and street profile for a street height to width ratio A of 3:1 Source: The author’s drawing

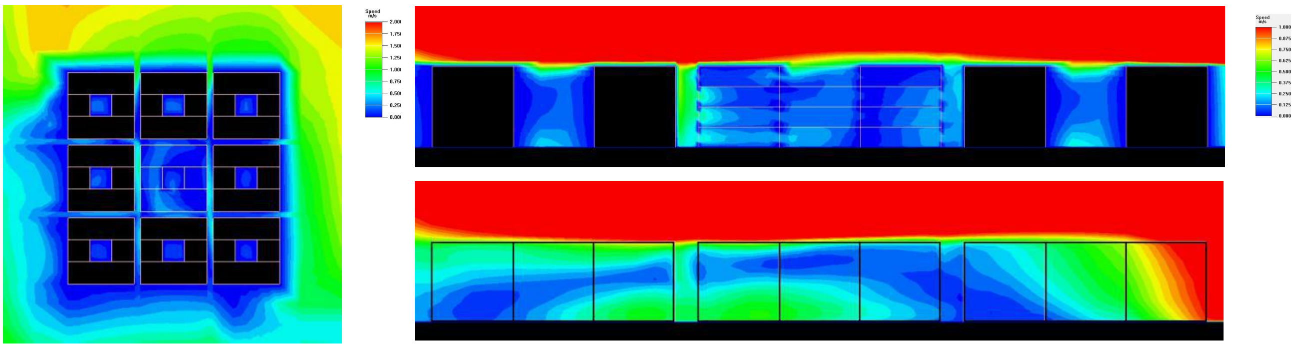


Fig. 129 Wind speed diagram of 1.5m plan and street profile for a street height to width ratio A of 3.5:1 Source: The author’s drawing

In contrast, when the street height to width ratio A is less than 2, the wind speed is higher at the street entrance in the direction of the dominant wind, reaching about 1m/s. The wind speed decreases gradually with the extension of the street. In another aspect, the wind speed distribution on the street plane is more uneven, and irregular turbulence is easily formed at the intersection, making the wind pressure distribution on the block surface uneven and forms a vortex phenomenon on the group surface. Due to the uneven distribution of wind speed on the street section, the effective wind-through effect is not formed inside the building. The direction and efficiency of natural ventilation are greatly affected.

When the street height to width ratio A is greater than 2, the wind speed on the street is reduced, but the overall distribution is uniform, the wind speed on the street is maintained at about 0.5m/s, and the turbulence phenomenon is not formed on the street plane. An effective natural ventilation effect can be formed inside the building, and the best effect of natural ventilation is achieved when the height to width ratio is 2 and 2.5.

In summary, under the Humid Temperate Climate, increasing the height to width ratio of the street can effectively reduce the wind speed of winter winds and avoid turbulence on the street, which can cause uncomfortable feelings for pedestrians. Increasing the height to width ratio of the street can also increase the uniformity of the wind distribution on the street, increase the local street wind speed, promote the natural ventilation inside the building, and facilitate the ventilation to cooling effect in summer. In the experiments of the model, the ventilation effect is best when the height to width ratio is between 2 and 2.5.

4.3.2.4 Passive space occupation ratio and wind environment

The ratio of passive space in the city is closely related to the building’s depth, and the building’s depth has a greater impact on the natural ventilation of the city. Generally speaking, when the depth of the building is less than 14 meters, it is easier to form wind through the building's interior. When the depth of the building is greater than 14 meters, the interior of the building is more obstructive to the natural wind so that the wind cannot pass through the building. Therefore, the building parts with smaller depth are usually ventilated by wind pressure, and the parts of the building with larger depth are ventilated by thermal pressure.

To further investigate the city's passive space ratio and wind environment, a block group is extracted. Different passive space ratios are set and placed in the urban environment for wind environment simulation. Six sets of simulated conditions are set for the block-enclosed buildings with depths of 6m, 9m, 12m, 15m, 18m, and 21m, respectively. The width of the street is 5m, and the number of floors of the building is 4. The width of the internal courtyard is 20m, and the window to wall ratio is 0.4.

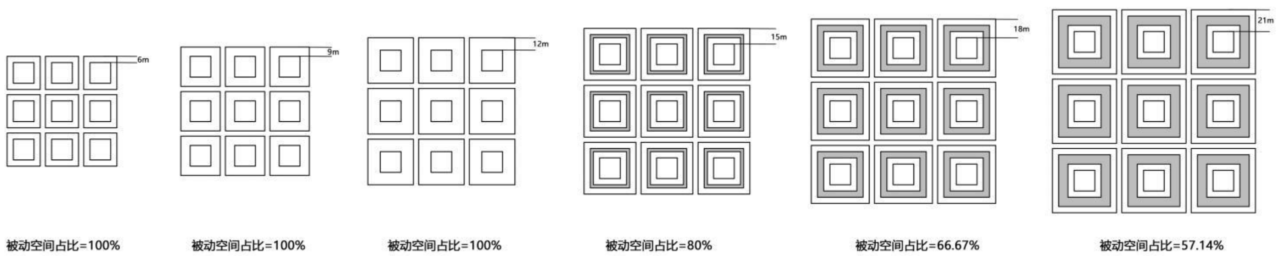


Fig. 130 Illustration of the base model for wind environment simulation with passive space ratio Source: The author’s drawing

The results of the experimental models for each group are organized as follows：

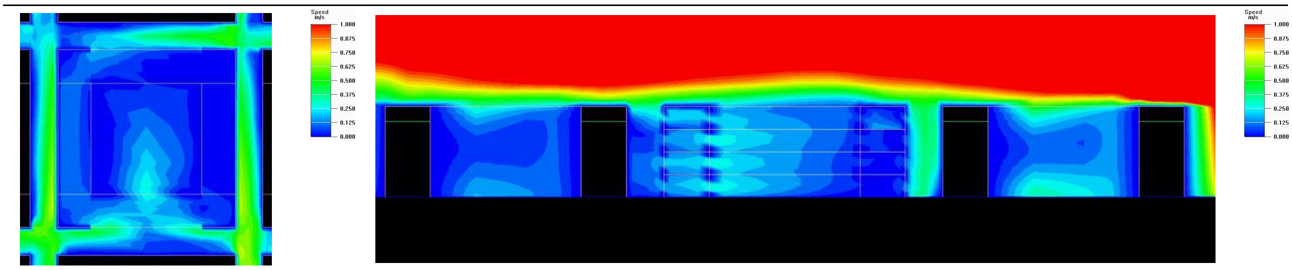


Fig. 131 Wind speed diagram of 1.5m plan and east-west profile when the building depth is 6m Source: The author’s drawing

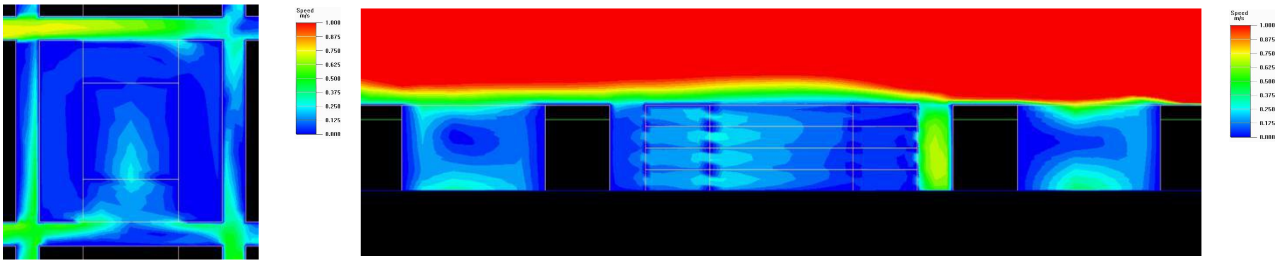


Fig. 132 Wind speed diagram of 1.5m plan and east-west profile when the building depth is 9m Source: The author’s drawing

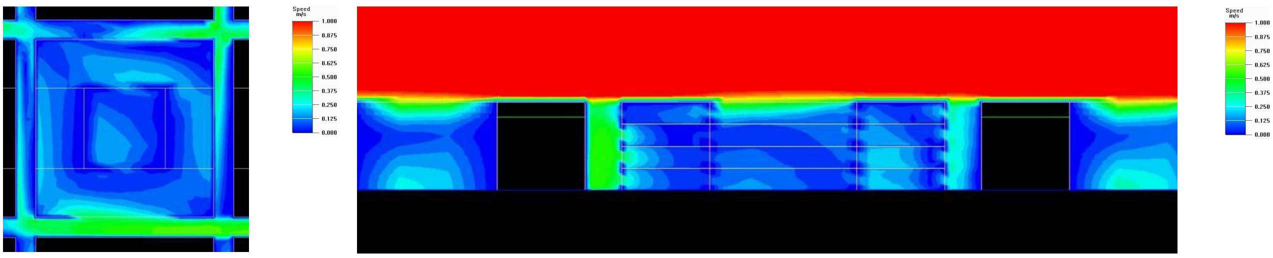


Fig. 133 Wind speed diagram of 1.5m plan and east-west profile when the building depth is 12m Source: The author’s drawing

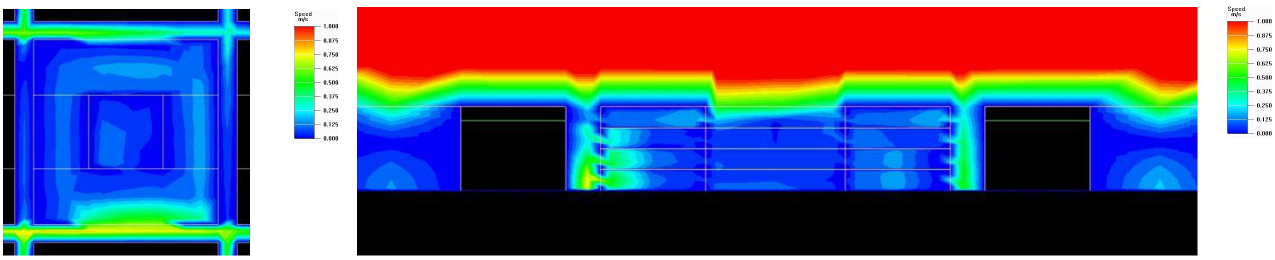


Fig. 134 Wind speed diagram of 1.5m plan and east-west profile when the building depth is 15m Source: The author’s drawing

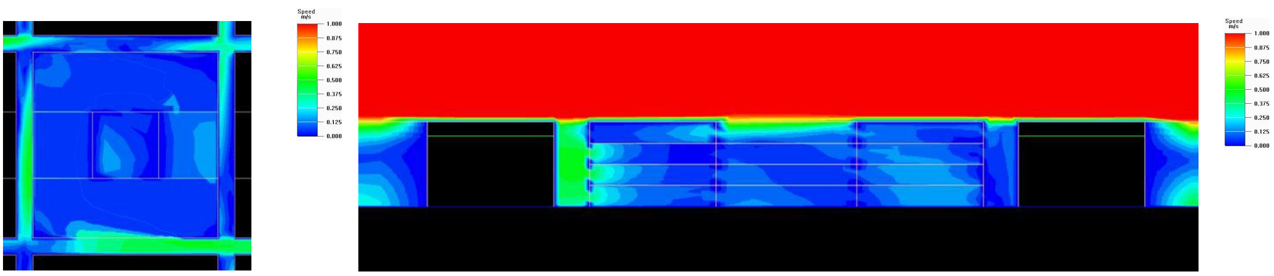


Fig. 135 Wind speed diagram of 1.5m plan and east-west profile when the building depth is 18m Source: The author’s drawing

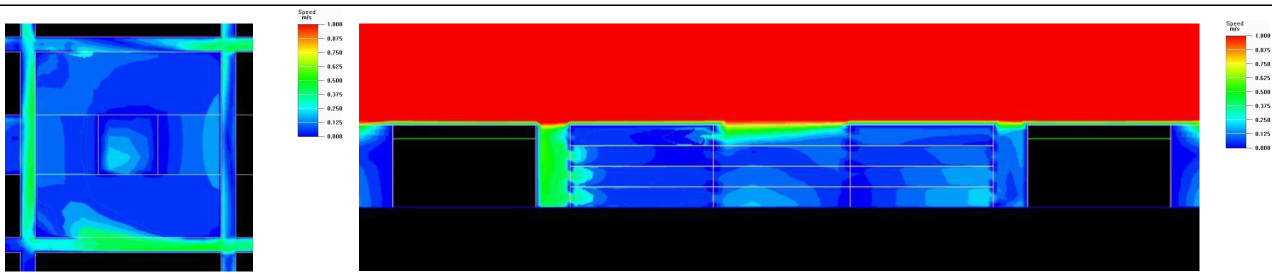


Fig. 136 Wind speed diagram of 1.5m plan and east-west profile when the building depth is 21m Source: The author’s drawing

The comparison found that when the building depth is 6m and 9m, there is obvious horizontal airflow that emerged along the street with higher wind speed in the block building. The wind enters the building interior from both sides of the street and penetrates from the negative shape space, forming a good natural ventilation effect. The average wind speed inside the building can reach 0.25m/s, which belongs to the comfortable wind speed range inside the building. Inside the negative shape space, the wind in the horizontal direction is dominant, and no vortex phenomenon is formed in the courtyard.

When the depth of the building is 12m, the wind from the street cannot pass through the interior. The wind enters the interior of the building from the side. When it encounters an obstruction on the way, the wind velocity decreases. Additionally, The top floor of the block forms a natural ventilation effect in the opposite direction in the direction of the windward wind. On the other side of the block, the ventilation effect of the interior is enhanced because the wind pressure is lower in the negative shape space and the street wind partially penetrates from the street. No obvious vortex phenomenon is formed inside the negative shape space because the horizontal wind is opposite to the external wind.

When the building depth is greater than 12m, it can be found that as the building depth increases, the area ratio of the low wind speed zone in the interior of both sides of the building gradually increases. The wind speed distribution becomes more uneven, indicating that when the wind pressure difference on the building's building surface is small, the ventilation effect in the building's interior is not obvious when the building depth is greater than 12m. The simulation experiment does not consider the influence of window opening position, indoor building layout, and other factors. When these factors exist, the blockage of the building for the wind becomes bigger, which is more unfavorable to the natural ventilation of the block. Moreover, inside the negative shape, there is a very obvious vortex generation.

Under Humid Temperate Climate conditions, with hot temperatures in summer and suitable climates in spring and autumn, natural ventilation in the city can greatly improve the comfort of urban public space and building space to a large extent. When the depth of the building is less than or equal to 12m-i.e., the ratio of passive space is 100%. However, the corresponding block shape coefficient is increased, which is not conducive to the heat preservation of the building in winter.

However, it can form a good natural ventilation effect inside the building and remove the heat generated inside. While the depth of the building is greater than 12m, the effect of natural ventilation inside the building is greatly reduced, although it can store heat in winter. However, the windless environment inside the building in summer and spring, and autumn will significantly reduce the comfort level inside the building.

4.3.3 The Conclusion of Effect Mechanism

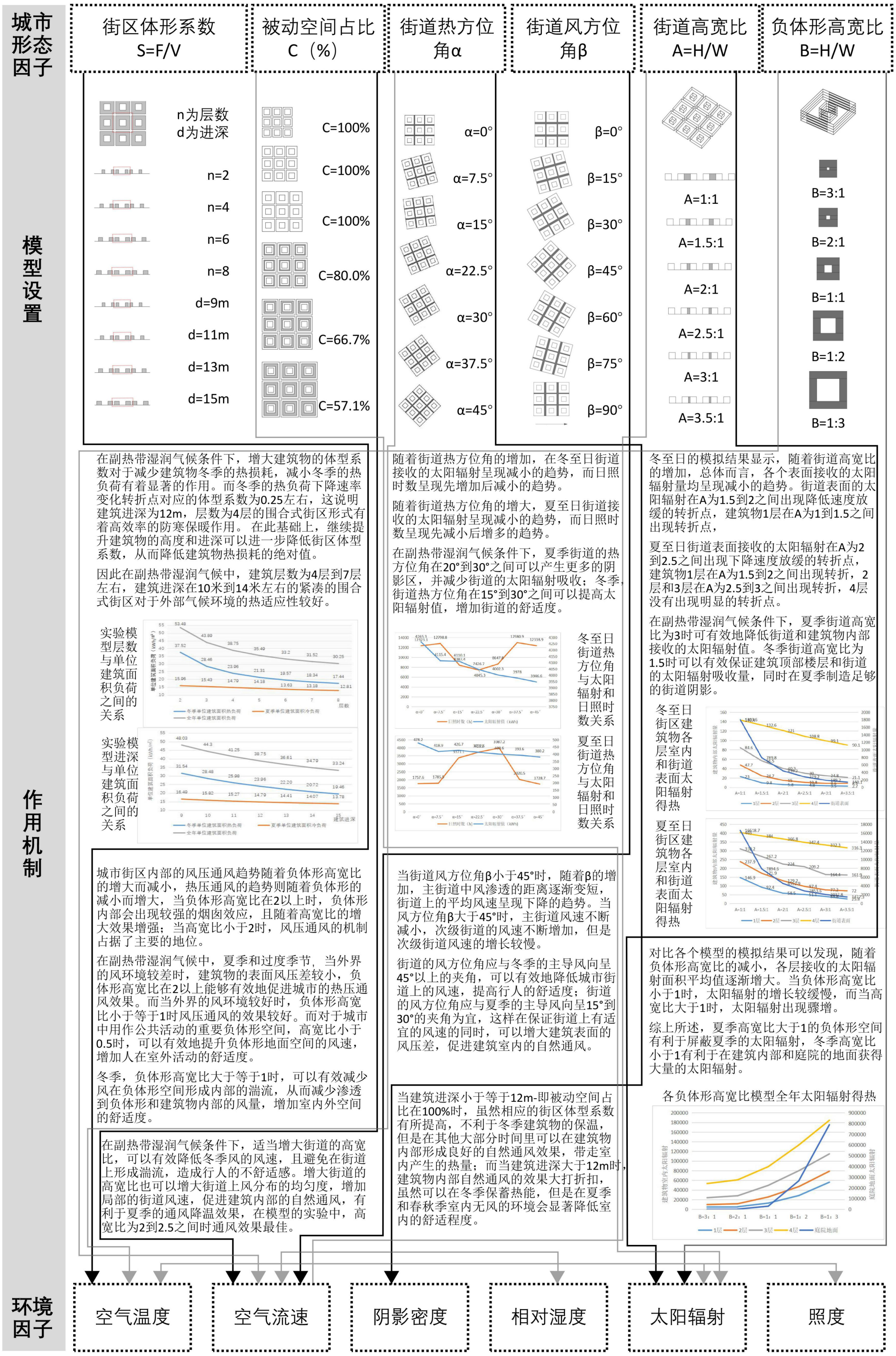


Fig. 137 Summary of the mechanism of urban environmental physical factors and urban morphological factors in subtropical humid climate. Source: The author’s drawing

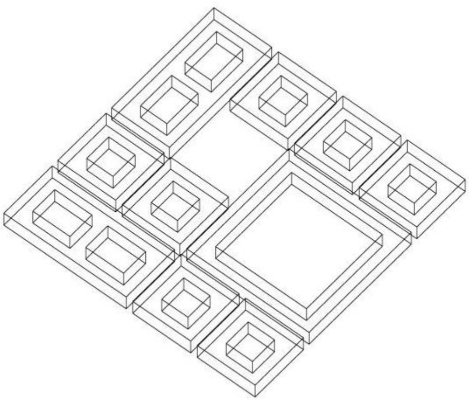
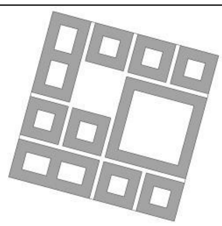
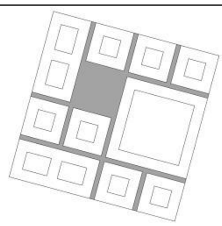
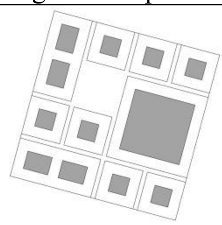
4.4 Conclusion and Verification of the Thermal Adaptive Alba-Model

The analysis of the mechanism of the urban morphology and the urban thermal and wind environment can summarize the valid range of the Alba-Model data for the thermally adaptive urban morphology in the Humid Temperate Climate(Table 19). Based on Alba, Italy's urban morphology parameters, the urban morphology of Alba is transformed into an Alba-Model that adapts to the Humid Termparte Climate through the comparative analysis of physical environmental performance. The data of the urban form factor of the Alba-Model meets the valid range in Table 19. It has the inductive nature of the type, the visibility of the texture, and the analytical nature of the quantitative calculation.

Table 19 The effective range of the urban form factor of the Alba model Source: The author’s drawing

<table>
<tr><td rowspan="2">Urban form factors</td><td colspan="2">Block form</td><td colspan="3">Street form</td><td colspan="3">Negative shape form</td></tr>
<tr><td>Block Shape Coefficient</td><td>Negative space ratio（%）</td><td>Street aspect ratio</td><td>Wind azimuth（°）</td><td>Thermal azimuth（°）</td><td colspan="2">Negative shape aspect ratio</td><td>Negative shape area ratio（%）[37]</td></tr>
<tr><td rowspan="2">winter</td><td rowspan="2">0.22-0.28</td><td rowspan="2">—</td><td rowspan="2">1-2</td><td rowspan="2">45-90</td><td rowspan="2">15-30</td><td>House</td><td>＜1 or ＞ 1[38]</td><td rowspan="4">20-35</td></tr>
<tr><td>Public space</td><td>＜1</td></tr>
<tr><td rowspan="2">summer</td><td rowspan="2">—</td><td rowspan="2">95-100</td><td rowspan="2">＞3</td><td rowspan="2">15-30</td><td rowspan="2">15-30</td><td>House</td><td>＞2 or ＜1</td></tr>
<tr><td>Public space</td><td>＜0.5</td></tr>
</table>

Table 20Urban morphological characteristics and data of an Alba model Source: The author’s drawing

<table>
<tr><td>Model Axonometric Diagram</td><td colspan="2">Block form</td><td colspan="3">Street form</td><td colspan="3">Negative shape form</td></tr>
<tr><td rowspan="4"></td><td colspan="2"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>Block Shape Coefficient</td><td>Negative space ratio</td><td>Street aspect ratio</td><td>Wind azimuth</td><td>Thermal azimuth</td><td colspan="2">Negative shape aspect ratio</td><td>Negative area ratio</td></tr>
<tr><td rowspan="2">0.238</td><td rowspan="2">100%</td><td rowspan="2">1.6</td><td rowspan="2">30°</td><td rowspan="2">15°</td><td>House</td><td>0.6</td><td rowspan="2">31.5%</td></tr>
<tr><td>Public space</td><td>0.17</td></tr>
</table>

[37] 负体形的面积比数据作为划分意大利传统城镇的热适应性类型的主要数据在第二章之中已进行讨论，因其与负体形的高宽比存在相互对应关系，因此作用机制的讨论只涉及负体形高宽比。

[38] 负体形高宽比小于 1 时，有利于冬季获得较多的太阳辐射，负体形高宽比大于 1 时，有利于冬季防止冷风入侵，这里的取舍视室外风环境的好坏与负体形空间的具体需求而定。

The model in Table 20 is an Alba-Model, and its various urban morphological data are within the valid range. The average shape coefficient of the model block is 0.238, which is conducive to reducing the heat load of the building in winter, and the passive space accounts for 100%, which is conducive to natural ventilation and lighting in summer and transition seasons. The street aspect ratio is 1.6, the wind azimuth angle is 30°, and the thermal azimuth angle is 15° so that the street space receives solar radiation in winter while ensuring thermal comfort in summer. In the model's negative body shape aspect ratio, the private house courtyard aspect ratio is 0.6. The public courtyard aspect ratio is 0.17, and the negative body shape area ratio is 31.5, which makes the negative body shape ground space have high thermal comfort.

In order to further verify the typicality of the Alba-Model in the subtropical humid climate zone, two towns located in the same climate zone, Pavia and Treviso, were selected for comparative analysis of data. It can be seen from Table 21 and Table 22 that in terms of block shape, the average Block Shape Coefficients of Pavia and Treviso are both around 0.275, which is within the effective range of 0.22 to 0.28. Their passive space occupies a relatively low effective range due to the relatively low passive space occupancy of public buildings such as churches in the selected urban area. In terms of street morphology, the aspect ratio of most streets in the two towns is between 1.5 and 2, which is basically in line with the effective range of the Alba-Model. Pavia's wind azimuth angle of 33° and thermal azimuth angle of 17° is consistent with Alba-Model's effective range. Treviso's azimuth is more difficult to judge. In terms of negative figure form, the negative figure aspect ratios of the two urban residential buildings are both above two, and the public buildings are below 1, which is within the effective range. At the same time, their negative body shape area ratio is also within the effective range.

It can be seen that the Alba model of thermally adaptable urban morphology can be verified in other Italian cities and towns in a humid subtropical climate, indicating that it has certain typical and generalized characteristics.

Table 21 Typical data on the urban form of Pavia[39] Source: The author’s drawing

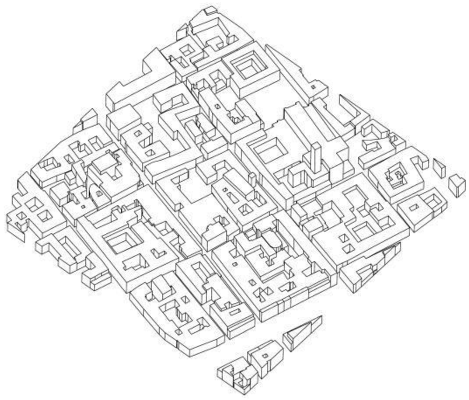
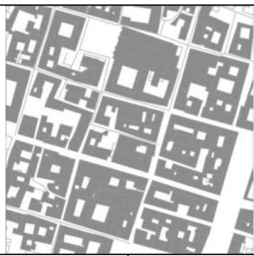
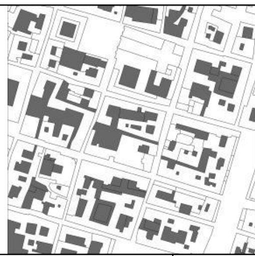
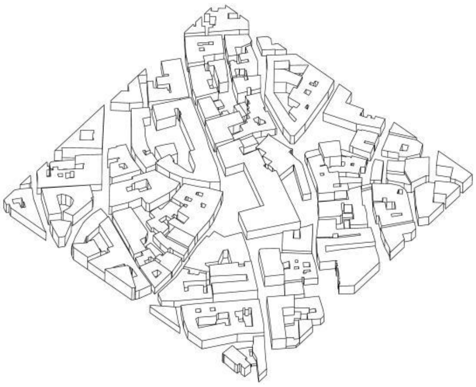
<table>
<tr><td>Model Axonometric Diagram
（400m*400m）</td><td colspan="2">Block form</td><td colspan="3">Street form</td><td colspan="3">Negative shape form</td></tr>
<tr><td rowspan="4"></td><td colspan="2"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>Block Shape Coefficient</td><td>Negative space ratio</td><td>Street aspect ratio</td><td>Wind azimuth</td><td>Thermal azimuth</td><td colspan="2">Negative shape aspect ratio</td><td>Negative area ratio</td></tr>
<tr><td rowspan="2">0.274</td><td rowspan="2">90%</td><td rowspan="2">1.5-2</td><td rowspan="2">33°</td><td rowspan="2">17°</td><td>House</td><td>2.41</td><td rowspan="2">31.66%</td></tr>
<tr><td>Public space</td><td>0.37</td></tr>
</table>

Table 22 Typical data on the urban form of Treviso[40] Source: The author’s drawing

<table>
<tr><td>Model Axonometric Diagram
（400m*400m）</td><td colspan="2">Block form</td><td colspan="3">Street form</td><td colspan="3">Negative shape form</td></tr>
<tr><td rowspan="4"></td><td colspan="2"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>Block Shape Coefficient</td><td>Negative space ratio</td><td>Street aspect ratio</td><td>Wind azimuth</td><td>Thermal azimuth</td><td colspan="2">Negative shape aspect ratio</td><td>Negative area ratio</td></tr>
<tr><td rowspan="2">0.276</td><td rowspan="2">92%</td><td rowspan="2">1.7-2.4</td><td rowspan="2">—</td><td rowspan="2">—</td><td>House</td><td>3.5</td><td rowspan="2">28.15%</td></tr>
<tr><td>Public space</td><td>0.49</td></tr>
</table>

4.5 Chapter Conclusion

This chapter analyzes the external urban environment and urban morphology by sub-items, taking the traditional Italian city morphology as a reference, summarizing and extracting the basic model of the urban morphology, and introducing the climate of Alba as the test conditions. Aiming at the thermal environment and wind environment of the city, the author, specifically studies the block shape factor (S), the passive space ratio of the block, the street thermal azimuth (α), the

39 表中的数据均为选取城镇范围内的平均数据

40 表中的数据均为选取城镇范围内的平均数据

street wind azimuth (β), the street aspect ratio (A=H/W), and the negative aspect ratio (B=H/W). The internal mechanism of the interaction between these parameters and the physical properties of the urban environment. In the actual research, the author focuses on the summer and winter seasons and summarizes and summarizes the simulation results of the performance simulation software. From the perspectives of ventilation, shading, and cooling in summer, and lighting and warmth in winter, the author sorted out the range of block shape coefficients suitable for Humid Temperate Climate conditions, the range of passive space occupied by the block, the angle range of street thermal azimuth and wind azimuth, and the Appropriate street range of aspect ratio and negative figure aspect ratio. In this way, a thermally adaptive urban morphology model under Humid temperate Climate conditions is established.

5. Conclusion

5.1 Conclusion of the Research

Based on environmental conditioning and formal energy laws, this research explores the mechanisms of thermal adaptation of urban morphology in a Humid Temperate Climate. Moreover, it analyzes and studies several morphological elements of Alba, a typical representative city in this climatic region of Italy. The research reveals the interaction mechanism between urban morphology and environmental physical performance and establishes a thermal adaptive Alba-Model that can adapt to Humid Temperate Climate.

This research takes Alba, Italy, as an example because, in the morphogenesis of traditional Italian towns, the different climates in different places have significant interaction with urban morphology. The author starts his research from the traditional towns and is inspired by the typology. Based on the principle of different thermal adaptability mechanisms in the Humid Temperate Climate, the author constitutes a visual and quantitative analysis method and schematic language to analyze and summarize the urban morphology model of this climatic zone. These methods provide design guidance and suggestions with environmental significance for the urban form.

The main research work and conclusions of this paper in the theoretical aspects of thermal comfort and thermal adaptation of urban morphology are as follows:

1) Constructed the "urban environment ternary model" of energy and material between External Energy System, Urban Conditioning System, and Human Response System, and analyzed the climate conditioning mode and significance of urban form from the perspective of urban thermal environment theory and thermal comfort theory in principle.
2) The environmental physical factors affecting urban morphology are proposed, including solar radiation, shadow density, and airflow rate at the level of urban space, air temperature, and airflow rate at the level of building space. Meanwhile, the relationship with the human comfort index is established by combining the environmental physical factors.
3) The generating factors of urban morphology and their variables are proposed and defined. The relevant morphologies under the influence of the urban physical environment can be mainly divided into three types: block morphology, street morphology, and urban negative shape morphology, among which there are block shape coefficients and passive space ratio in block morphology, and there are street wind azimuth, street thermal azimuth and street height to width ratio in street morphology, and there is negative shape morphology in negative urban height-to-width ratio.
4) The urban morphological characteristics of different climatic zones in Italy are analyzed from urban morphological texture. The different urban morphological characteristics that

evolved in the development process to adapt to the climatic environment of different regions are typologically organized. Alba is chosen as the main object of analysis, focusing on the evolutionary typology of the continuous courtyard city in northern Italy.

In terms of modeling thermal adaptive urban morphology Alba-Model in Humid Temperate Climates, the main research work and conclusions accomplished in this paper are as follows:

1) Alba, Italy's urban morphological characteristics and environment physical performance were analyzed, and the action mechanism of thermal adaptation in Alba was derived. In terms of block morphology, a lower block shape factor and a higher ratio of passive space are conducive to reducing the heat loss of the block in winter and increasing natural ventilation and lighting in summer and transitional seasons. In terms of street morphology, the angle with the solar insolation direction and the dominant wind direction makes the street space more comfortable in both summer and winter. In terms of negative shape morphology, courtyard spaces with a lower height to width ratio absorb solar radiation and shield winter winds. In comparison, courtyards with a higher height to width ratio serve to shield solar radiation and promote natural ventilation.
2) This paper investigates the inner mechanism of the interaction between urban morphological and urban environmental factors in a Subtropical Temperate Climate based on Alba's study. Specifically, it explores the mechanism of urban morphological factors in different environmental physical environments through a sub-analysis of different system factors. Among them, those corresponding to urban wind environment are street wind azimuth angle, negative shape height to width ratio, street height to width ratio, and passive space ratio, and those corresponding to the urban thermal environment are block shape coefficient, street thermal azimuth angle, street height to width ratio and negative shape height to width ratio.
3) In terms of block morphology, the enclosed block form, which the block building depth is 12m, the number of floors is 4. The block shape coefficient is about 0.25, has high efficiency of cold insulation in winter, and increasing the building height, or depth can further reduce the shape coefficient. However, it will affect the solar radiation absorption inside the building and in the courtyard. In addition, a higher ratio of passive space can promote natural ventilation in summer and transitional seasons and ensure natural light inside the building.
4) In terms of street morphology, a street wind azimuth of 45° or more can effectively reduce winter wind speeds, while a street wind azimuth of 15° to 30° can improve natural ventilation in summer; a street thermal azimuth of 15° to 30° can improve streets natural lighting and heat gain in winter and summer. When the street aspect ratio is

above 3, it can effectively reduce the solar radiation in summer. When the street aspect ratio is 1.5, it can ensure the solar radiation reception of streets and buildings in winter. Furthermore, increasing the aspect ratio of the street can effectively reduce the wind speed on the street in winter.

5) In terms of negative shape morphology, in summer, when the negative shape height to width ratio is greater than 2, it is conducive to thermal pressure ventilation inside the block, when the height to width ratio is smaller than 1, it is conducive to wind pressure ventilation in the block, and when the height to width ratio is less than 0.5, it is conducive to public activities on the ground level of the negative shape space; in winter, a height to width ratio greater than one can effectively prevent the penetration of cold winds in winter. When the aspect ratio is greater than 1, the solar radiation in summer can be shielded in terms of thermal environment, and the solar radiation in winter can be used when the ratio is less than 1.

Under Humid Temperate Climate conditions, in the long development process of cities, they exchange material and energy with the external environment by adjusting their morphological changes, affecting the environmental physical properties of urban space. Furthermore, it influences residential comfort. This interactive process makes the city's morphology show the characteristics of thermal adaptation, forming the similarity of urban morphology in the same climatic zone and the differentiation of urban morphological characteristics in different climatic zones, thus adapting to different climatic environments.

5.2 Shortcomings and Prospects

Due to the author's ability and limited writing time, there are still many problems and shortcomings in completing the thesis.

(1) Discussions on urban morphology under Humid Temperate Climate conditions are limited to traditional urban cases in northern Italy, while there is a lack of research and discussion on the morphology of other cities or settlements in the same climatic zone in the world, such as China’s village morphology where it is hot in summer and cold in winter.

(2) The author only stays based on qualitative analysis and partial quantitative analysis, and comprehensive scientific and effective quantitative analysis is still relatively superficial for the discussion of the urban morphological factors and their combination of urban environmental conditioning and control. In the future, the author should have a deeper and more comprehensive grasp of performance-oriented quantitative analysis.

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