BREATHING CITY

Mitigating air pollution through Urban microclimate design

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Urbanism
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Fig. 1. Urbanization of Shanghai
Source: https://www.shplanning.com.cn/Home/News/detailid/151.html

This graduation project is the result of the work of the Master's degree at Technology University of Delft over the last ten months. It is also a valuable result of working during a special epidemic. During all of those times, there were people around to help me stay in tune with my work and maintain the right motivation to stay focused. First, I want to thank my mentors, Marjolein and Frank, for their time and dedication, and thank them for their efforts. and their constructive counsel. Sometimes it's a technical solution, sometimes it's a programmatic addition and extrapolation.
My parents gave me unwavering support and were unable to do field work due to the epidemic outbreak, but they helped me in any way they could. I would also like to thank my friends for their input, discussions and the time we spent together. Their encouragement and time allowed us to overcome such special times together.

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Hanwen Hu

Abstract

In recent years, with the deepening of the urbanization process, high-density, high-volume-ratio urban development models have led to a series of climatic problems such as poor urban ventilation and air pollution. Urban morphology forms a unique microclimate in the city, which has an important impact on the diffusion and distribution of pollutants inside the urban boundary layer. Chengdu, as a large central city in the southwestern of China, has developed rapidly, with numerous sources of atmospheric pollution. At the same time, its basin topography and climatic conditions make it difficult to dilute and disperse pollutants.

In this thesis, the background of Chengdu was introduced, and the severe trend of urban development and air pollution was stated at first. Secondly, further understanding of the theory will be involved. The relationship between urban morphology, urban microclimate and air pollution will understand. Then starts the risk assessment in the city scale, with a view to defining the most vulnerable area. Thereafter, it is possible to evaluate the microclimates represented by the wind and heat environment in these sites. Then integrating pollution abatement and microclimate design into the urban design process by using a maximization approach. From the aspects of street canyon morphology, surfaces and urban trees, proposing wind-heat coupled optimization solutions to reduce the pollution. Guiding suggestions for street canyon planning are aimed at improving the scientificity of urban planning and providing a reference for the creation of sustainable and healthy cities.

Key words: Air pollution, Microclimate, Urban design

Contents

Motivation

In recent years, Chengdu, as a large central city in the southwestern of China, has developed rapidly, with numerous sources of atmospheric pollution, huge amounts of pollutants discharged, summer temperatures rising sharply, and winter smog lasting. In the first half of 2018, the average level of haze in Chengdu was more than twice the WHO limit, severely affecting residents' health and livability.

One of the most significant reasons is that compared with other first-tier cities in China such as Beijing and Shanghai, Chengdu Plain is located in the centre of Sichuan Basin, and the east and west are the Longquan Mountains and the Longmen Mountains. Such terrain blocks and weakens the cold air and cold wave invasion in the north of the winter. The average wind speed is low and the still wind frequency is high at the same time. In winter, the frequency of near-ground inversion temperature rises and the cold air intensity is weak, which causes the pollutants in the basin to be difficult to dilute and spread. In addition to traditional measures such as industry and traffic control, this problem requires a more extended solution.

GLOSSARY OF TERMS

1.URBANIZATION

Urbanization refers to "the increase over time of the proportion of the total human population that is urban as opposed to rural"(Davis,1965).

2.URBAN MICROCLIMATE

An urban microclimate is the distinctive climate in a small-scale urban area and is constituted by the influence of the built environment on the larger scale climatic conditions. (Pijpers-van Esch,M, 2015) the specific manifestations are the spatial distribution differences of humidity, temperature, wind speed and heat radiation.

3.URBAN HEAT ISLAND(UHI)

The UHI effect describes the fact that cities' temperatures tend to be higher than in their surrounding rural areas. This becomes especially significant during the night, when all the heat that has been stored during the day in the different materials that built the city is released, resulting in an impediment for the natural cooling process of the air (Oke, 1982).

4.VENTILATION CORRIDOR

'Urban ventilation corridor' originated from the German word "Ventilationbahn" developed by Kress (1979). It is suggested that people should consider the 'functioning area' and the 'compensating area' before creating urban ventilation corridor which serves to link these two areas together to improve air exchange and ventilation conditions. (Chao, R.2018)

5.STREET CANYON

The street canyon is one of the most widely used models for expressing the state of the city's surface. It was proposed by Nicholson in 1975 and mainly refers to the canyon-like space formed by the street and the buildings on both sides.

6.THE URBAN CANYON EFFECT

The modification of the characteristics of the atmospheric boundary layer by the presence of a street canyon is called the street canyon effect. Street canyons affect temperature, wind speed and wind direction and consequently the air quality within the canyon(Zhao jin yuan,2019).

7.STILL WIND FREQUENCY

Still wind frequency is defined as the percentage of still winds (no wind direction) to the total number of observed statistics.

8.PM2.5/PM10

PM2.5 refers to atmospheric particulate matter (PM) that have a diameter of less than 2.5 micrometres. Also known as the accessible lung particulate matter. PM10 is particulate matter 10 micrometres or less in diameter, they are the main pollutant index for characterizing ambient air quality.

9.O3

"Near-earth ozone is mainly produced by the photochemical reaction of nitrogen oxides and volatile organic compounds produced by human activities under high temperature and strong radiation conditions. It is a typical 'secondary pollutant'.(Chengdu Daily,2019)

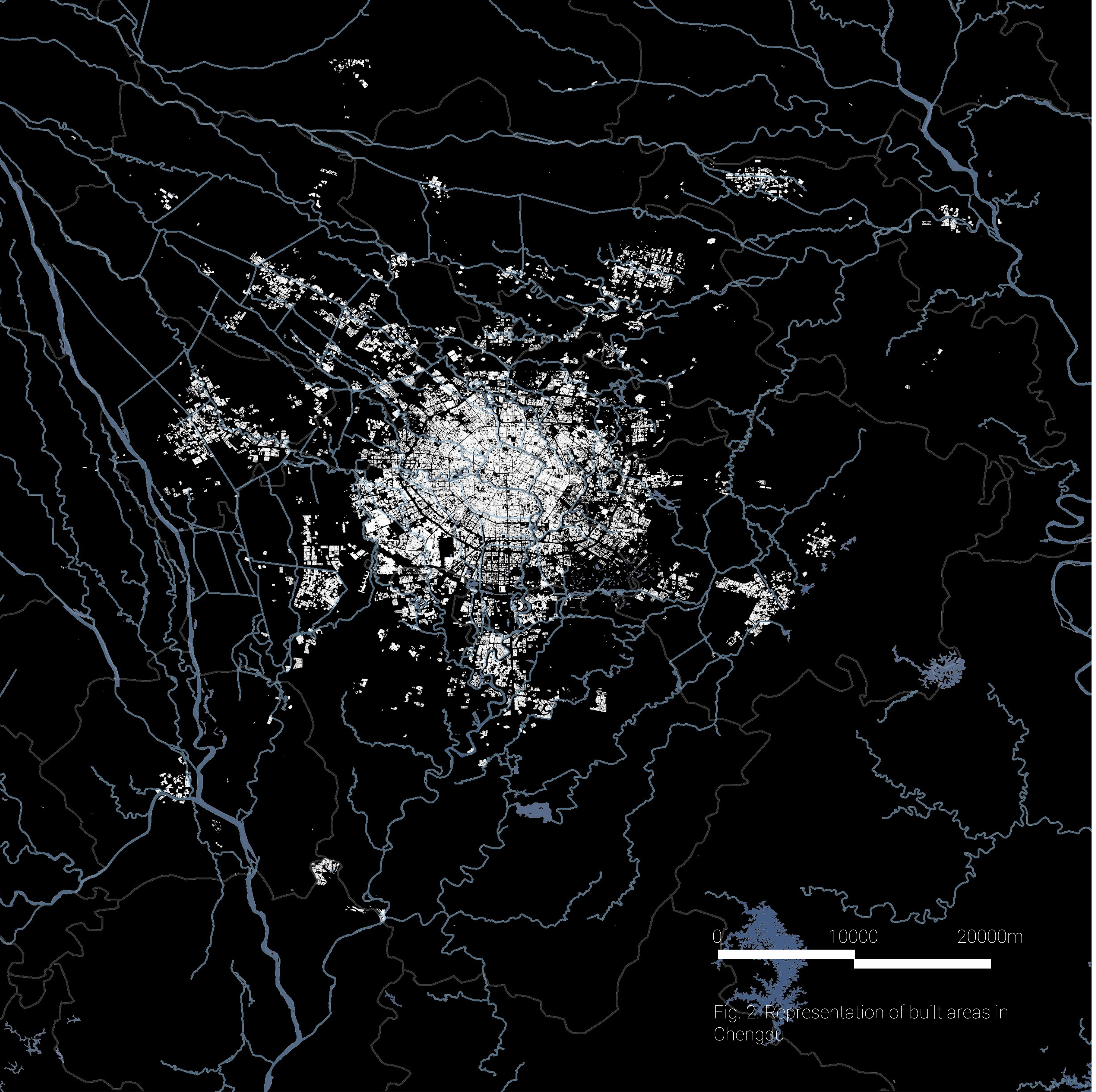


Fig. 2. Representation of built areas in Chengdu

2. Problem Analysis

Since the reform and opening up, due to the accumulation of population and capital, the urbanization process in Chengdu has been fierce, and several large industrial zones and satellite cities have been built.

The expansion began in 1988 when the government started planning for urban development, and since China implemented the western development in 2000, it accelerated investment in Chengdu, and the urban expansion has intensified, far exceeding the urban expansion plan prepared by the government in 1998. According to the data obtained from surveying and mapping in 2000, 2005, 2010, 2013 and 2016, the urban area of Chengdu is 210 km^2, 323 km^2, 445 km^2, 533 km^2 and about 600 km^2. Chengdu's central urban area in 2016 is almost three times that of 2000. At the meanwhile, its population is growing steadily to about 14 million in 2016.

The rapid expansion and population growth of the city have brought a series of environmental problems to Chengdu. According to the Chengdu Statistical Yearbook, the air quality standard days and AQI statistics of Chengdu in 2006-2015, the air quality of Chengdu after 2011 is remarkable declining, the number of days in which air quality reach and above Level 2 (API≥51) in 2013 was only 139 days, which seriously threatened the health of the public. In response to the negative impact of urban expansion, urban planners in Chengdu have focused on environmental protection in recent years, aimed at mitigating urban pollution.

Urbanization of Chengdu

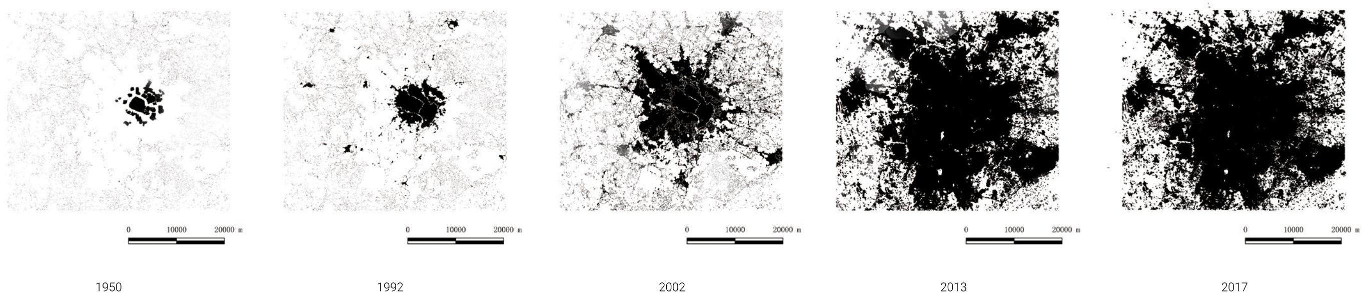


Fig. 2.1.1. Urbanization of Chengdu
Source: Author

Figures 2.1.1 and 2.1.2 show the rapid urbanization of Chengdu since 1990, and Figure. 2.1.3 shows the population growth of the city in recent years.

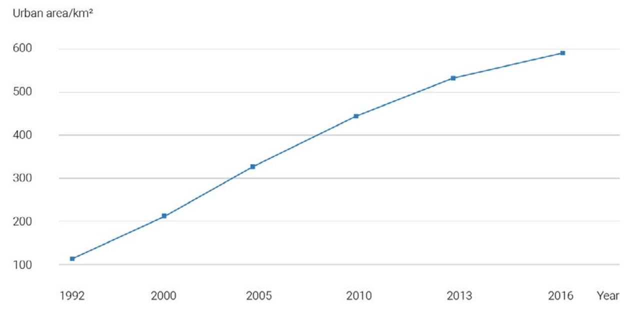


Fig. 2.1.2. Urban area growth.
Source: Chengdu Statistical Report 2016

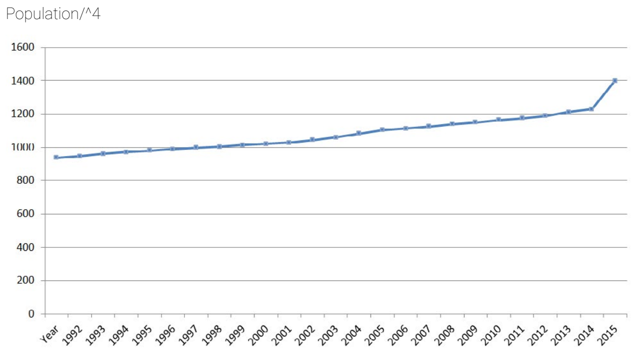


Fig. 2.1.3. Chengdu Population growth.
Source: Chengdu Statistical Report 2016

Air pollution in Chengdu

According to the monitoring data of Chengdu ambient air quality from May 2014 to December 2017, the air pollution situation and the temporal and spatial variation characteristics of pollutant concentration in Chengdu were analyzed. The results show that the primary pollutants in Chengdu urban area are mainly **PM2.5**(Fig. 2.1.4), and the suburbs are mainly **O3,PM10**.

In Chengdu, nitrogen oxides and volatile organic compounds in PM2.5 and ozone are mainly derived from emissions of urban dust, motor vehicle exhaust, coal dust and industrial waste gas.

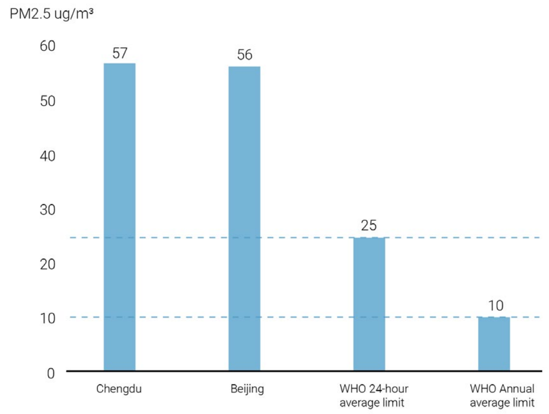


Fig. 2.1.5. Average PM2.5 in the first half of 2018
Source:Municipal pollution monitors Analysis Smart Air smartairfilters.com

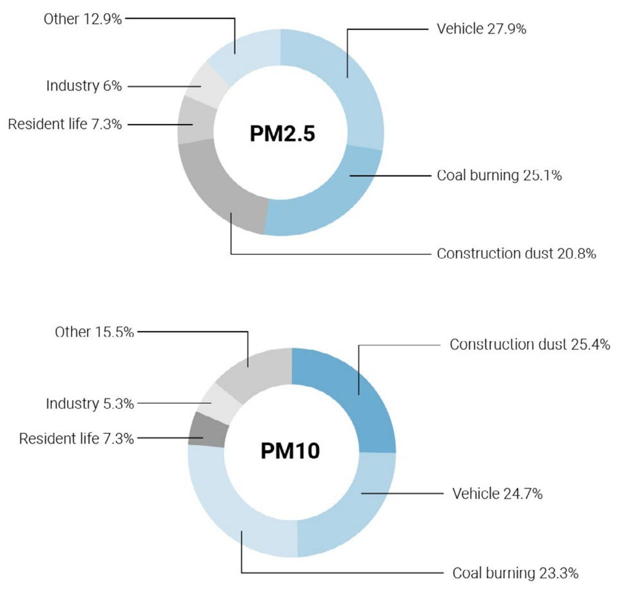


Fig. 2.1.4. Major sources of PM2.5
Source: Chengdu Business Daily 2016.12.12

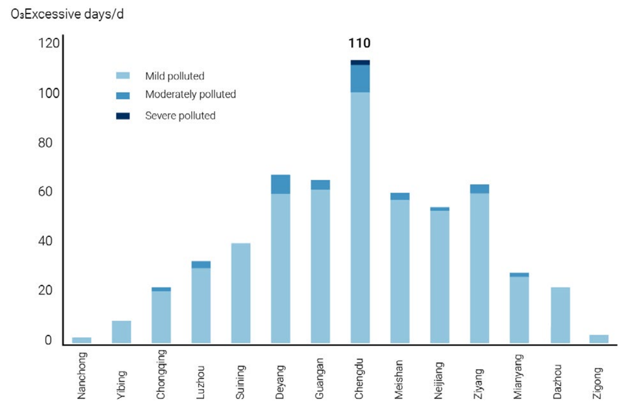


Fig. 2.1.6. Number of days of O_3 concentration non-attainment in CCUA during 2015-2016
Source:China Environmental Testing Center.
Analysis Smart Air smartairfilters.com

Terrain of Chengdu

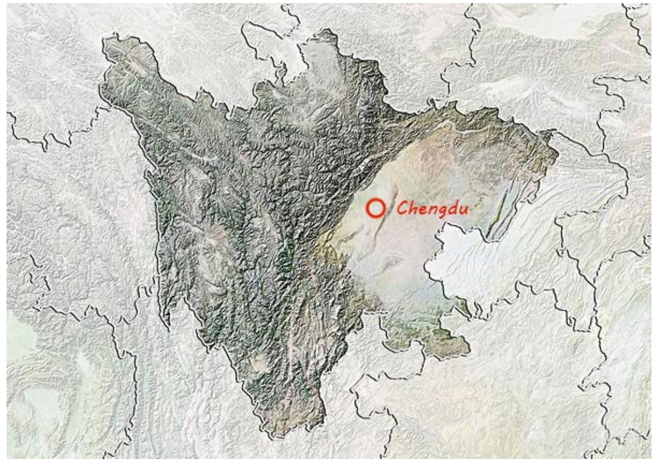


Fig. 2.1.7. Sichuan topographic map
Source: http://mp.163.comv2/article/detail D7LPSL6A0524C9AP.html

Chengdu is located in the Sichuan Basin, the central part is the Chengdu Plain, and in the east and west are the Longquan Mountains and the Longmen Mountains.

Under the influence of the basin topography, the atmospheric airflow sinks to the airflow in the low-lying area. During the movement of the sinking airflow, the smog particles gradually flow to the place where the terrain is low. Under this circumstance, the smog particles in the basin area cannot diffuse, and some smog particles are converging with the sinking airflow, which leads to the phenomenon of high smog pollution in the basin(Huichao, J.2014).

This basin topography is also one of the reasons for the formation of an inversion layer. After cold air enters the basin, the temperature around the basin rises faster, and the air temperature above the corresponding basin also rises, forming an inversion phenomenon. Because the inverse temperature phenomenon is obvious, the pollution in the Chengdu area is more likely to accumulate.

Climate environment of Chengdu

Chengdu is located in a subtropical humid monsoon climate zone with few sunny days. The annual average sunshine percentage is generally between 23% and 30%. The annual average solar radiation is 80.0 kcal/cm 2 - 93.5 kcal / cm², the wind speed is low, the most wind direction is NNE, the wind speed is 1-1.5 m / s, which provides favourable conditions with the accumulation of air pollution.

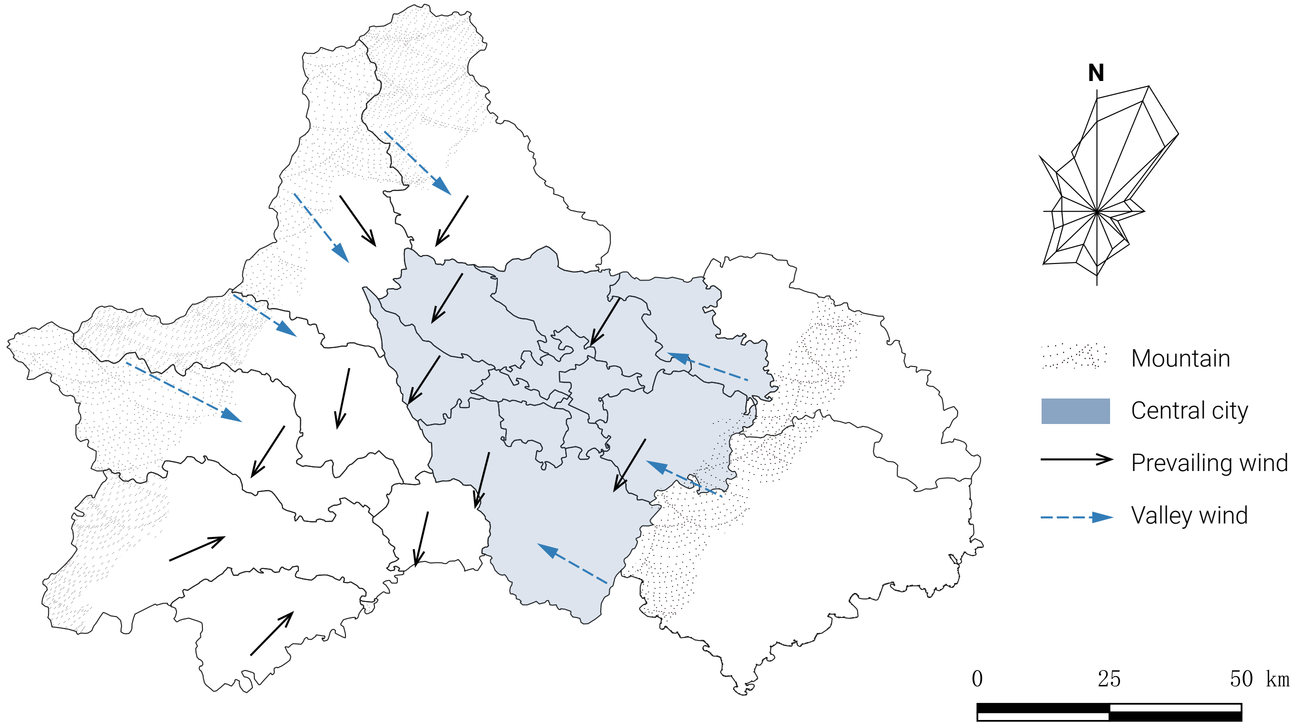


Fig. 2.1.8. Climate environment of Chengdu
Source: Liu Y, Analysis of urban climate environment in Chengdu. 2014

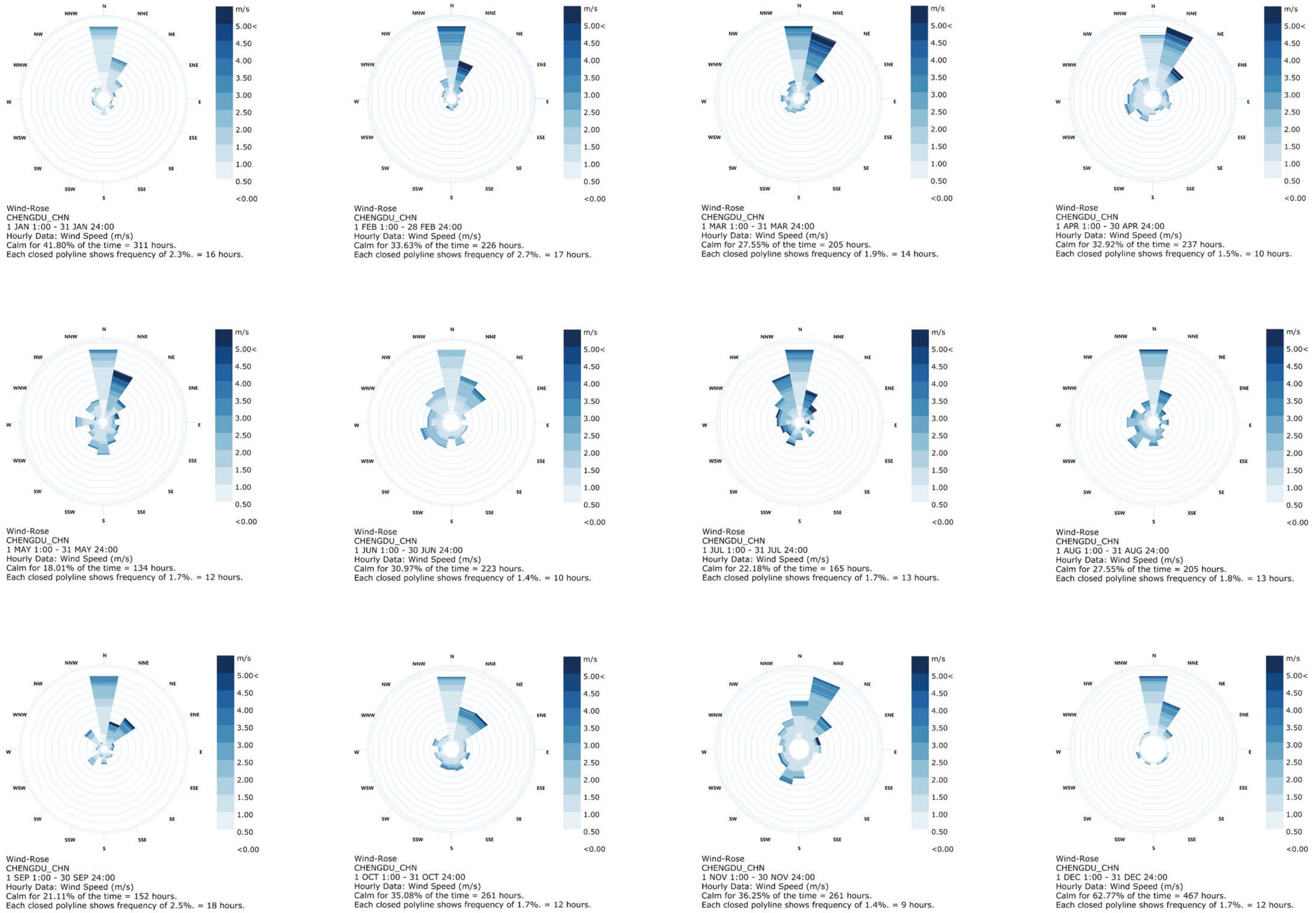
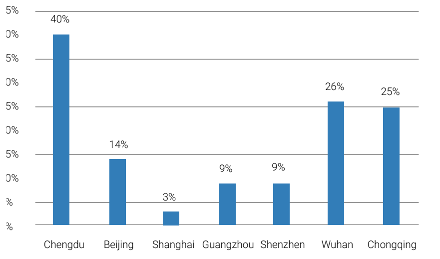
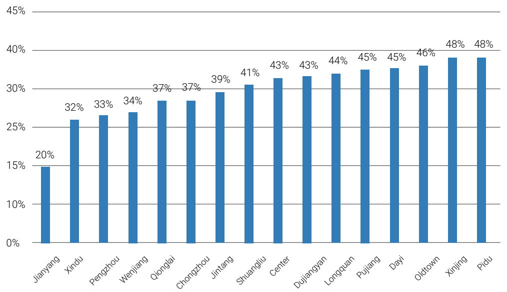


Fig. 2.1.9. Chengdu 2011 Jan-Dec Wind Rose Map
Source : https://www.energyplus.net/weather



Comparison of static wind frequencies in major cities in China



Comparison of static wind frequencies in various districts of Chengdu

Fig. 2.1.9. Comparison of still wind frequencies
Source: http://weixin.china-up.com/weixin/2019/04/25/6b84bfec34/

2.2 Problem Statement

The air pollution has attracted great attention from the environmental protection and planning departments in Chengdu. For urban land use-air quality, comparing corridor-type cities, marginal cities, and compact urban air quality simulations to find that compact urban air pollutant emissions are minimal (Marquez L O, 1999). From the perspective of urban planning, in addition to controlling traffic emissions in cities, coal combustion, etc., negative urban development models will worsen air quality (Stone B. 2008), the microclimate phenomenon formed by the high density built environment will lead to the variation of pollutant diffusion conditions. Therefore, urban development is directly related to its microclimate and urban air quality.

In the accelerated phase of urbanization, how to adjust the urban form in this development and reduce the problems brought about by urbanization has become the focus, such as urban heat islands effects, air pollution and the decrease of residents comfort.

Environmental climatologists suggest that urban physical form will affect urban climate characteristics, including urban temperature, urban ventilation conditions, and urban radiation balance and sunshine conditions. The description of its impact lacks practical applications and experiments. Optimizing Chengdu's microclimate by regulating urban form is a complex multidisciplinary project with great potential.

2.3 Interscale approach scheme

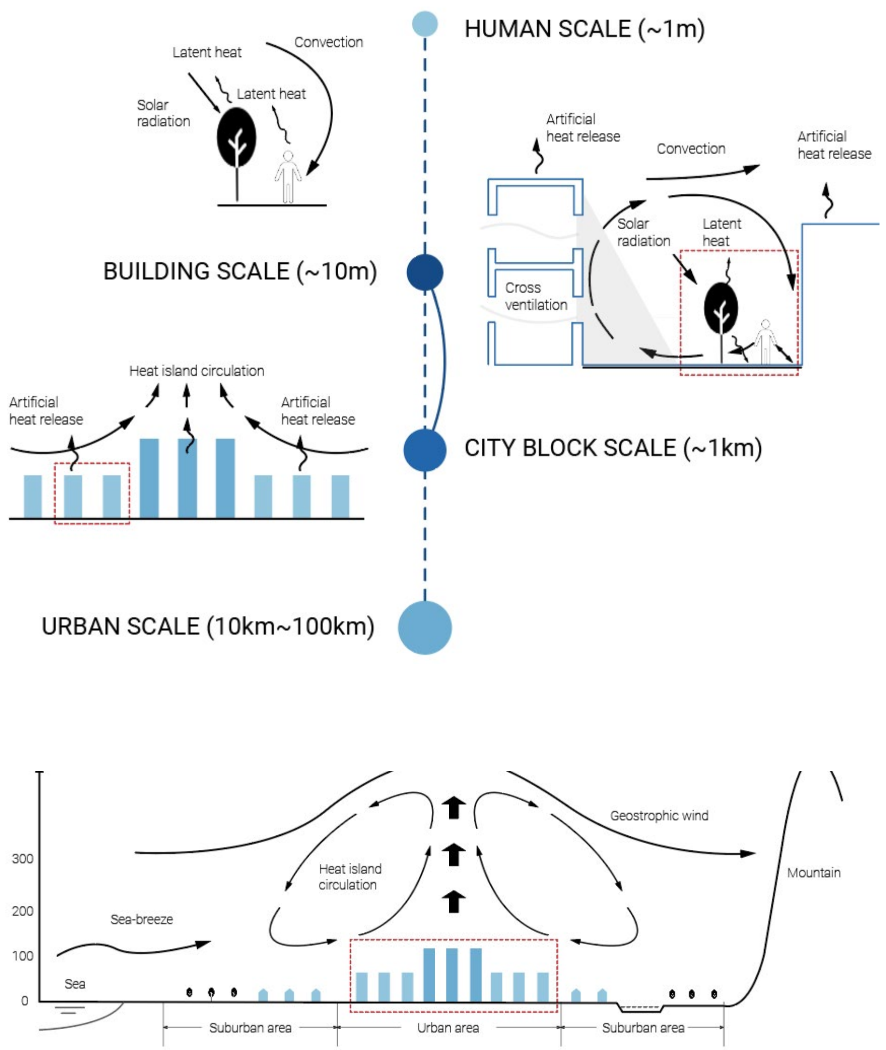


Fig. 2.2.1. Various scales related to wind climate
Source:Murphy, C., Gardoni, P., & McKim, R. (2018).

Since the urban microclimate manifests itself as differences in the spatial distribution of humidity, temperature, wind speed and thermal radiation. Among them, in the past, urban wind and heat environment research were roughly divided into the urban scale (10-100km), city block scale (~1km), building scale (~10m)and human scale (~1m) (Murakami, S, 1999) The urban wind and heat environment at the block scale mainly studies the airflow, heat transfer, and pollutant distribution processes in the urban canopy. Geometrical conditions such as canyon orientation and building height play an important role in the formation of the wind and heat environment inside the urban canopy (Edussuriya, P. 2011).

This project mainly focuses on the analysis and intervention of the wind-heat environment and pollutant distribution at the city scale and the block (street canyon) scale, as well as the connection between the two scales. This will be analyzed in detail in later chapters.

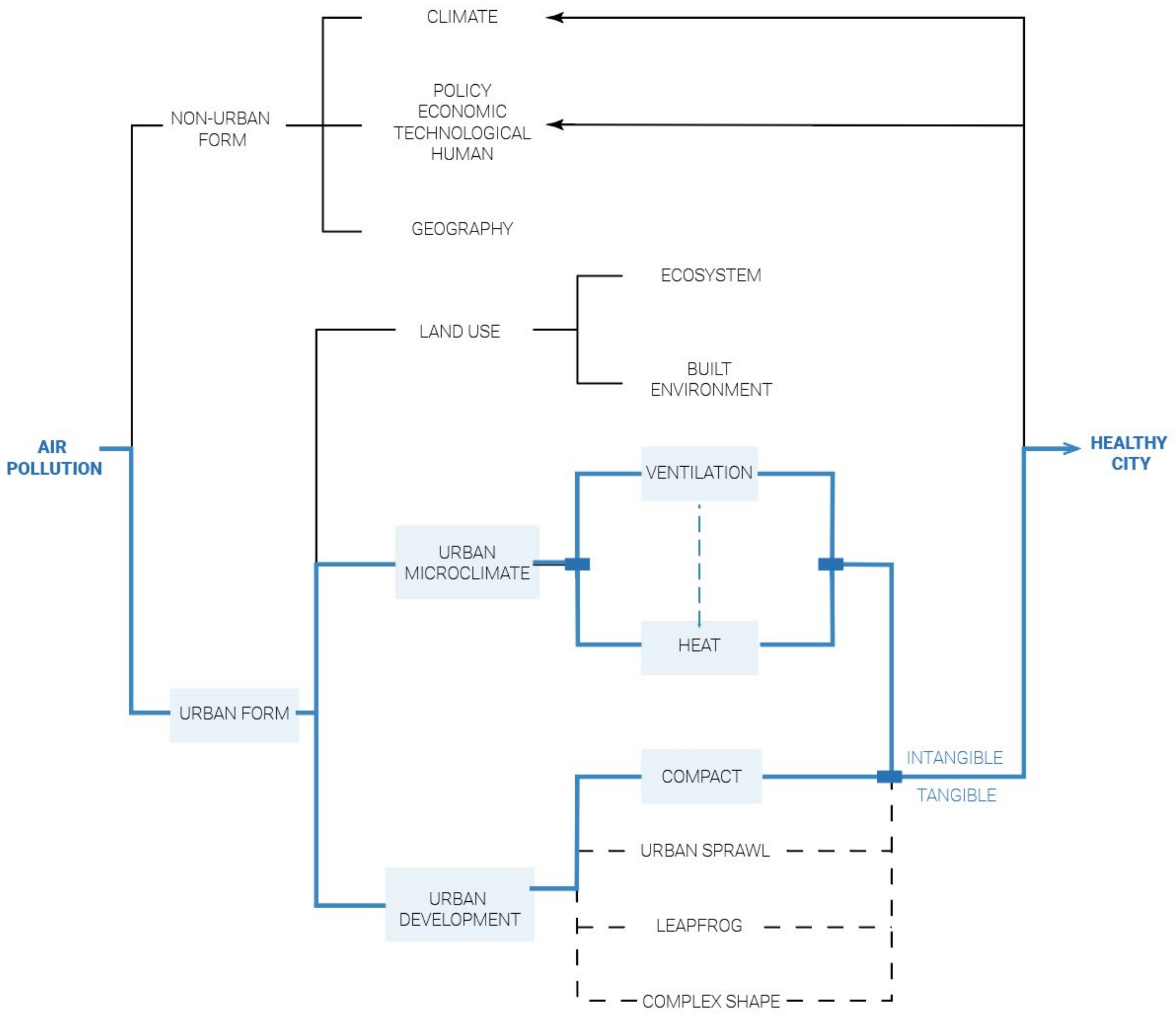


Fig. 2.2.2. Scope of the project
Source: Author

2.4 Rsearch question

Main Research Question

How to mitigate air pollution through urban microclimate design in Chengdu?

Sub Questions

1. What is the relationship between urban morphology, microclimate and air pollution? What the main parameters are included in these three systems?

2. What is the climate characteristic of Chengdu and which part is the most unfavourable microclimate and vulnerable area for air pollution?

3. What are the urban characteristics are most relevant can be identified for the mitigation of air pollution through urban microclimate mechanism in canyon scale?

4. In what way is the microclimate affected by different morphological features? In what way is the air pollution affected by different microclimate?

5. What kind of spatial interventions in terms of microclimate most effective to mitigate air pollution?

6. How to integrate microclimate design and air pollution issues into the urban design process?

7. How implementable are these sites and to what extent are the interventions on one typical site transferable to the rest?

2.5 Methodology

In order to achieve the research goals and answer the questions, the process requires a variety of methods to illustrate the impact mechanism between urban form, urban microclimate and air pollution, while achieving the goal of improving the air quality through urban microclimate design.

This project can be divided into explorative, theoretical, analytical, interventive, evaluative and reflective six stages. In the first phase, the background of Chengdu was introduced, and the severe trend of urban development and air pollution was stated. Secondly, we will further understand the theory involved. Due to the geographical location and meteorological conditions of Chengdu, we will understand the physical knowledge and relationship between urban high dense form, urban microclimate and air pollution. The third stage is based on the most vulnerable area in Chengdu, with a view to defining more specific intervention scales and geographic locations. Thereafter, it is possible to evaluate and design the plots under empiricism and simulate the microclimates represented by the wind and heat environment before and after the intervention. The final stage is to reflect on the inadequacies of the project and the research that needs to be further explored in the future. The main methods used are described in the following paragraphs.

Literature review: In the early stage of the research, an extensive search was carried out on keywords such as "urbanization impact", "microclimate" and "air pollution", and searched for relevant research literature, works, research results, etc., and systematically organized the research materials. Inductively, understand the individual and mutual operating mechanisms and connections, and determine the main research direction. At the same time, it has an in-depth understanding of objective theories such as wind-heat relationship, fluid dynamics and pollution diffusion.

Data collection: Collect meteorological data from Chengdu, the occurrence and causes of pollution formation, and prepare for mapping.

Mapping: After forming a certain theoretical framework and data collection, the analysis is done through GIS mapping, so that sub-question 2.1 can be answered.

Risk assessment: As a method in environmental risk management, risk map can not only explore the spatial characteristics of pollutant effects but also be an important tool for risk visualization. It is used as a method to identify the highest risk areas in Chengdu during the analysis phase of this project.

Numerical simulation: Due to the complexity and determining the influence of the location, it is impossible to define the effects of air pollution and microclimate interventions. Using ENVI-met software to simulate the microclimate environment of different sites, accurately and objectively display the objective development law of things, provide a scientific basis for the final space optimization strategy, and evaluate the effects of interventions.

Multiple methods may be applied at each stage. The timeline corresponding to each method and the sub -questions that can be answered are shown in the figure below.

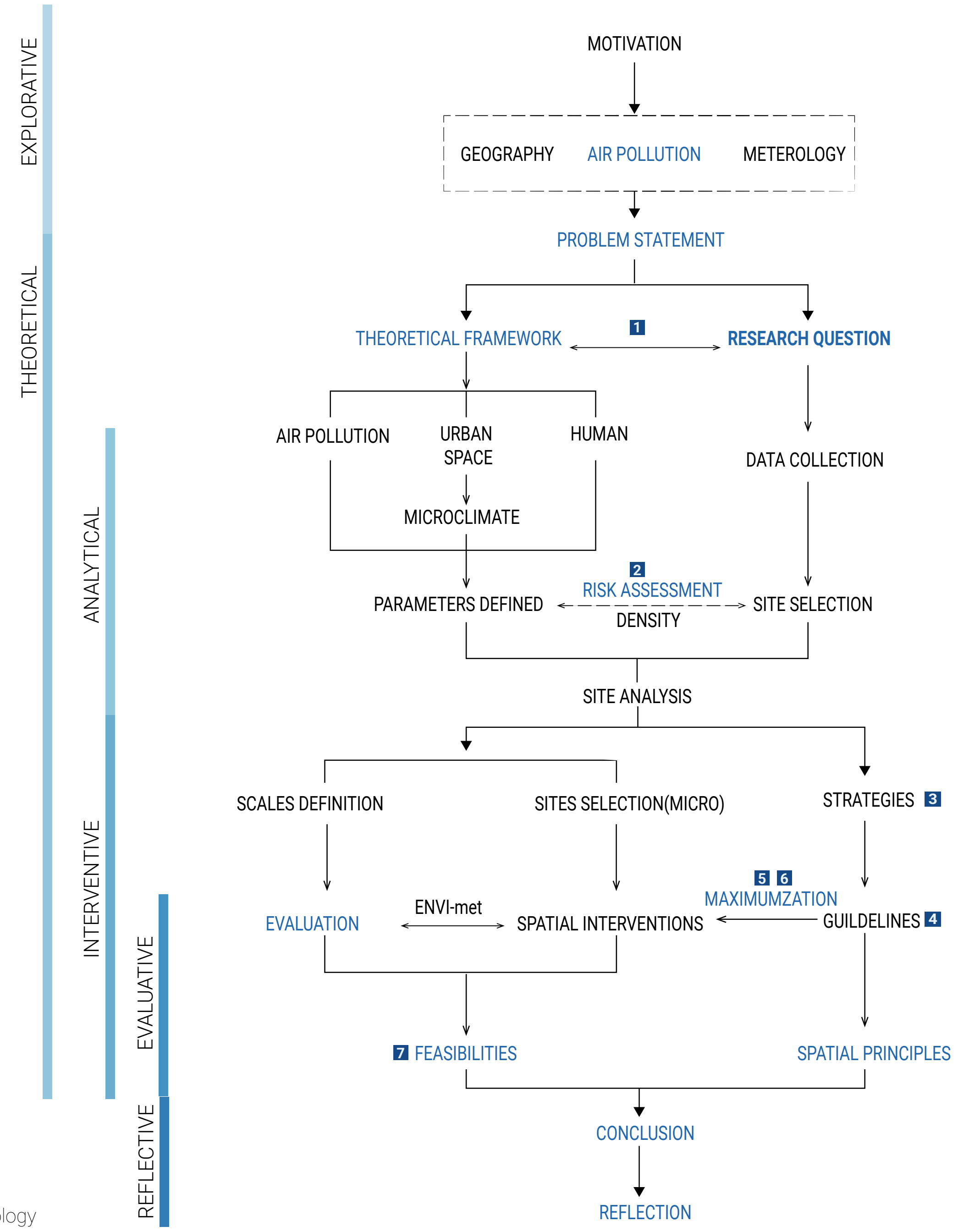


Fig. 2.2.3. Methodology
Source: Author

Research aim & Expect research output

The aim of this research is to mitigating air pollution through interventions in the urban microclimate in Chengdu, which shows a characteristic of urban morphology. The synergy might be found from the implementation of actions for the mitigation of air pollution may transcend its original definition and become a driver for more profound changes in the building external environment.

Through the project, the impact factors, distribution and optimization methods of Chengdu's microclimate (Wind-Heat) environment are defined, and a set of urban microclimate design method framework and theoretical framework based on the air pollution mitigation both in urban and block scale in the basin city is formed. Conduct sustainable strategy research on the regions (typically urban forms) in Chengdu and explore the feasibility of these strategies in other areas or cities.

The key variables are urban form and spatial structure, which are in the context of the city's urbanization. Finally, reduce air pollution while creating a healthier microclimate, and ultimately feeding back into the climate, creating a more sustainable and livable urban environment.

Outcome

Urban Planning

Clear linkage between the concepts of urban form, microclimate and air pollution, and a set of parameters to measure all previous aspects.

Density maps and a selection of representative maps according to chosen relevant parameters.

Guidelines for the design of urban forms that create a good microclimate.

A positive or negative conclusion on the transferability of the guidelines to other parts of the city.

Urban Design

An identification of design elements that contribute to air pollution mitigation in the city in the form of a library of strategies.

Each set of interventions is formed in different areas.

Conclusive design tests for every representative area.

A strategic framework for the application of these interventions.

2.6 Research approach & Time planning

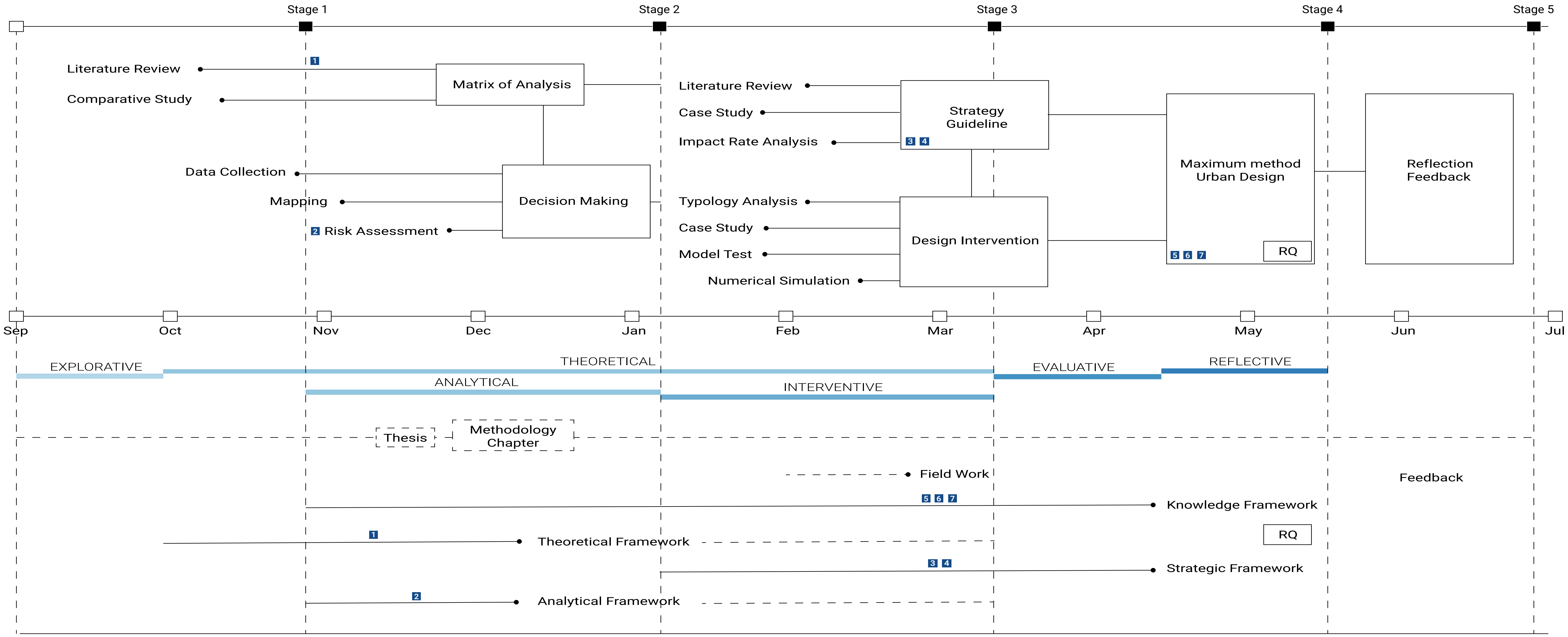


Fig. 2.2.4. Research approach & time planning
Source: Author

3. Theoretical Framework

This chapter offers an overview of the theories, methodology and research methods that have been used during this project. This chapter is divided into three parts; the theoretical framework, the conceptual framework, and the assessment method which will be used to answer the research questions.

Three theoretical bodies are drawn around the main topic of air pollution: Urbanization, microclimate and air pollution. This section explains which concepts this thesis will draw from these bodies, and how these theories are connected.

3.1 Urbanization

Urbanization refers to "the increase over time of the proportion of the total human population that is urban as opposed to rural"(Davis,1965). Urbanization started in Great Britain in the 1900s as a result of the industrial revolution (Davis 1965). In the 1950s, the rate of urbanization doubled that of the preceding 50 years (Davis 1965).

Urban development and urban environment can be linked in a vicious cycle.First, the rapid urbanization increases the consumption of natural resources in order to attain better urban services, which in turn aggregate the negative impacts of the climate change. (Chao Y,2018). In response to the extreme climates that have emerged, taking the urban heat island effect as an example, on the one hand, the urban heat island has aggravated the hot summer climate, and air conditioning and refrigeration will cause a large amount of energy consumption, resulting in seasonal power shortage.
On the other hand, an increase in energy consumption will result in the discharge of a large amount of heat and exhaust gas, which in turn will further increase the temperature of the city and increase the intensity of urban heat islands, thus creating a vicious circle.(Bin,C. 2018)

Second, the increase in thermal discomfort and air pollution associated with urbanization has contributed to urban sprawl. Although urban residents ease from the city centre to the urban fringe to get a healthier living environment, they often return to work in the city centre and enjoy better metropolitan services. As a result, this suburbanization campaign increases vehicle mileage, which means increased traffic energy consumption and emissions. Heat islands and air pollution are intensifying, creating a vicious circle.(Chao,Y2018)

High-density urban planning

Strengths

Since the current urban development hasn't mitigated the adverse impact of global climate change, a proactive and proportionate modification to the current urban development is needed. Some researches evaluated several alternative paths of urban development: compact (high-density) urban development and other scattered urban development. They indicate that compact development significantly decreases air pollution, whereas scattered development has more traffic. (Stone B. 2008).

In terms of energy and land consumption, densely populated cities may have limited demand for roads and may, therefore, translate into more efficient infrastructure and better public transport, resulting in a reduction in total per capita emissions(Newman P, 2006), In this respect, compact cities are expected to produce lower emissions of transport-related pollutants compared to a fragmented city. Therefore, dense cities may reverse the vicious circle between urban development and urban environment, and make cities better adapt to climate change.

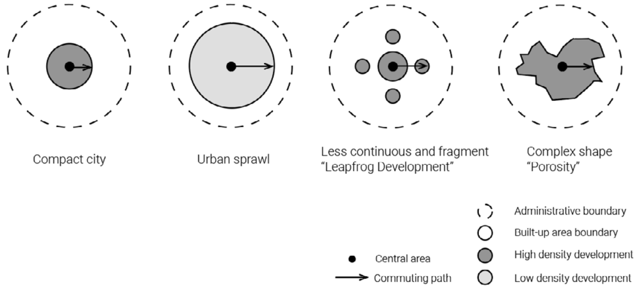


Fig. 3.1.1. The influence of urban form on traffic
Source: Rodríguez M C.2016, Air pollutionand urban structure linkages:: Evidence from European cities

Limitations

Despite the apparent strengths of compact urban development, studies have also identified serious environmental issues (e.g, poor ventilation performance) associated with compact urban development (Arnfield 2003; Ng 2012; Ng et al. 2011)

In Hong Kong, for example, this development has led to stagnant air in high-density urban areas. At the Kings Park monitoring station, the impact of compact urban development over the past few decades, on airflow has been evident, with the annual average wind speed dropping from 3.5 to 2.0 m / s from 1960 to 2015, 20 m above the ground (building roof). For decades, the average wind speed drop in urban areas has seriously affected outdoor thermal comfort levels. In addition, reduced wind speeds may result in traffic-related air pollutants accumulating at the urban canopy layer (Yuan et al., 2014).

Conclusion

In summary, in the current urban development and climate change, the energy and land use required for compact urban development is less than other development programs, so compact urban development is considered to be attractive for future urban development. Although urban environmental problems arising from high-density planning need to be addressed, such as poor ventilation and air quality. Therefore, climate knowledge and scientific urban planning and design strategies are the keys to making high-density urban areas healthier and more livable.

Fig. 3.1.2. Pearl River International Center, Wenjiang District, Chengdu.

3.2 Urban microclimate

As the development and construction of the city form a new material space completely different from the natural geomorphological conditions, produces a climatic environment different from the natural climate, called the urban microclimate. Urban buildings use cement and concrete on construction materials, which are very easy to absorb and store heat, and the wind passing through the city is also blocked by the high-rise buildings. These phenomena have changed the small-scale climate environment of the city to varying degrees, and the impact on the urban microclimate has become increasingly prominent.

Due to the many factors in urban microclimates, it is not possible to measure all of these factors. In this paper, a review of the literature reveals that the hot air environment has a more pronounced impact on air pollution and that both indicators also are both factors more related to urban morphology. Therefore, the wind-heat environment is chosen as the main urban microclimate study object.

This chapter focuses on the effects of heat and wind environments in microclimates to air pollution.

Heat

In general, the higher the temperature, the faster the chemical reaction. Therefore, the continuous high temperature in the urban climate environment will lead to the acceleration of certain specific atmospheric chemical cycles, resulting in an increase in the ozone content in the atmosphere. The high concentration of ground-level ozone environment will lead to an increase in the frequency of urban photochemical smog, leading to accelerated ageing of materials and affecting people's health. In addition, high temperatures also lead to an increase in bio hydrocarbons and an increase in the evaporation rate of artificially volatile organic mixtures, all of which affect the production of ozone in the troposphere. Therefore, if the urban heat island effect can be effectively mitigated, the degree of atmospheric pollution caused by the increase in urban temperature can be reduced to some extent, and vice versa, less air pollution also decreases the UHI.

On the other hand, there is a temperature difference between urban heat and cold sources, which can cause local air turbulence and contribute to the diffusion and dilution of pollutants. At the urban scale, it can improve air pollution by using heat island circulating air to bring clean, cool air from the suburban area into the city. Therefore, the placement of urban cooling sources can also have a significant impact on the city's ventilation system.

Wind

For wind environment, TTOke, Summers PW, Zhang Jingzhe and others have pointed out that the location of the heat island effect and the heat island intensity is related to the wind direction and wind speed to a

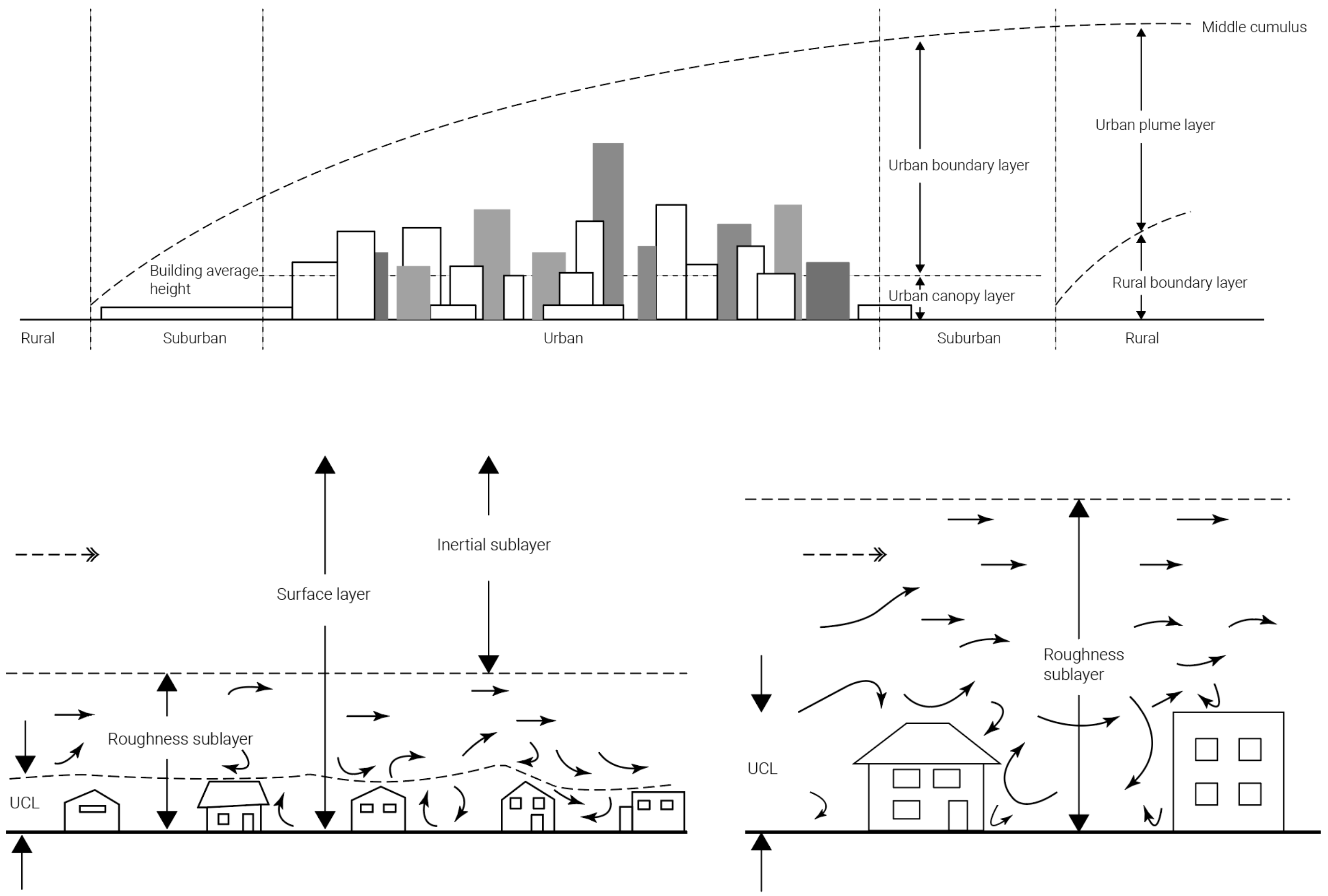


Fig. 3.2.1. Various physical processes at mesoscale,local scale,and microscale.
Source: Oke(1987)

certain extent. Good ventilation can effectively alleviate the urban heat island effect and dispel the air pollutants above the central area of the city; if the wind speed increases to a certain value, the heat island effect will even disappear, which will also significantly improve the city air quality.

Oke first gave the definition of the urban canopy in 1987 （Fig. 3.2.1）, clearly distinguishing between the urban canopy and urban boundary layer. The urban canopy refers to the atmosphere between the ground and the average height of the roof of the building. In the urban canopy, the underlying surface structure and human activities have a greater impact on the thermal and dynamic processes of the atmosphere (Roth.M, 2000).

3.3 Air pollution

The cities with high-speed construction have concentrated a large number of industries and cars. The huge amount of traffic caused by this has caused serious air pollution. The relationship between air pollution, urbanization and urban microclimate (wind and heat) has been discussed previously.

After a preliminary analysis of Chengdu's pollution situation, causes and consequences and brief analysis of the relationship between urban morphology, urban microclimate, and air pollution in the previous chapters, due to the lack of data, there is a lack of visual data to identify the most polluted as well as the most unfavourable areas for pollutant dispersion in Chengdu. Therefore, it was necessary to identify the areas that are most representative of pollutant concentrations and low wind speeds through analysis and literature review. This chapter discusses in detail the important urban morphological factors at different scales and develops an analysis matrix.

3.4 Matrix of analysis

Development of analytical matrices related to air pollution and the wind and heat environment. The matrix is composed of some main variables, but it is not comprehensive enough and can not involve all variables that affect air pollution. The matrix was selected based on its importance in the literature review. The following paragraphs will explain the main components of the matrix.

Multi-scale

In the cross-scale approach scheme, this thesis defines air pollution as a multi-scale phenomenon with the urban wind and heat environment and explains that this paper focuses on the analysis and correlation of urban and block scales. However, due to the large area of Chengdu, the scale of data is difficult to unify Therefore, the analysis is divided into three levels: macro, meso and canyon. The macro and meso scale belong to the urban scale, and the street canyon belongs to the block scale (1km-10km) in the urban wind and heat environment. The main goal of the analysis is to understand the pollution, wind and heat environment and urban form of Chengdu from different scales by combining the theoretical framework and the preliminary understanding of Chengdu, with a view to discovering the intervention areas and reachable intervention measures.

Sources, Dispersion, Effect area, Urban Microclimate

In general, air pollution can be divided into three phases: source, dispersion, and effect area. After a preliminary understanding of air pollution in Chengdu, a detailed analysis of each stage is needed. The source mainly analyzes urban traffic pollution emissions; in the dispersion stage, the factors that have a greater impact on microclimate and air pollution are selected from the literature review, and the microclimate column shows the correlation between factors and wind-heat separately (decided by the author from the literature review); At effect area, people are mainly regarded as receivers of pollution.

Operability

As the main analysis and intervention phase, urban space dispersion stage has different physic layers. The rate of workability defines therefore which layer urban designer can more easily work with and change.

Goals & expected results

In the analysis stage, the main goal is to answer the corresponding research sub-questions (some sub-questions need to be concluded after specific analysis) in combination with the theoretical framework, determine the areas where Chengdu is in urgent need of air pollution, and determine the intervention areas. The next step is to analyze the street-canyon scale of these areas, and further understand the interaction mechanism of urban morphology, microclimate, and air pollution in Chengdu, and divide the types of different characteristic areas. (In different factors, there is no hierarchy setting).

	Source	Dispersion	Effect	Urban Climate (Wind / Heat)	Operability	Analytical Sub Question	Theoretical Framework
Macro	Pollutants	Terrain Urbanization				Where is the most polluted place in Chengdu? What is the climate characteristic of Chengdu?	Oke, T.R. (1987). Boundary layer climates. New York, Rutledge. Murphy, C., Gardoni, P., & McKim, R. (2018). Climate change and its impacts : risks and inequalities.
Mesoscale	Landuse (Industry) Traffic + Congested + Vehicle Flux	Density + FSI + GSI Building Frontal Area Land Surface Temperature Vegetation(NDVI) Land Use	Population + Density + Over 65 + Under14 + Baidu Heat Value			What are the parameters of density/urban form that affect air pollution through wind and heat environment? Where is the most unfavorable microclimate area for air pollution?	Newman, P. W. G. (1999). Sustainability and cities: Extending the metabolism model. Landscape and Urban Planning, 44(4), 219–226. Esch, M. P. (2015). Designing the Urban Microclimate. https://doi.org/10.1007/978-94-007-5631-1 Yuan, C. (2018). Urban Wind Environment — Intergrated Climate-Sensitive Planning and Design. Ren, C., Spit, T., Lenzholzer, S., Yim, H. L. S., van Hove, B. H., Chen, L., ... Katzschner, L. (2012). Urban Climate Map System for Dutch spatial planning. International Journal of Applied Earth Observation and Geoinformation, 18(1), 207–221.
Urban Canopy	PM10	Density + FSI + GSI Geometric Layout + H/W + Symmetry + Height + orientation Surfaces + Colour + Material Urban Green Sunlight Hours Landuse	Population + Density + Age			What are the urban morphological characteristics of these areas? Which elements of urban forms are most relevant in Chengdu can be identified for the mitigation of air pollution through urban microclimate mechanism? What kind of spaptial interventions in terms of microclimate can be applied in Chengdu?	Jiwu.W,Wei.W. Space Form and Pollutant Distribution in Urban Street Canyons: A Case Study of Hangzhou Zhongshan Road[J].Planning Studies, 2010(12):57-63. QIU Qiaoling.WANG Ling. To research for street geometry structure planning base on polluting mechanism in street canyon[J].Urban Studies,2012(7):16-21. Chan Andy T, So Ellen S P, Samad Subash C. Strategic Guidelines for Street Canyon Geometry to Achieve Sustainable Street Air Quality[J]. Atmospheric Environment, 2001(35):561-569. P Kastner-Klein, E J Plate. Wind-tunnel Study of Concentration Fields in Street Canyons[J]. Atmospheric Environment, 1999(33):3973-3989. Changwang.Z.(2019). Study on the urban microenvironment numerical simulation based on ENVI-met. Murakami, S., Ooka, R., Mochida, A., Yoshida, S., & Kim, S. (1999). CFD analysis of wind climate from human scale to urban scale. Journal of Wind Engineering and Industrial Aerodynamics, 81(1–3), 57–81.

Fig. 3.4.1.
Matrix of analysis.
Source: Author

Wind-heat related physical factors

Density

The floor-space index (FSI) expresses the built intensity of an area. It shows how many square meters is built within a hectare of land. The higher the number, the more intensely built up the area is.
The ground-space index (GSI) expresses the compactness of an area. It shows what percentage of a hectare is covered by a building footprint. The higher the number, the more land is built upon within an area, the more compact it is.

Pont and Haupt (Pont and Haupt, 2010) define several variables able to describe density: the floor-space index and the ground-space index are the most important.

In, general, as the GSI increases, the air temperature in the area increases, the wind speed decreases, and the intensity of the heat island increases. As the FSI increases, the effect of using ventilation to reduce air temperature and mitigate the heat island effect becomes more obvious(Zhou X F,2013).

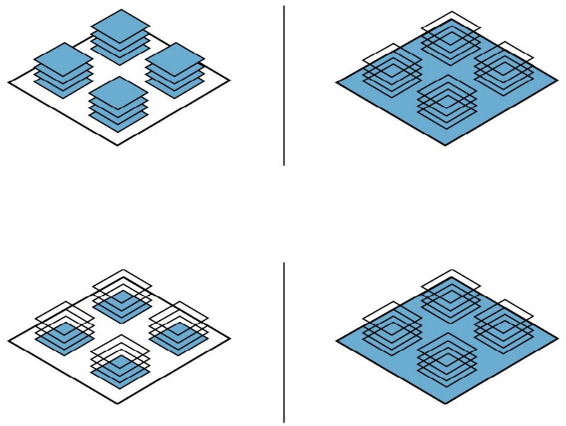


Fig. 3.4.2. Numerator and denominator for the calculation of the FSI and GSI.
Source: Berghauser, 2010

Vegetation index (NDVI)

The urban green space system exerts its ecological benefits by using the green open space system as an open space to reduce the pollution concentration of the city by the dilution and diffusion of pollutants by the wind. Forests or high trees cover will hinder ventilation, although dust can be reduced by plant adsorption and filtration. In the breeze and still wind conditions, the ecological benefits of the urban green space system are greater. Through advection-diffusion between cool and heat sources, while filtrating air pollution, the pollution concentration is also reduced by the effect of turbulent diffusion.

On the other hand, the lower the NDVI value, the more obvious the interference of human activities, the more concentrated the industrial economic layout, and the greater the amount of pollution. In order to indicate the distribution characteristics of the area by reflecting the factors such as the distribution of land use and population.

Therefore, the dilution or diffusion capacity of cities can be used as a reference through vegetation analysis. Vegetation can exist in the city in various ways, and it is highly operable.

Ground surface roughness

Surface roughness originates from the concept of aerodynamics, which refers to the geometrical height when the airflow in the air is affected by the resistance of the rough element, and the wind speed on the wind speed profile is zero. Due to the high-density construction of the city, especially the obstruction of airflow by buildings is becoming more and more obvious. The urban surface is much rougher than the natural surface. Quantitative calculations using urban morphological parameters can more accurately represent the true and effective surface roughness.

The lower the surface roughness, the smaller the resistance of the airflow to pass through, and the greater the wind speed. When constructing urban ventilation corridor, it is based on the calculation of ground surface roughness, combined with other form factors of the city to simulate in the city, reduce the urban heat island effect and improve air quality.

Normally the frontal area index (FAI) and frontal area density (FAD) are calculated as the surface roughness by using the urban morphological parameters.

Frontal Area Index

The frontal area index is one of the parameters for judging the effect of buildings in the city on wind shielding. It refers to the ratio between the frontal area of buildings and structures in the calculated wind direction and the maximum possible frontal area. When the wind direction is kept constant, the rotating building itself, the largest possible frontal area appears.

In order to modify this factor in an existing area, it would be required to replace or add buildings, which is not generally feasible. Its operability is considered as low although it can be considered for new developments.

Land surface temperature

The surface temperature indicates the surface temperature of land water, vegetation, soil, rocks, etc., that is, the temperature at the surface interface. It is often used to study the urban heat island effect. The heat island effect has an important impact on the generation and distribution of pollutants, which are mainly driven by thermal and dynamic processes above the city.

Therefore, when considering how to increase urban green space and forest coverage, it is necessary to consider the heated area, and in which area, which types of trees can be used to slow down the urban heat island and suppress pollutants.

Urban canyon

Orientation

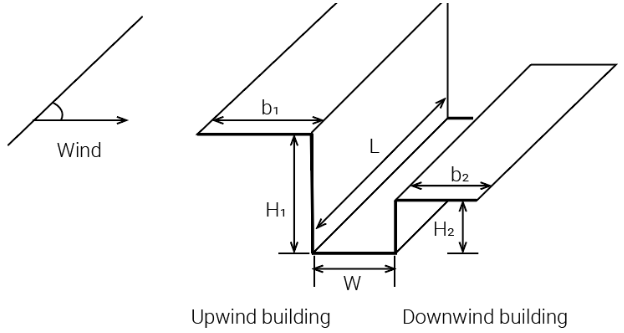


Fig. 3.4.3. Illustration of a typical street canyon
Source: Author

The influence of the angle between the street canyon direction and the wind direction on air pollution is significant. When the direction of the street is perpendicular to the direction of the incoming wind, air vortexes tend to form in the street canyon and the air quality is poor; when the direction of the street is parallel to the direction of the incoming wind, the longer the street is, the more obvious the "the effect of narrow" (Zhao LL, 2017). For the respiratory height or the area of crowd movement, the pollution degree of the short street canyon (L / W = 1) increases with the increase of the angle between the street canyon direction and the wind direction (Liu J, 2009). When the street is relatively long, the pollutants accumulate along the direction of the street canyon, and the pollution is heavier. As the included angle increases, the cumulative effect of pollution weakens. The 45 ° included angle pollution is the lightest. When the included angle increases again, the ventilation weakens. Contamination at 90 ° is still the worst (Yassin MF, 2013).

Symmetry

When the building heights on both sides of the street canyon are not consistent, it is called an asymmetric street canyon. The ratio between the upwind building height (H1), downwind building height (H2), and width (W) in the street canyon lead to different wind field structures. When H1 is less than H2, it is called "step-up" canyon, and conversely, when H1 is larger than H2, it is called "step-down" canyon. The turbulence intensity of the wind field in various types of street canyons is in order: "step-up" canyon is greater than " step-down" canyon, and the turbulence intensity of the parallel street canyon is the smallest. Generally, concentrations in step-up canyons are a factor two lower compared to step-down canyons (Hoydysh & Dabberdt, 1988; et al.).

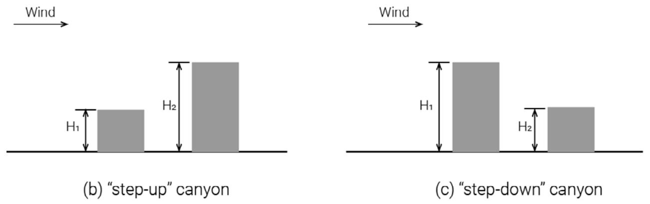


Fig. 3.4.5. Asymmetric urban canyons
Source: Author

H/W

Street canyon wind field can be divided into isolated roughness flow, wake interference flow and skimming flow (Baik & Kim, 1999; et, al). It is mainly affected by the aspect ratio (H / W) of the street canyon.
The vertical interface at the centre of the street canyon forms different vortices due to different H / W. When the wind direction and the street valley tend to be the same, the wind speed inside the street canyon increases, and pollutants are not easy to accumulate (Zhao L L, 2017). When the direction of the incoming stream is perpendicular to the street valley, the H / W has different effects on its internal wind environment. When H / W <0.2, the street valley is wide, and two opposite vortices appear on both sides of the street canyon; When 0.33 <H / W <1.67, there is only one vortex; when 1.67 <H / W <2.5, there are vortices with opposite directions; When H / W is further increased, three or more vortices are formed in the street canyon wind field (Sini J F, et al, 1996; Xie X M et al, 2006; Leung K K et al, 2012). Due to the different wind field structure, the street canyon pollution diffusion ability is different. In general, as H / W increases, the pollution diffusion capacity decreases and air pollution increases (Park S K, 2004).

Roof shape

In the research on the influence of roof on ventilation and air pollution in street canyons, most of them are based on flat-roofed street canyon buildings as a basis and contrast. The changes in the roof will change the height, symmetry and width of the street canyons. The resulting H / W variation and asymmetry of street valleys are consistent with the influence of flat-roofed street canyon morphological changes on street canyon ventilation(Huang Y D,et al,2009). Such as vaulted roof, trapezoidal roof, slanted roof, and wedged roof, on the airflow patterns in street canyons(Tan Z J.2016).

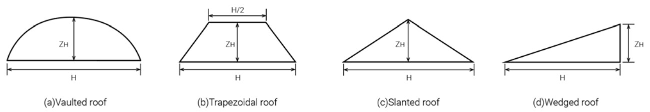


Fig. 3.4.7. Schematic diagram of four different roof shapes
Source: Yuan-dong Huang,2015

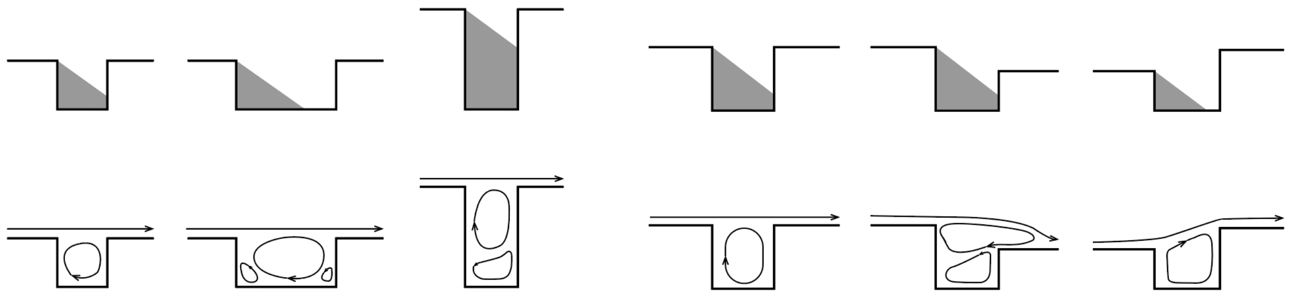


Fig. 3.4.6. Schematic diagram of the shadow area and streamlines in different street canyons.
Source: Xie, X.2005

Tree

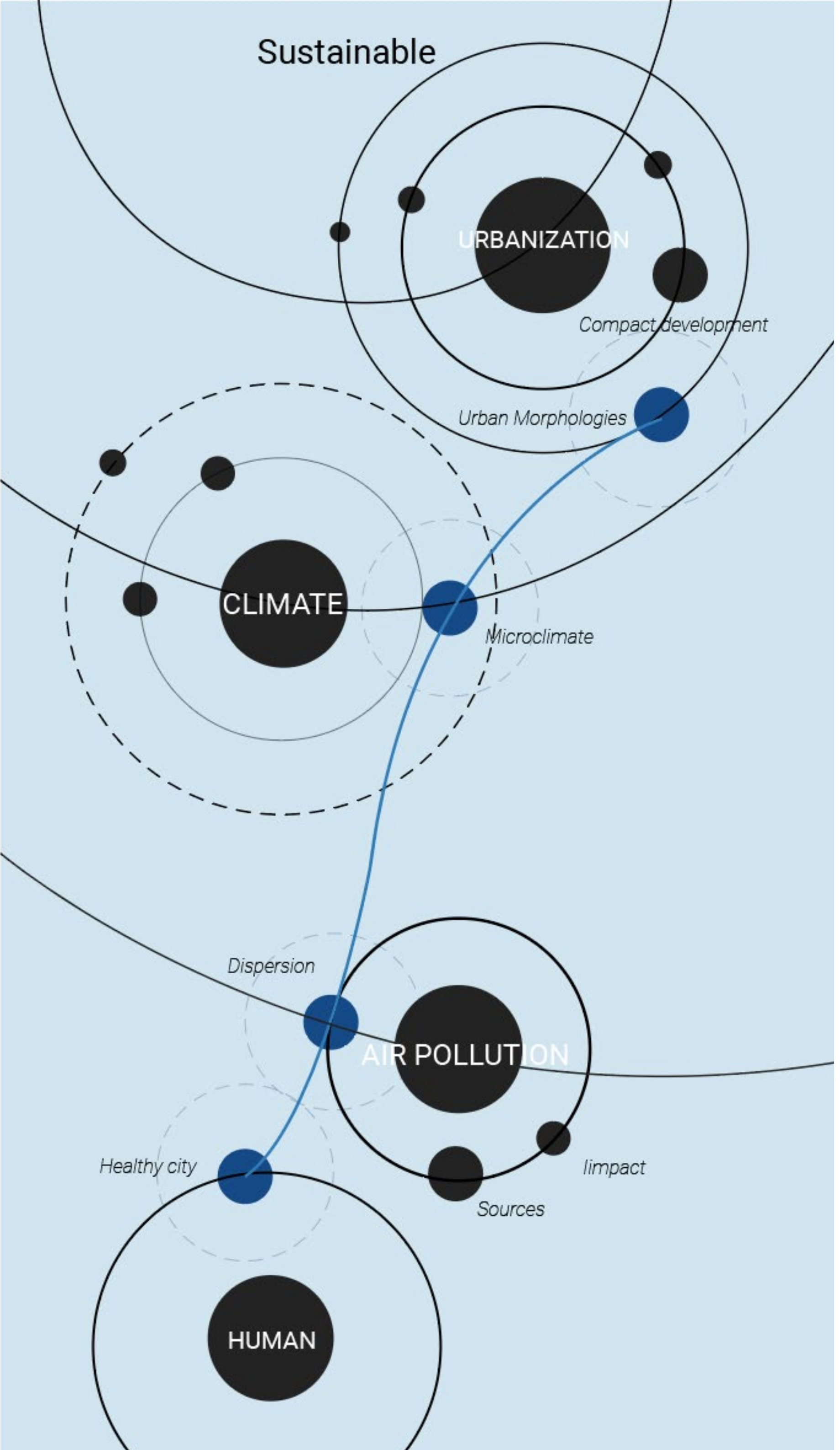
Street trees are common street canyon facilities. Vegetation has a certain weakening and blocking effect on the street canyon airflow, often reducing the overall ventilation efficiency and contaminants are difficult to spread and the concentration increases. In addition, plant species, distance from the wall, continuity, and spacing will also affect street canyon ventilation and air pollution (Ji W & Zhao B, 2014). On the other hand, the characteristics of the vegetation's absorption of heat radiation will affect the street canyon's thermal environment. In the strong summer, not only can a large amount of heat energy be consumed through transpiration, but the canopy can also increase the reflectivity of solar radiation, and produce a climatic effect of reducing the ambient temperature in the shadows appearing on the sidewalk trees. At the same time, the plants convert solar energy into bioenergy, reducing the fluctuation range of the air layer (Zhao J Y, 2019).
Vegetation leaves can absorb certain particulate matter to reduce pollution. Particulate matter precipitation is related to factors such as particle size, wind speed, plant species, leaf area, and particulate matter concentration (Gao H L, et al, 2017).

Others(wall,materials)

In addition to the main morphological factors inside the street valley mentioned above, viaducts, pedestrians, vehicles and other facilities also affect the distribution of air pollution in the street valley.

Green roofs, technical measures such as wall surfaces, moisture storage building materials, and radiation coatings also play an important role in improving the urban wind and heat environment (Zijing, T, 2016). On the one hand, solid boundaries such as walls and streets are the main factors that constrain and restrict air movement. For instance, non-smooth surfaces can drag and disturb fluids, thereby affecting the street and valley wind environment, while building surface materials and landscape paving materials, etc., change the thermal environment of streets canyons according to different surface reflectances and wall thermal effects.

In addition to the use of new building materials, the color of the materials also has a certain effect. Studies have confirmed that when cities use white roofs, the heat island effect will be significantly weakened.



3.5 Conceptual Framework

For the purpose of this thesis, the urban microclimate is chosen as the impact mechanism between urban morphology and air pollution. Focusing on air pollution from the perspective of urbanization, finding conflicts between urban development and urban environment, and linking tangible urban space with intangible urban air pollution problems through microclimate design, with the aim of forming a healthier and more livable urban form. After discussing the relationship between the three, the urban morphology factor and microclimate factor most relevant to air pollution are obtained, and then different urban form factors in different scales(FSI/GSI, canyon geometric layout, vegetation, et, al are concerned), designers can use it for microclimate, while microclimate elements (wind, heat) can be used for air pollution mitigation.

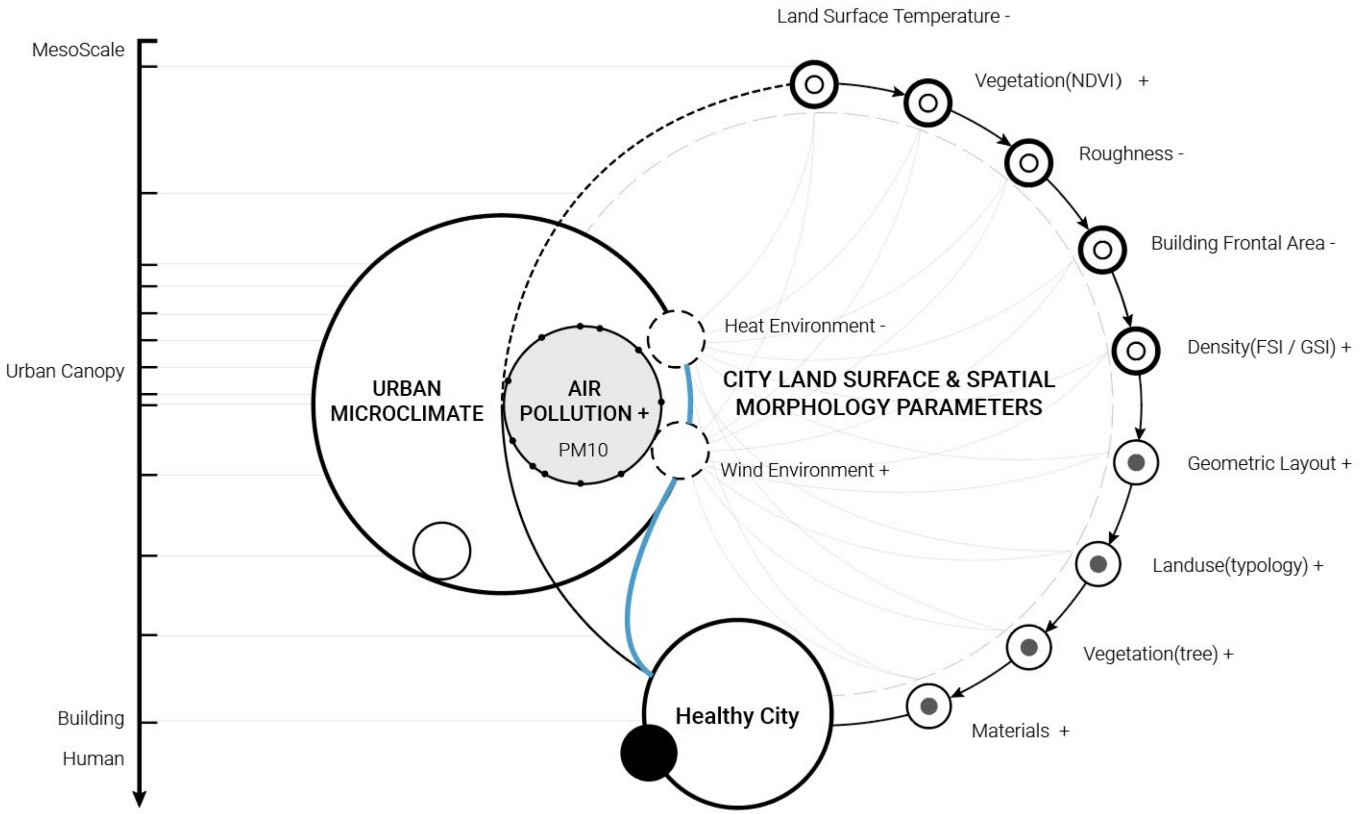


Fig. 3.5.1. Urbanization, climate and air pollution.
Source: Author

Fig. 3.5.2. Conceptual framework.
Source: Overall connections between selected urban space factors, microclimate and air pollution. (author)

3.6 Risk Assessment: Environmental Risk Mapping

The main purpose of the analysis chapter is to find the most polluted and the most unfavourable microclimate(low wind speed) area to the spread of pollutants in Chengdu. This thesis uses the environmental risk mapping method to do the risk assessment. It is an effective way to explore the spatial characteristics of pollutant concentrations, exposures, and effects. During the evaluation process, this project mainly includes the following types of maps.

Pollution/risk map: A map or forecast of environmental pollutant concentration levels in a region.

Vulnerability map: Map the more sensitive and less sensitive areas using the presence and geographic distribution of environmentally sensitive receptors (this refers to climate and human vulnerability).

Cumulative risk map (single stress and multiple stress cumulative risks): overlay the above maps to combine single stress risks.

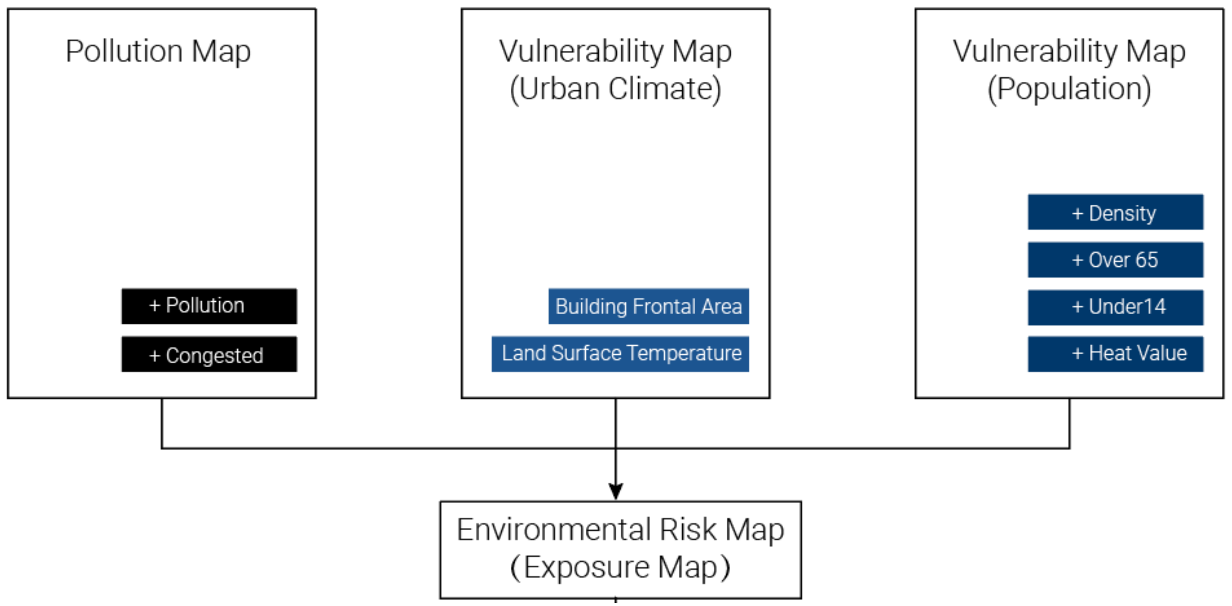


Fig. 3.6.1. .Methodology of the environmental risk mapping development
Source: Author

Summary

The impact mechanism between high-density urban morphology, urban microclimate, and air pollution is multi-disciplinary and multi-scale. In order to achieve research goals and answer research questions, multi-disciplinary and interscale methods are usually required.

In the six stages of the entire chapter, the analysis matrix was completed through literature review and comparative study, thereby selecting urban morphological factors related to urban microclimate and pollution, and a large amount of literature provided support. In the decision-making process, first collecting data is an important step. Second, the method of environmental risk maps is used for decision-making, and then the transition to the street-canyon scale for analysis. In proposing planning and design interventions, in addition, to use the method of literature review, stakeholder analysis is an indispensable part at the end of the thesis, which makes the object and the feasibility of the entire project more clear. In the street canyon design stage, the relevant dynamic models used in the software will be selected and test first, then set the parameters in order to get closer to the real site situation, followed by numerical simulation using ENVI-met software, and finally, the design results will be evaluated.

Throughout the thesis, there are a large number of references on the study of wind and heat separately with urban morphology, but it is difficult to draw more accurate conclusions due to its complexity, but it still provides the possibility to study wind and heat coupling optimization measures on air pollution mitigation. On the one hand, the analysis matrix provides a method for selecting different layers to establish a theoretical framework. On the other hand, in the environmental risk assessment method, the population vulnerability map reflects the distribution of the population that is more likely to be affected when exposed to pollution. Contributed to the consideration of social justice. Finally, considering the feasibility aspects of the intervention, stakeholder analysis will help identify investors, decision-makers, or implementers involved in urban planning or urban design. Help predict the extent to which the project can be implemented. Therefore, through the above-mentioned multiple methods, the three systems of urban form, urban microclimate, and air pollution can be interconnected, and they are involved in multi-scale theory and practice.

4. Analysis

In this section of the city-scale analysis, the most polluted areas of the city, as well as the most disadvantaged areas for diffuse and dilution of pollution, were identified mainly by means of environmental risk mapping.

As mentioned earlier, the main components of environmental risk mapping are the pollution/risk map, the climate vulnerability map and the population vulnerability map. Then select the area of intervention at the next scale.

1. Pollution map

Understanding the distribution of pollution in Chengdu is the first step. According to the literature, it is known that Chengdu's pollution is mainly concentrated in central urban areas, and vehicle exhaust emissions have become the main source of urban pollution (Mao Hongmei, 2016). Therefore, this thesis mainly analyzes the distribution of traffic pollution in Chengdu.

2. Vulnerability map(urban climate)

In the second stage, the wind and heat environment of Chengdu was analyzed through the frontal area index (FAI) and the land surface temperature (LST). The data of this part of LST came from June 5, 2018 (USGS, 2018). Understanding the areas where Chengdu's wind environment may be weak and temperatures are high may be detrimental to the dispersion of air pollution. Briefly analyze the building, land use and green space index (NDVI) of Chengdu, and try to find possible relationships in preparation for the subsequent design phase.

3. Vulnerability map(population)

The purpose of the vulnerability map(population) is to find areas that are more sensitive to air pollution, which may be areas with high incidence of disease, which can be areas with more elderly or young people, or areas where the population is exposed more outdoors. This thesis uses Baidu heat value maps to indicate areas where human exposure is more concentrated as a map of population vulnerability, with a view to reducing pollution in these areas, eliminating and reducing the impact of built-up environmental elements with potential risk of disease on the human body.

4. Site selection

Based on the above analysis, after assessing the environmental risk of Chengdu, further analyze the relationship between density and urban wind and heat in the physical characteristics related to urban microclimate. On the one hand, higher physical density hinders urban ventilation.On the other hand, higher physical density will bring higher surface roughness and increase the urban heat island effect. At the same time, areas with high physical density may correspond to more people exposed to outdoor pollution. Therefore, assessing the expression of urban air pollution in different types of density is helpful to understand why different urban forms become high-risk areas. Use GSI and FSI to study the physical density of Chengdu, generate a density typology, and choose different types to analyze the characteristics of air pollution and wind-heat environment in a smaller scale.

4.1 Pollution map

According to a literature review, Chengdu's pollutants are concentrated in downtown areas. The spatial distribution of CO is closely related to industrial process sources and motor vehicle emissions, mainly concentrated in the urban area of Chengdu and surrounding industrial areas and highways outside the urban area. The spatial distribution of SO2 is closely related to the distribution of industrial point sources, mainly concentrated in industrial areas around Chengdu; in addition to being related to industrial point sources, the distribution of NOx is also closely related to road vehicle emissions. The spatial distribution of PM10 and PM2.5 are mainly related to building dust, road dust and industrial point source emissions. PM10 and PM2.5 emissions in the central urban area are relatively higher (Zhou ZH, 2018).

At the same time, as of the end of 2016, Chengdu 's vehicle ownership exceeded 4 million and it began to show obvious characteristics of motor vehicle pollution (He Kebing, 2014). Chengdu 's vehicle ownership ranks among the top three in China. Mitigation of motor vehicle pollution is of great significance for improving urban air quality.

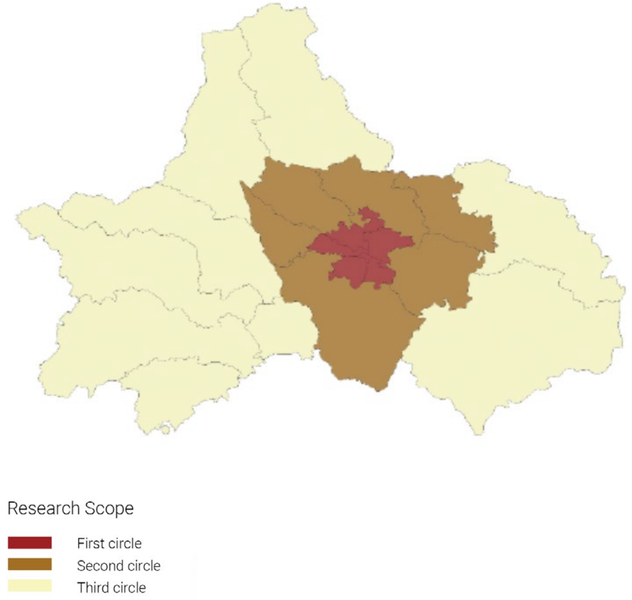


Fig. 4.1.1. Research scope
Source:Author

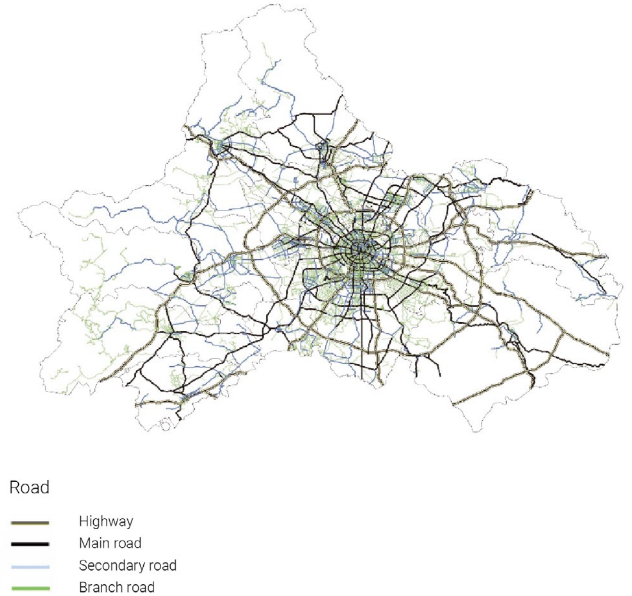


Fig. 4.1.2. Chengdu road network
Source:http://www.openstreetmap.org/

Spatial distribution of road source emissions in Chengdu

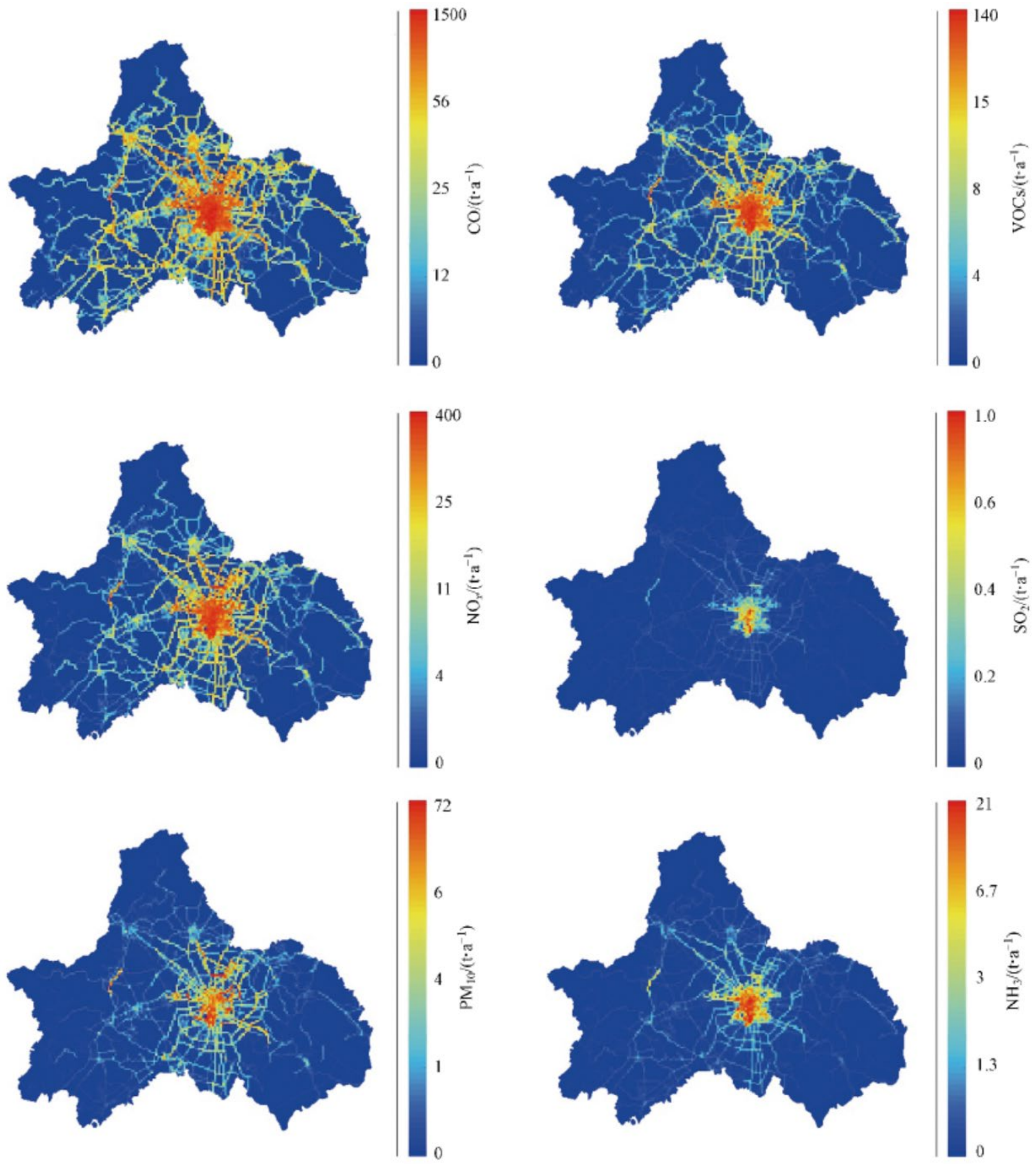


Fig. 4.1.3. Spatial distribution of road source emissions in Chengdu.
Source:Zhou zihang, et al, 2018. On-road mobile source emission inventory and spatial distribution characteristics in Chengdu

PM10 pollution intensity map of the second ring road in Chengdu

Fig. 4.1.4. PM10 concentration in the Second Ring Road of Chengdu,
Source： Huang rui, 2015. The green roof landscape study for alleviating the air pollution in calm-wind and high density cities.

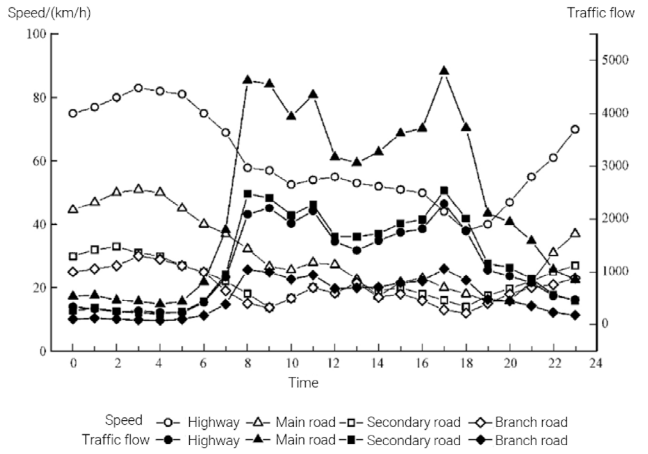


Fig. 4.1.5. The daily speed and traffic flow of various road types
Source:Zhou zihang, et al, 2018.On-road mobile source emission inventory and spatial distribution characteristics in Chengdu

Zhou Zihang et al conducted emissions calculations through measured corrections and IVE models and obtained a spatial-temporal distribution map of Chengdu's traffic pollution emissions by establishing a spatial grid with a resolution of 1km × 1km. The spatial distribution of pollutant emissions in Chengdu shows a decreasing trend from urban centres to satellite cities and remote suburbs. From the analysis, it shows the pollution of Chengdu city centre is mainly contributed by the emissions of passenger cars. Among them, Chenghua District, as a former logistics distribution base, has a higher contribution of SO_2 and PM10 emissions from its trucks.

The main contributors of NOx and PM10 are heavy goods vehicles, and their spatial distribution is mainly concentrated on freight roads such as highways and main roads. It is worth noting that, as the centre of urban construction and logistics distribution, the central urban area has a large emission intensity of NOX and PM10, while other areas are mainly concentrated in transit roads; the number of motor vehicles in the central urban area accounts for 38% of the number of motor vehicles in Chengdu. But the poor driving conditions in the central urban area lead to higher pollution emissions. The periphery of the second ring floor has more obvious emission characteristics of trucks. It is related to the fact that Chengdu's transit highways, freight roads, and logistics bases are mostly distributed in the second ring floor near the centre, contributing 41% of PM10.

From the perspective of passenger vehicle emission factors on different roads, the order of road pollution in Chengdu is secondary roads ≥ branch roads> main roads> highways. This result is due to the fact that Chengdu belongs to a typical circular road network. Branch roads carry a large number of vehicles, and more congestion leads to worse driving conditions and higher emissions (Zhou zihang, et al, 2018). Therefore, Chengdu branch roads, as important road capillaries, need to further develop measures to reduce pollution.

Traffic flows

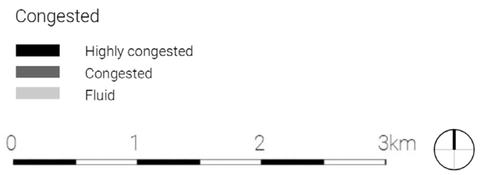


Fig. 4.1.6. Traffic flow map
Source: CBNData Di Di (2016.07-09)

The congested sections and locations of Chengdu are mainly distributed in Chunxi Road as the core business and leisure area. 1.Renmin South Road Section 3 and 4, 2.Second Ring Road, South 2 Section 3. Third Ring Road 4, South Section 5 4. Wuhou Avenue Shuangnan Section 5. The area around Chunxi Road.

4.2 Vulnerability map(Urban Climate—Frontal Area Index)

A reliable method for calculating the surface roughness of cities is field observations through micrometeorology, which are expensive and complicated. Therefore, several morphometric models have been developed to determine the roughness parameters in a particular situation. Among them, the frontal area index(FAI) and the frontal area density(FAD) are often used. The FAI is the proportional relationship between the prevailing wind in the city and the total frontal area of urban buildings and the standard unit grid area under the building.

Fig. 4.2.1. Regional boundary selection: building block grid-regular grid 200×200m
Source: Author

During the area calculation of the simulation experiment, due to the different methods of regional boundary and scale selection, there is uncertainty in the spatial statistical analysis, that is the modifiable areal unit problem (MAUP). Here the research plot is divided into a regular grid of a certain area.

Pearlmutter et al calculated the density of the frontal area in the range of 200 square kilometres, and the results of grid sensitivity tests showed that the grid size of 200 × 200m is a relatively reliable accuracy. Chengdu's downtown area is about 600 square kilometres. From the perspective of computer operation capabilities and image visibility, a 200 × 200m unit grid is selected to analyze the urban morphological characteristics and calculate the FAI.

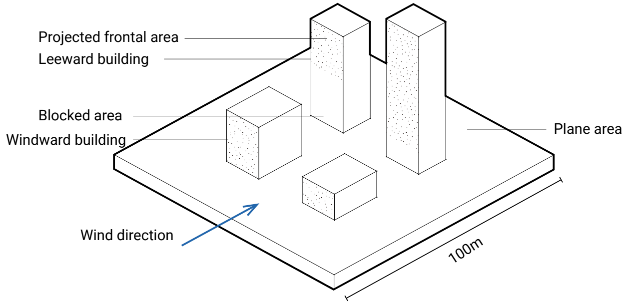


Fig. 4.2.2. Example of frontal area calculation
Source:Man Sing Wong, Janet E, Nichol, To P H, et al,2010.

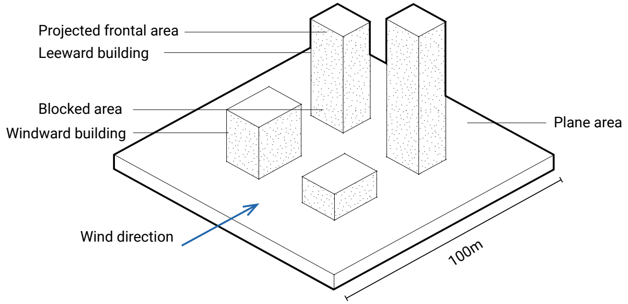


Fig. 4.2.3. Frontal area calculation
Source:Liu junyong,2012

In the study of this thesis, Chengdu is a vast city, and the central urban area lacks specific wind environment data. At the same time, every facade of the building will have an obstructive effect on the wind and a deflection effect on the wind direction. It manifests that not only changes in wind speed, but also changes in wind direction. At the same time, the prevailing wind still wind frequency in Chengdu is extremely high. More consideration should be given to local wind conditions.

Therefore, calculating the ratio of the façade area to the total plane of all the buildings in the storey can also characterize the complex ventilation situation of the city in a large-scale research environment to a certain extent.

This thesis uses the method of agglomerating adjacent buildings (Aggregation distance is 1m), using the perimeter and height of the agglomerated building, to relatively easily calculate the frontal area index that has an obstructive effect on the wind. Later, according to the research results of scholars such as Man Sing Wong, the FAI was divided into five levels.

Frontal Area Index

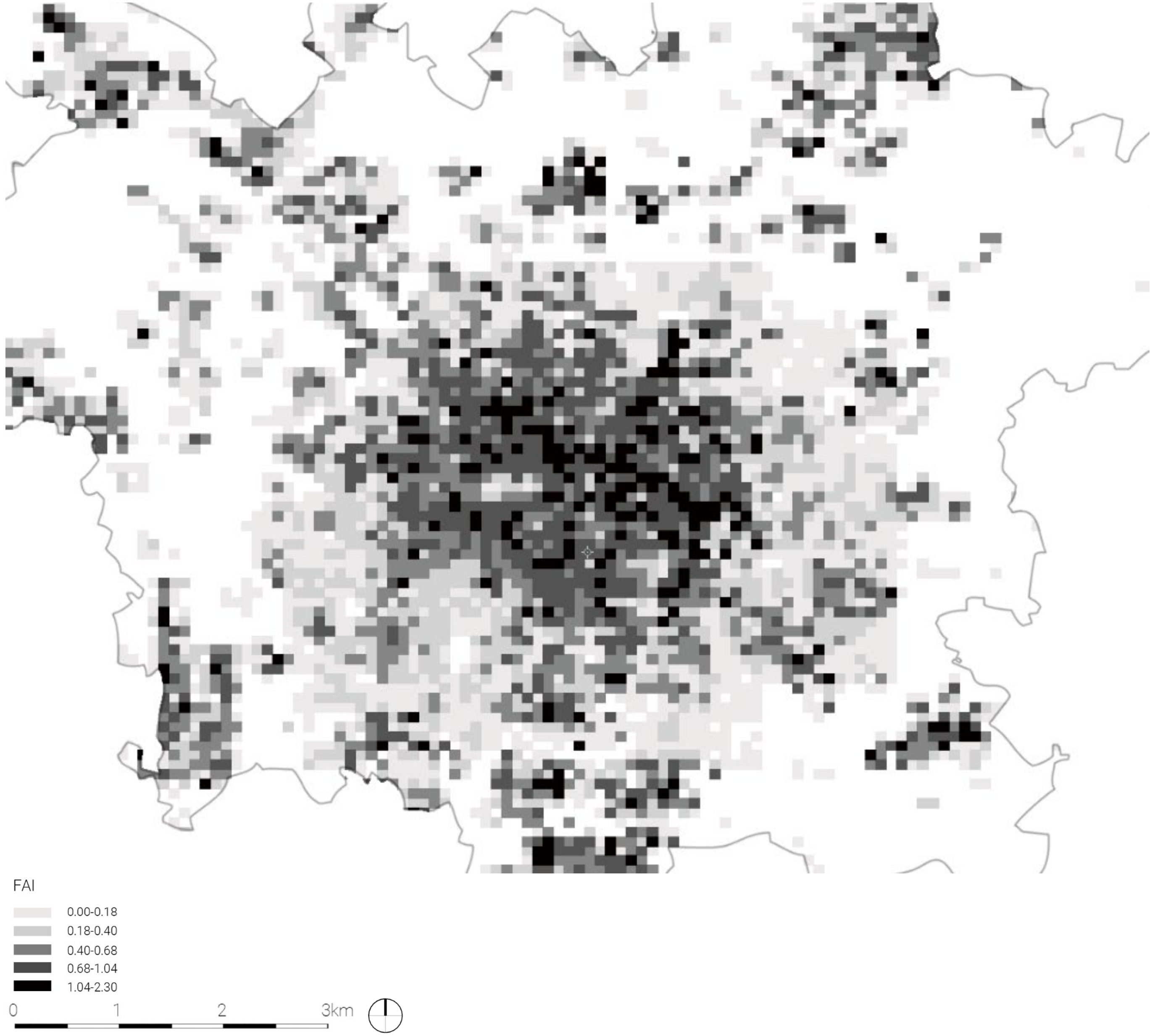


Fig. 4.2.4. Frontal area index map.
Source: Geospatial Data Cloud. Generated by author using GIS

Land Surface Temperature

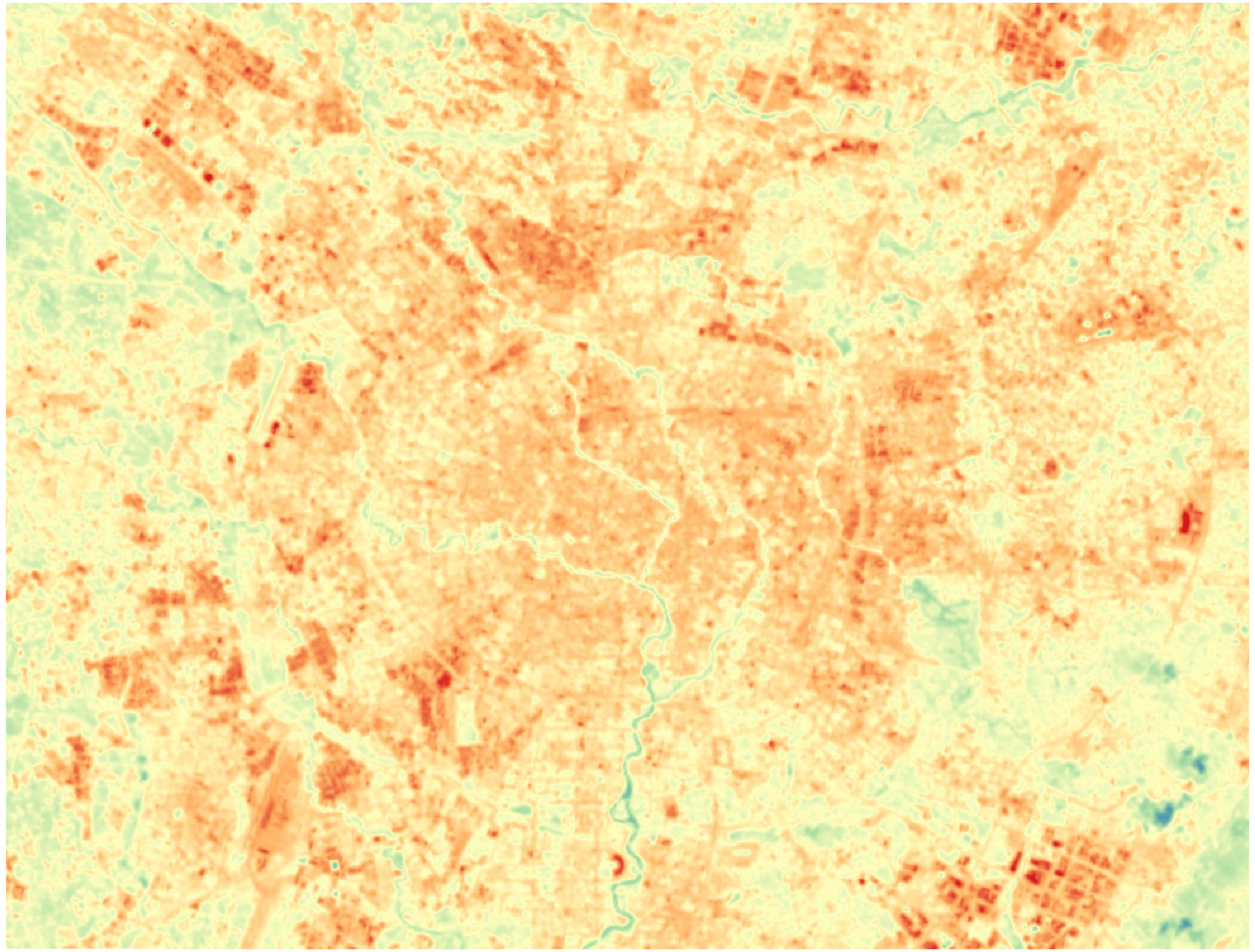


Fig. 4.2.5. LST map.
Source: https://www.geoportal.org/ LC08_L1TP_129039_20180605_20180615_01_T1_B10. Generated by author using GIS sofware, based on images obtained from the satellite Landsat 8 (05/06/2018). LST displayed on the block layer.

VEGETATION INDEX(NDVI)

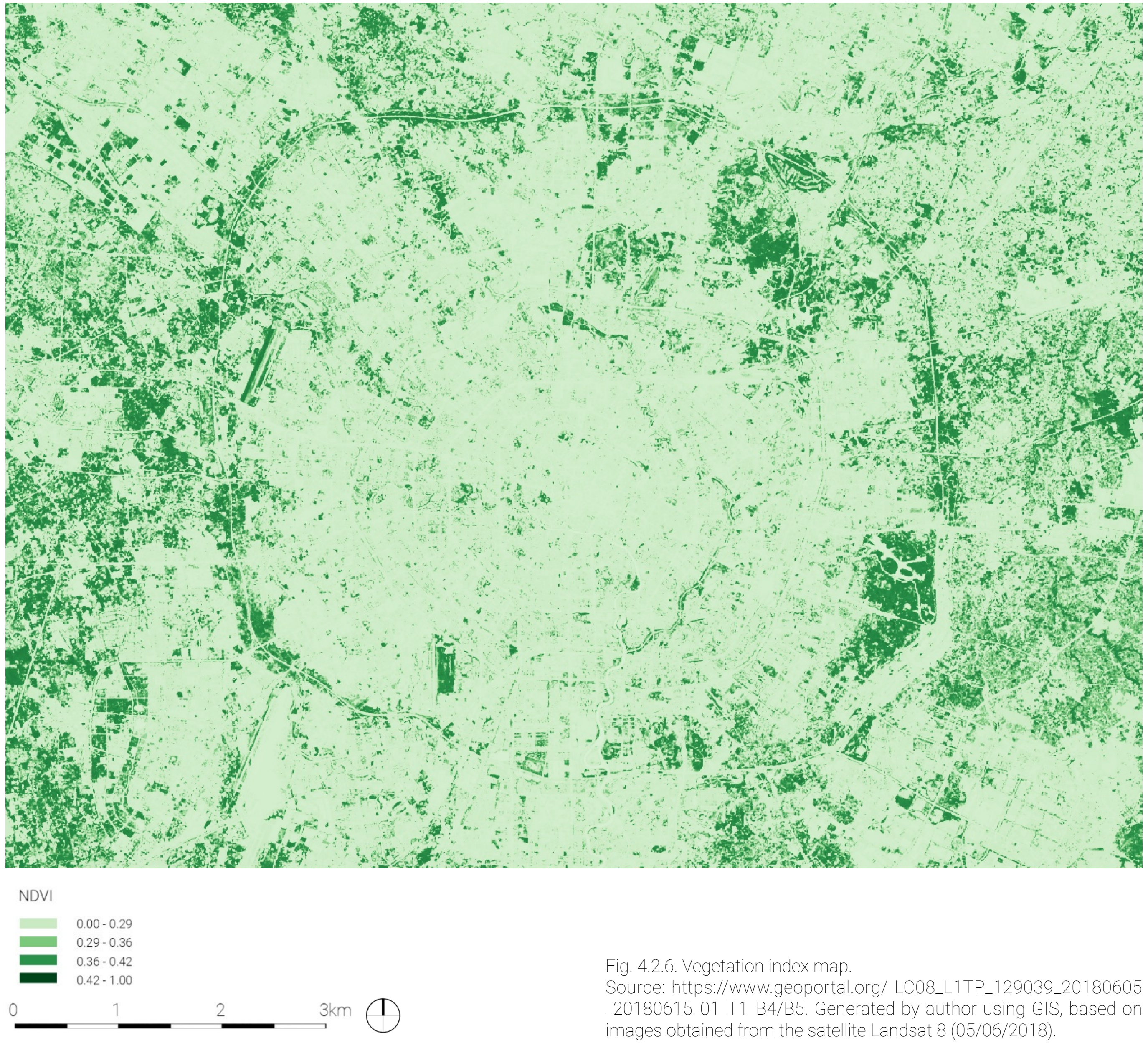


Fig. 4.2.6. Vegetation index map.
Source: https://www.geoportal.org/ LC08_L1TP_129039_20180605_20180615_01_T1_B4/B5. Generated by author using GIS, based on images obtained from the satellite Landsat 8 (05/06/2018).

Building height

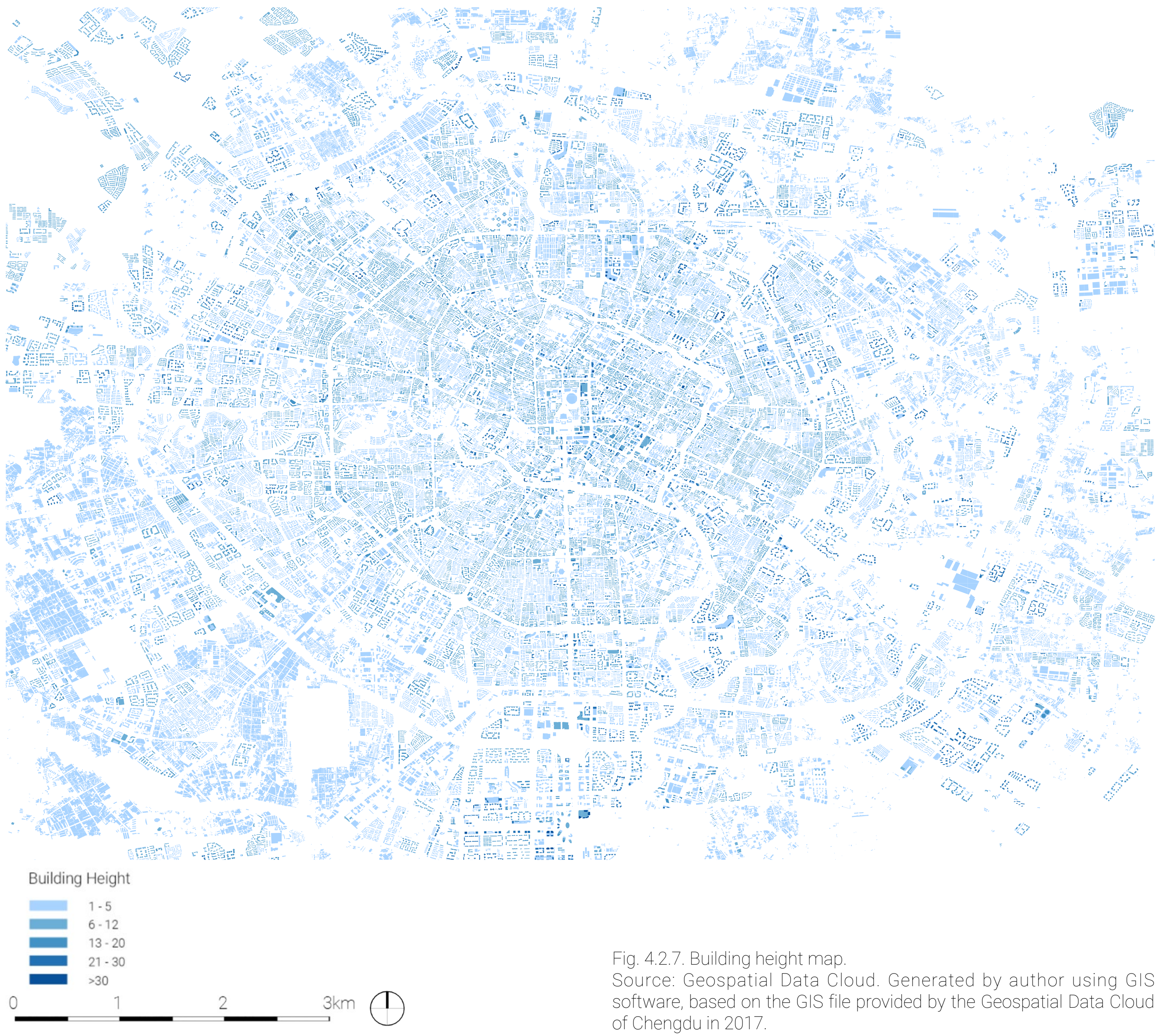


Fig. 4.2.7. Building height map.
Source: Geospatial Data Cloud. Generated by author using GIS software, based on the GIS file provided by the Geospatial Data Cloud of Chengdu in 2017.

Land use

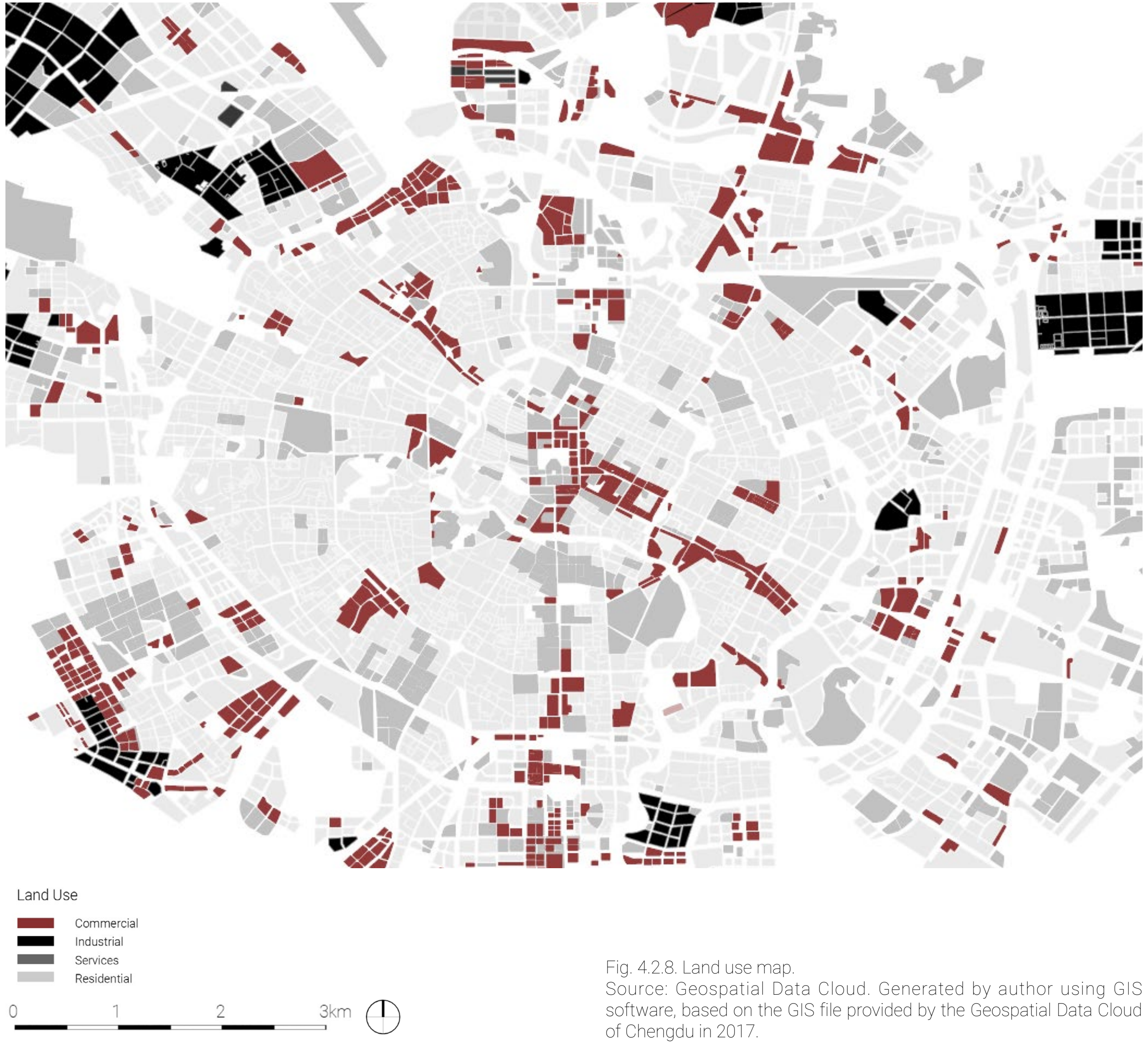


Fig. 4.2.8. Land use map.
Source: Geospatial Data Cloud. Generated by author using GIS software, based on the GIS file provided by the Geospatial Data Cloud of Chengdu in 2017.

Summary (Urban climate vulnerability map)

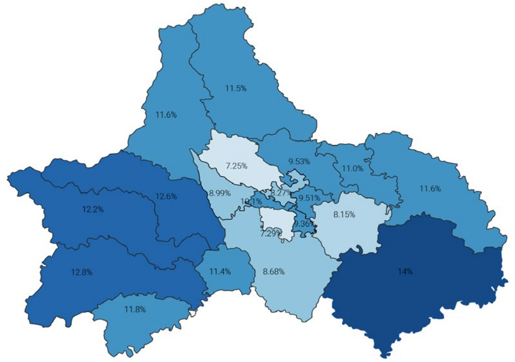
The purpose of the urban climate vulnerability map is to focus on areas with low winds and high temperatures. Improve local ventilation in urban areas while dividing hotter areas as much as possible to improve the local thermal environment. Some scholars have shown (Man Sing Wong, 2010) that the ventilation performance is poor when the frontal area index of the building is higher than 1.00. It can be seen from the frontal area index map.

a) There are many areas with frontal area index above 1.00 in Chengdu's downtown area, and the ventilation is poor; these areas are the traditional commercial and trade areas of Chengdu, with high building density.

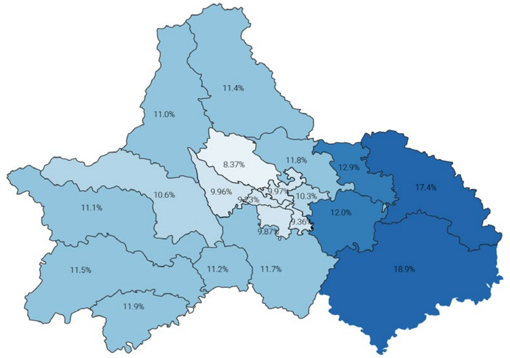
b) Due to the large-area green wedge around the city highway, the ventilation effect is better, it also has a certain penetration effect in the urban area, and it has a certain improvement effect on the ventilation situation around the central urban area;

c) The areas with high temperature are industrial areas around the central urban area. The wind direction of these areas should be carefully controlled to avoid bringing industrial pollution or hot air into the city centre.

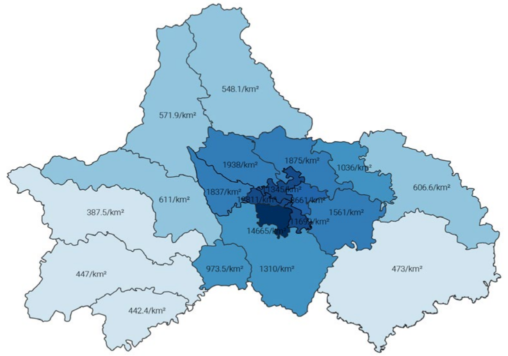
4.3 Vulnerability map (Population)



source: Proportion of population over 65 years old of 2010
https://www.citypopulation.de/zh/china/sichuan/admin/



source: Proportion of population under 14 years old of 2010
https://www.citypopulation.de/zh/china/sichuan/admin/



source: Population density of 2017
https://www.citypopulation.de/zh/china/sichuan/admin/

In addition to the urban climate, the Chengdu Vulnerability Map also includes a population vulnerability map. Population data can identify areas with high disease incidence, human exposure areas, or population distribution areas that are more sensitive to air pollution, such as the elderly and young people, which can more effectively define vulnerable areas in Chengdu.

Unfortunately, accurate maps of the above population distribution data are lacking. As shown in the figure, Chengdu has the highest population density in the central area of the first circle, followed by the second circle. The elderly and young people are mainly distributed in the outer circle of Chengdu. The central area is mainly occupied by young and middle-aged people.

Due to the lack of data, the distribution of Chengdu's population is for reference only, and the area where the population is gathered will be used as a map of population exposure vulnerability according to the Baidu heat map of Chengdu on December 25 and 26, 2016.(Baidu heat value map is based on the location information carried by smartphone users when accessing Baidu products (such as search, maps, weather, and music, etc.), clustering is performed according to location clustering to calculate the crowd density and flow speed in each region).

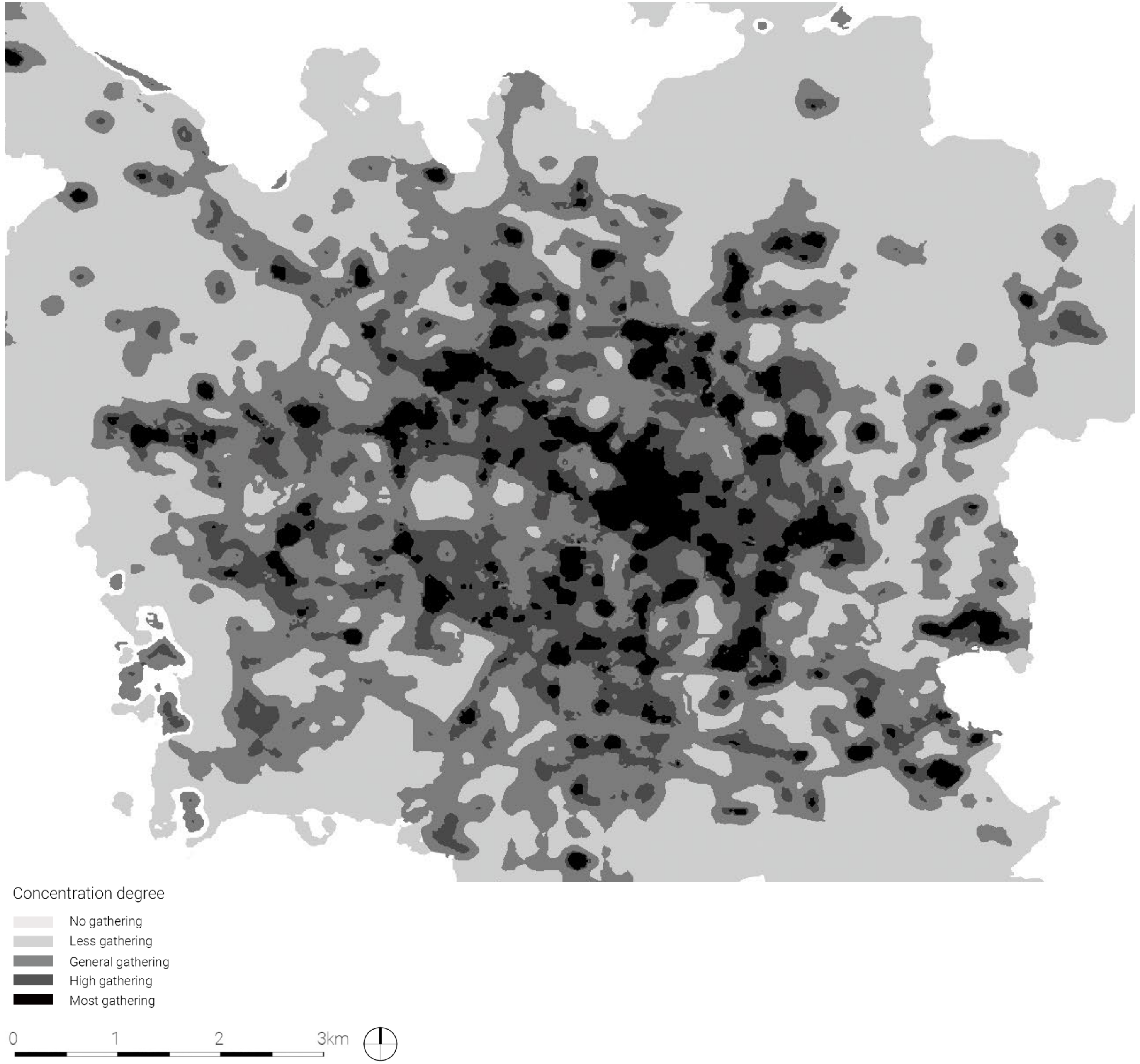


Fig. 4.3.4. Heat value average and high average map (2016.12.25)
Source: Analysis of the distribution characteristics of crowd activities in downtown Chengdu based on Baidu heat map

Fig. 4.3.5. Baidu heat map (2016.12.26 9:00)
Source: Analysis of the distribution characteristics of crowd activities in downtown Chengdu based on Baidu heat map

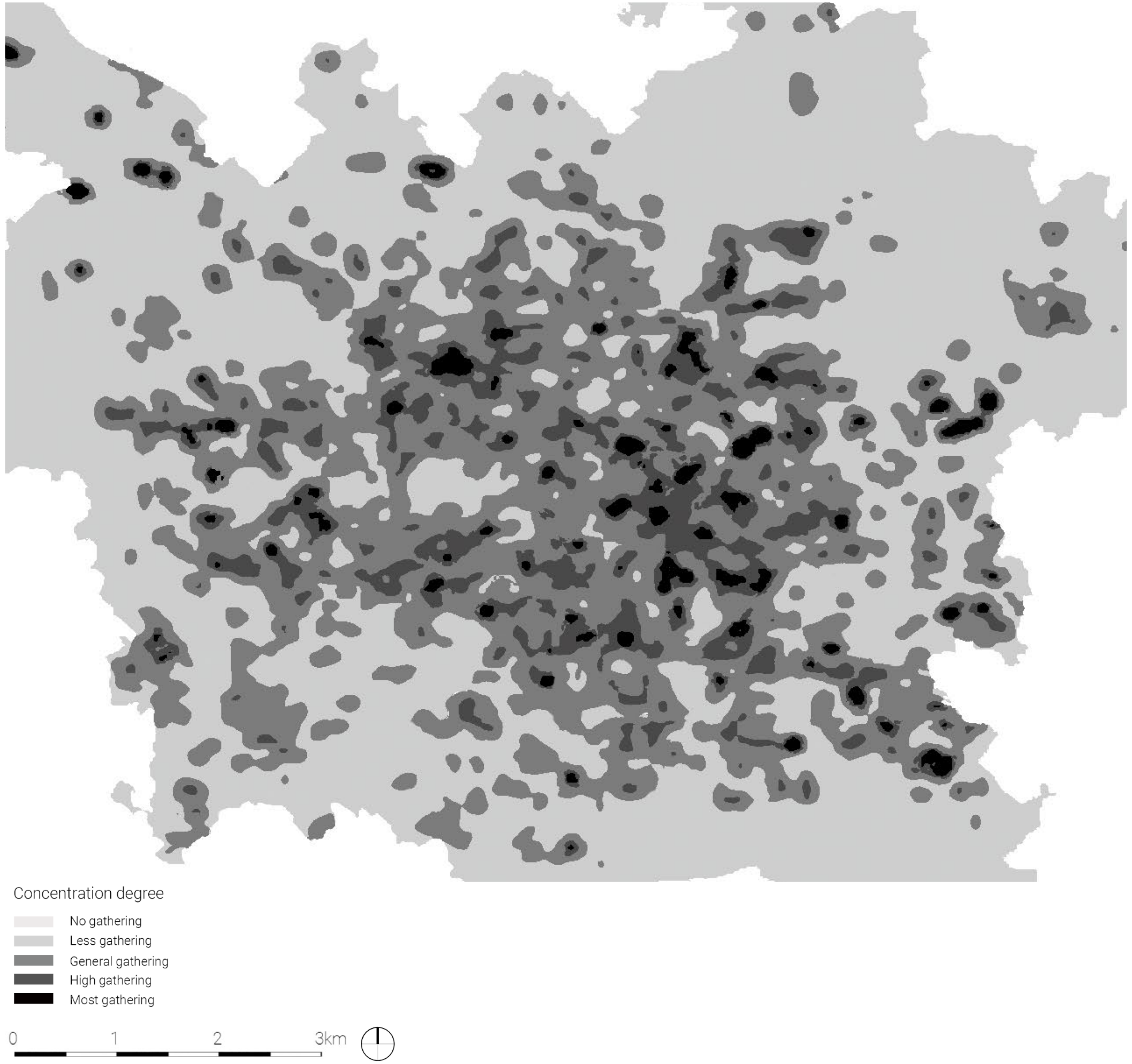


Fig. 4.3.6. Baidu heat map (2016.12.26 23:00)
Source: Analysis of the distribution characteristics of crowd activities in downtown Chengdu based on Baidu heat map

Fig. 4.3.7. Heat value average map (2016.12.26)
Source: Analysis of the distribution characteristics of crowd activities in downtown Chengdu based on Baidu heat map

Summary (Population vulnerability map)

During the holidays, the crowd gathering points are mainly distributed around the city's main roads, and the largest population is gathered in areas such as Hehuachi, Chunxi Road, Hongpailou, Xihuan Plaza, Jinjiang Wanda, Wannianchang, and Vientiane City; There are more crowds in the east of the city than in the west. The largest crowds are in Chunxi Road.

The areas with high concentration on weekdays are business office areas. The areas with high concentration through the identification of heat maps include Tianfu Square and Chunxi Road Area, North Station Area, Provincial Hospital and Guanghua Area, Xihuan Plaza, Hongpailou, Tongzi Lin area and hatchery area form horizontal and vertical two city axes along Renmin North Road-Renmin South Road-Tianfu Avenue and Shudu Avenue-Yinghui Road.

The average heat value map can reflect the degree of aggregation at each point in the city. The larger the average, the more people gather, that is, the stronger the aggregation effect; conversely, the smaller the average, the fewer people gather.

Combined with Chengdu's existing business district layout, the comprehensive analysis found that the areas with a larger average value were urban centres or regional centres of various districts and counties, such as Chunxi Road, North Railway Station, and West Plaza, etc. Areas with large standard deviations were mostly professional Markets and transportation hubs, such as the Lotus Pond Market and the East Railway Station area.

Limitation

The heat value map uses only one day's data source for holidays and workdays, so the results are somewhat accidental and inaccurate.

Fig. 4.3.8. Environmental Risk Map
Source: Author.

Results

It is very difficult to assess the air pollution risk of Chengdu from three aspects: air pollution, urban climate and population exposure. But in general, Chengdu 's traffic pollution is mainly concentrated in the central urban area and the main roads in the south. This is due to the pollution caused by the large traffic flow in the city and the poor condition of the city's branch roads, which is prone to congestion. The pollution of peripheral highways and main roads mainly comes from trucks.

In terms of urban wind and heat environment, the area with the higher frontal area index is the horizontal axis of the northwest-southeast, and it is also the horizontal axis of the city, which is dominated by traditional commerce and trade. Areas with higher temperatures are distributed in industrial areas around the city, so it is even more necessary to carefully control urban ventilation corridors to avoid bringing hot air or industrial pollution into the city centre.

In terms of population fragility, it can be seen from the figure that the main distribution areas of Chengdu's crowd activities are the western lotus pond market, Shuangnan, Chunxi Road, etc., where a large number of service industries and Sichuan Normal University areas are gathered. On weekdays, people gather in business office areas, including Tianfu Square, Chun Xi Road, Provincial Hospital, Hongpai Lou, TongziLin Area, Hatching Garden Area, along Renmin North Road-Renmin South Road-Tianfu Avenue and Shudu Avenue, form two urban axes of horizontal and vertical. The horizontal axis is mainly based on the traditional trade industry, and the vertical axis is mainly dominated by IT, finance and other industries.

For the final results,FAI higher than 1, the most gathering areas and places with the highest pm10 pollution are chosen. Since the goal is to define the urgent areas for air pollution mitigation, the concentration of pollution and exposure heat value will be given more weight. In this case. Although the northwest axis side is the least ventilated area, the south is considered to be the most vulnerable area.

The impact rate

In the process of developing and establishing a risk assessment, air pollution, urban wind and heat environments, and population exposure are taken into account. At this stage, it is not determined which area is selected, but different building density types are selected. The degree of influence of different factors will be revealed before the design phase.

4.4 Site selection

Density

As mentioned earlier, the urban microclimate (wind and heat environment) is closely related to the density of urban morphology. The urban built environment cannot be only represented by FAI. Based on the risk assessment, the criteria for selecting the area will according to the characteristics of urban morphological density. It aims to alleviate the air pollution problems in different types of built cities. And use this to discover more comprehensive solutions.

There are two indexes used to describe the density of Chengdu: the Floor Space Index (FSI) and the Ground Space Index (GSI) (Berghauser, 2010).

In the case of Chengdu in this thesis, the blocks range was generated by erasing the buffer zone of the road network map from the administrative divisions of neighbourhoods in GIS.

Fig. 4.4.1. Procedure for the definition of urban blocks.
Source: Author

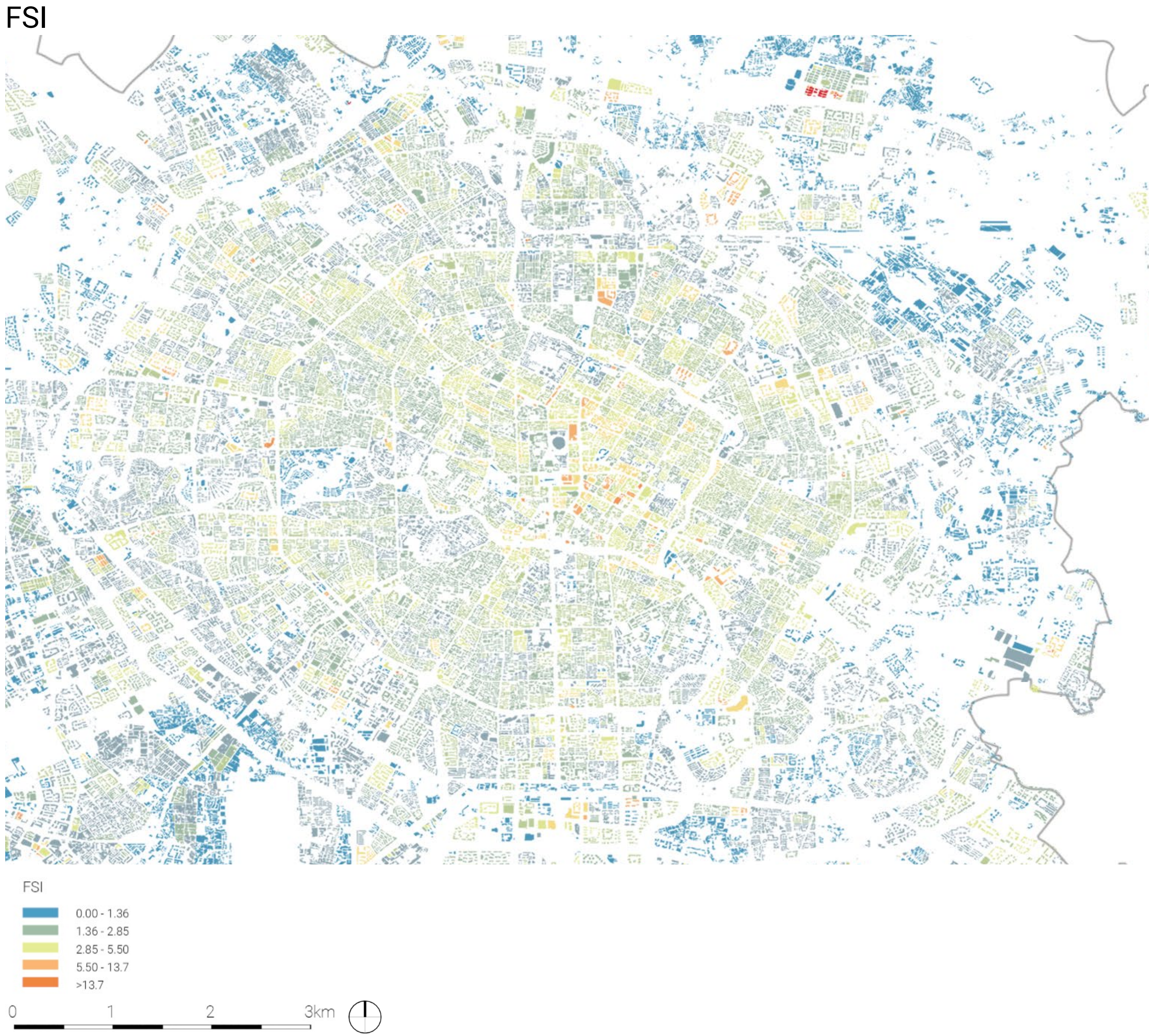


Fig. 4.4.2. FSI map.
Source: Geospatial Data Cloud. Generated by author using GIS software, based on the GIS file provided by the Geospatial Data Cloud of Chengdu in 2017.

GSI

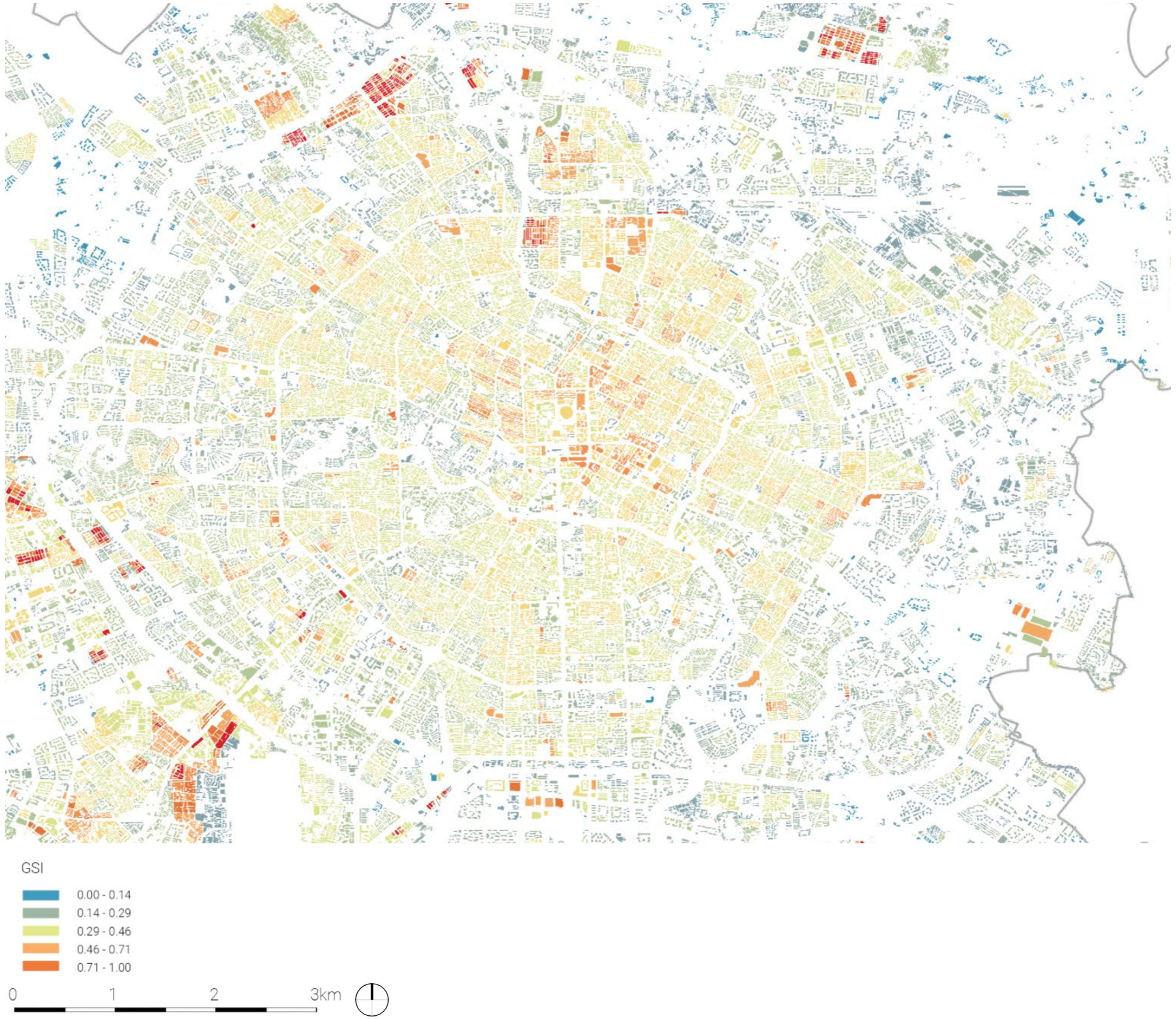


Fig. 4.4.3. GSI map.
Source: Geospatial Data Cloud. Generated by author using GIS software, based on the GIS file provided by the Geospatial Data Cloud of Chengdu in 2017.

Generation of A Density Typology

The density variables FSI and GSI are used to identify the density type and clustered using SPSS to generate similar urban density types (Berghauser Pont, M, et al, 2017), using the k-means clustering method, according to the position of the specific building type on the GSI and FSI correlation chart, the initial test centre is randomly selected as the centre point of the cluster, and then the cluster centre is used to calculate the sum distance between each data point and the cluster centre during the iteration process.

Seven categories are obtained in space matrix, namely "no buildings", "sprawl", "suburban", "compact low", "city center", "compact city", and "modernistic". They represent seven different types of building density (Berghauser Pont, M, et al, 2017); This project will use fewer clusters and select a more representative density form in Chengdu. The end result is a map containing three density types.

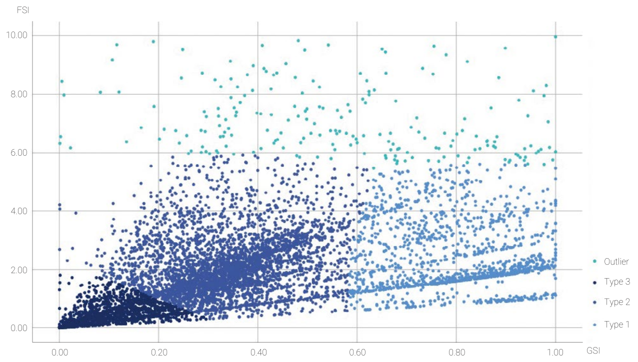


Fig. 4.4.5. Spatial correlation figure of FSI and GSI and three clusters.
Source: Elaborated by the author using SPSS software.

Type	Mean FSI	Mean GSI	Quantity	Percentage
1	2.37	0.48	4537	63.6%
2	0.90	0.20	1551	21.7%
3	0.21	0.04	747	10.5%
Outliers	6.17	0.68	300	4.2%

Fig. 4.4.6. Mean FSI, GSI and quantity for each density type,relative size of cluster.

Each type represents a group of blocks with similar conditions: 1) Represents the most densely populated areas in Chengdu, the city center and commercial areas. It is related to the type of land use. 2) Represents some medium-density areas, such as low-rise residential or industrial areas. 3) Represents buildings with relatively low FSI and GSI, corresponding to some separate houses and single land types in Chengdu. These density types all represent specific urban physical environments. In areas with high risk and high risk assessment, different density types with different spatial characteristics will receive corresponding intervention measures.

Fig. 4.4.7. Density type map.
Source: Generated by the author using SPSS, based on previous GSI and FSI maps.

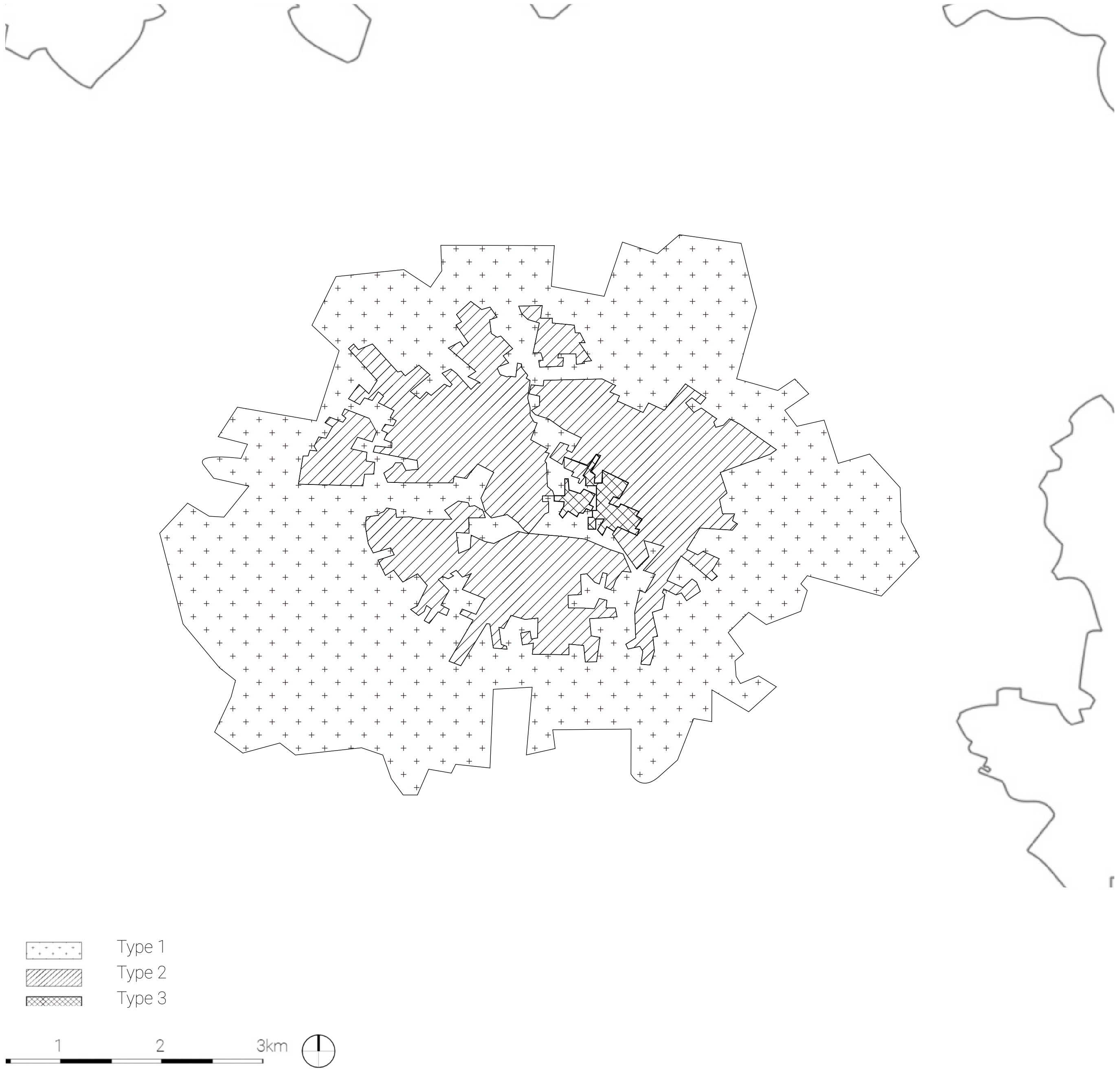


Fig. 4.4.8. Density type map.
Source: Author

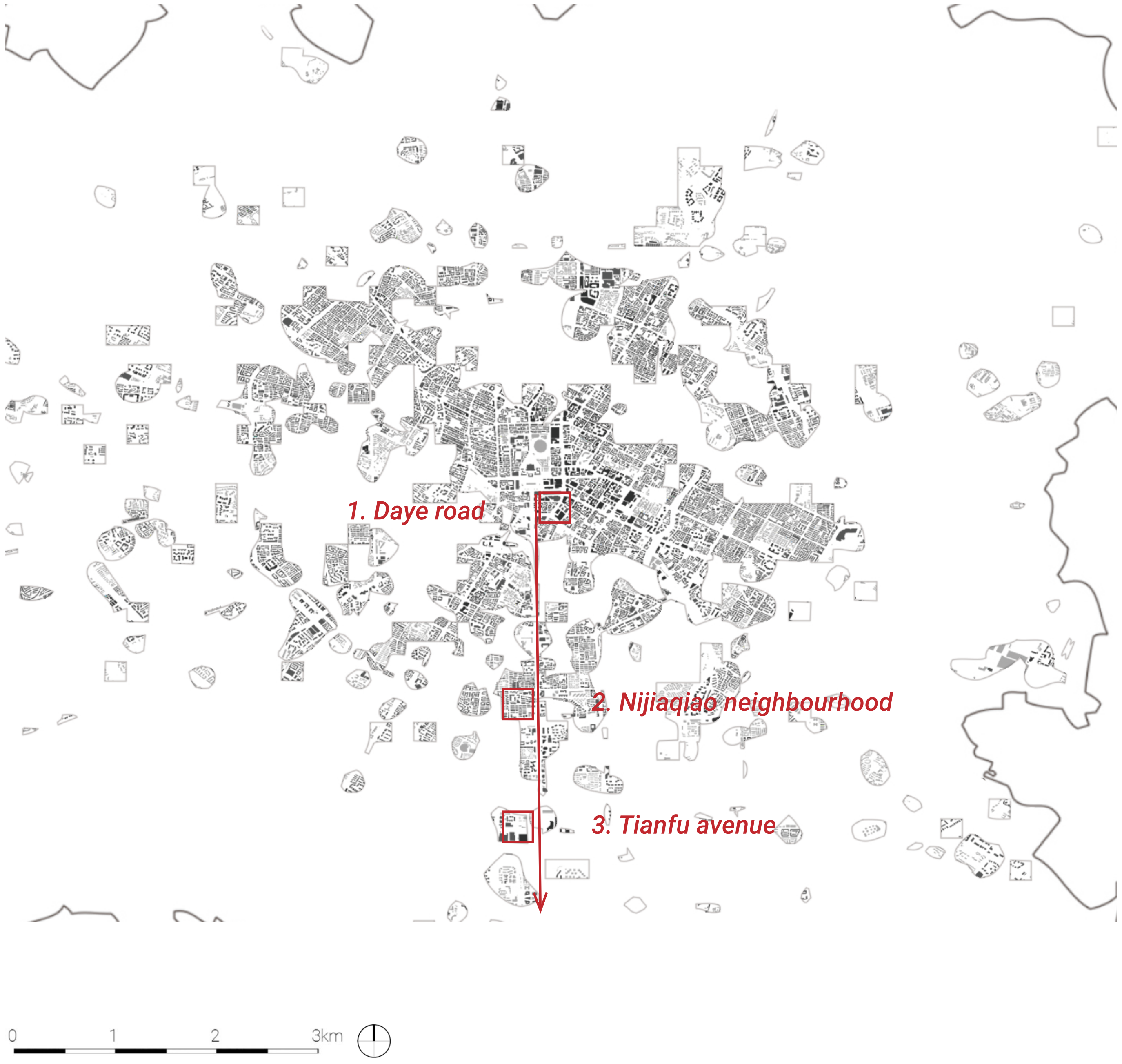


Fig. 4.4.9. Site selection map.
Source: Author.

Site selection

As mentioned earlier, a small-scale analysis is needed to select some representative regions. It can be seen from the density type map that the density is lower in some areas, but there are still serious pollution situations. Based on the risk assessment, density is used as the decision variable to ensure that multiple locations with different conditions are selected in areas where air pollution is urgently needed to be solved. When analyzing at a smaller scale, not only the density but also other factors must be considered. This analysis method can explore as many site heterogeneity and potential as possible.

Criteria for the selection

It can be seen that the density distribution of buildings in Chengdu is distributed in layers, descending from inside to outside. Combined density type map and the environmental risk map, three locations on the south axis are chosen, these areas are located in different development areas of Chengdu. They represent the three urban densities that are all highly vulnerable. They are located in the first ring, between the second ring and the third ring of Chengdu. They are not the areas with the lowest frontal area index, but as the areas with the heaviest traffic pollution and the most exposed population. To some extent, it can represent three functional areas with different densities in the development of Chengdu. Each area provides a special combination of conditions, including environmental and socioeconomic conditions. These conditions define their performance and response to air pollution. In addition to the parameters that have been analyzed, there are other unique characteristics of these regions that will be analyzed separately.

5. Site Analysis(micro)

Building

Source: derived from previous ones

Daye Road

Nijiaqiao Road

Tianfu Avenue North

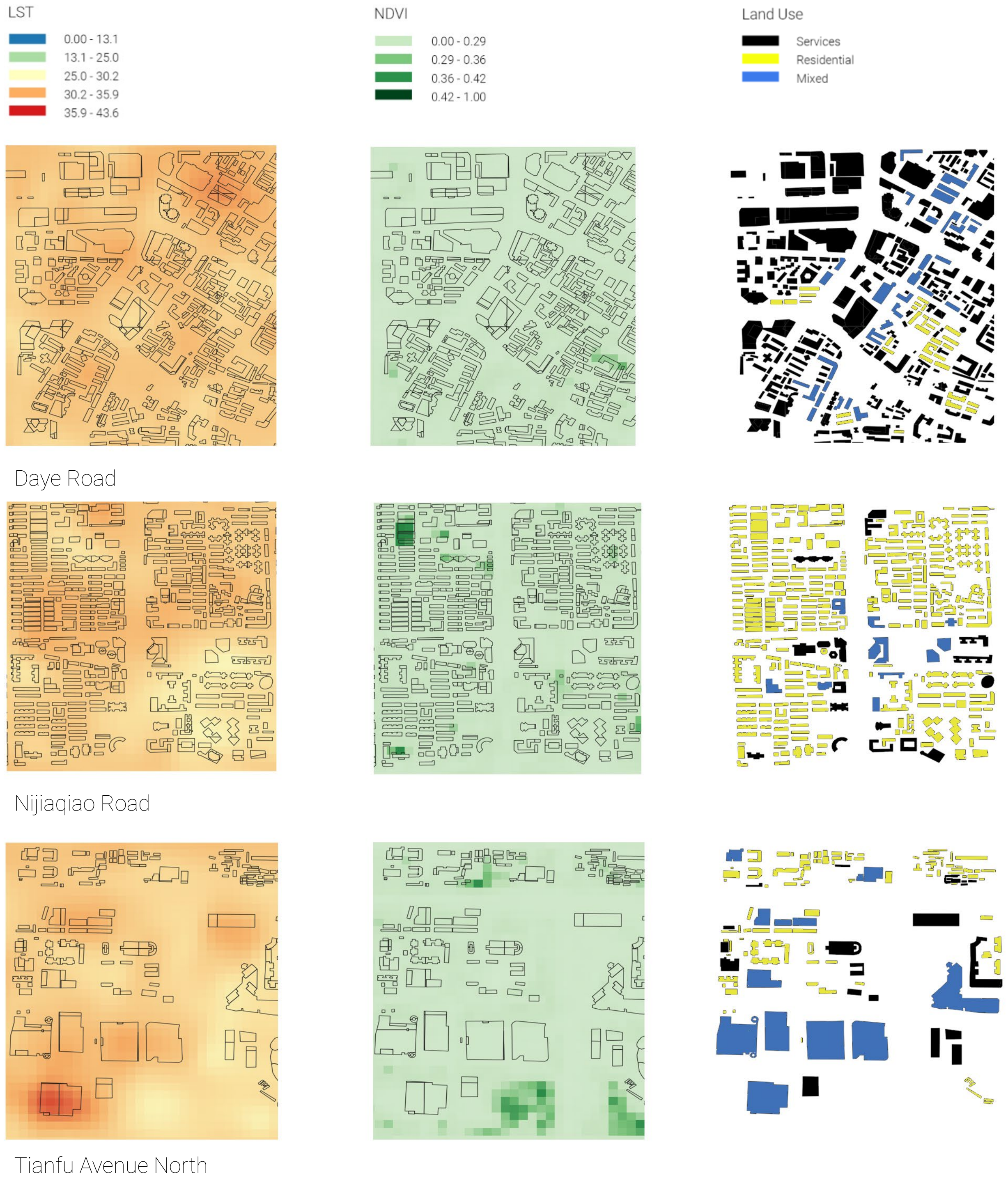


Fig. 5.1.1. Daye Road
Source: Baidu Street View Map

Daye Road

Introduction

Daye Road is located in the Yanshikou commercial district of Chengdu. Yanshikou commercial district is one of the three core commercial districts of Chengdu. It is connected to the historic Qingnian Road and Ranfang Street. It is not far from Chunxi Road commercial district. Throughout the city's development history, Daye Road is the commercial hinterland of downtown Chengdu, where many new and old shopping malls come together. At the same time, its geographical location and social attributes have attracted huge human traffic, heavy traffic, slow speeds, and prone to congestion, which has led to its relatively serious air pollution. The population has a long outdoor exposure time, high vulnerability, and high density. Poor ventilation makes it one of the places where intervention is needed.

Potential

As the core area of Chengdu, it is also one of the important public spaces. Understanding its air pollution and ventilation and heat dissipation conditions, it can propose intervention measures to reduce air pollution and increase the quality of public space.

Fig. 5.1.2. Nijiaqiao Road
Source: Baidu Street View Map

Nijiaqiao Neighbourhood

Introduction

On the side of Nijiaqiao District, there are the most urban-style streets in Chengdu, with a complex social and demographic composition. On the one hand, the presence of large companies, the US Consulate, and the European Style Street are examples of Chengdu's petty bourgeoisie life. It is this area that reaches the high-rise building. On the other hand, the Nijiaqiao area also has low-rise residential buildings, crowded streets, and exhaust pollution on the streets is difficult to spread. In addition, there are a large number of domestic pollution sources, posing a certain threat to the surrounding residents.

Potential

There are low-rise residential buildings and high-rise office buildings on both sides of the streets in this area. Not only their social attributes are quite different, but their wind and heat environment also has its own characteristics. It is best to consider the different social demographics while proposing microclimate spatial intervention.

Fig. 5.1.3. Tianfu Avenue North
Source: Baidu Street View Map

Tianfu Avenue

Introduction

Tianfu Avenue is a major north-south traffic artery in Chengdu. It is the south extension of Renmin South Road, the central axis of Chengdu. It has a total length of 13.5 kilometers, a two-way 12-lane (including auxiliary road), and a road width of 86 meters. The northern section of Chengdu Tianfu Avenue is outside the Third Ring Road, inside the Ring Expressway and near the South Railway Station.High pollution levels in areas near the viaduct.

Potential

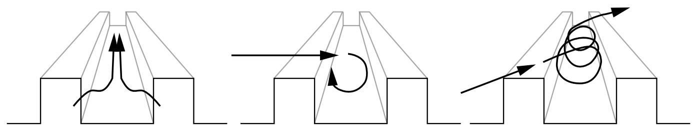
As mentioned in the previous literature review, research shows that the impact of urban vegetation on air quality is more complex. Sometimes the vegetation on the roadside may lead to an increase in the concentration of pollutants. The effect of different vegetations on dust absorption is also far away. The space quality also has a large space for improvement, so Tianfu Avenue North was selected as one of the places for intervention.

As previously explained, the comparative analysis of density parameters provides an initial understanding on the main physical differences between fabrics. However, even within blocks of similar characteristics, there is space for multiple materialisations, which would result in complete different roughness, albedo or greenery, for instance.

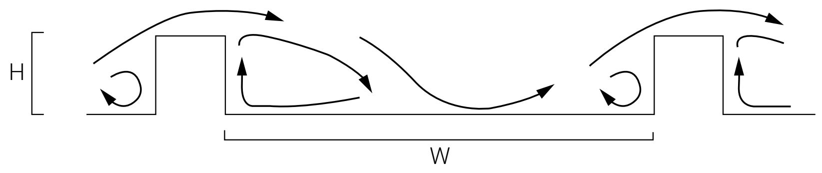
Therefore, it is necessary to conduct an in-depth analysis of sites with different density and microclimate-related wind-heat parameters. In the analysis section, according to the analysis matrix, subjective analysis of the site's geometric layout (roughness), surface materials and colours, urban greening and land use, at the same time, Envi-met and grasshopper software conducted an analysis of the wind-heat environment and pollution distribution, which including wind speed, PM10 concentration and sunlight hours analysis. Different blocks combining different external features will form a specific type.

5.2 Site Analysis

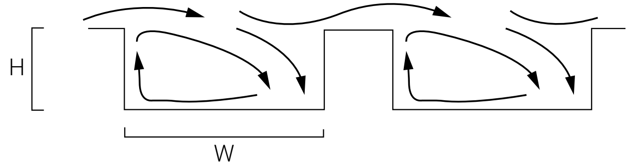
Rughness



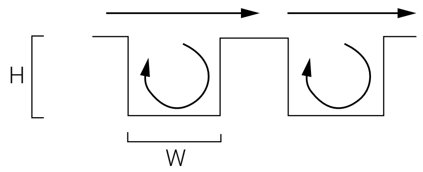
Flow patterns in the urban canyon, related to the wind direction at roof height; parallel, perpendicular or at an angle to the canyon axis



Isolated roughness flow



Wake interference flow



Skimming flow

Fig. 5.2.1. Flow regimes associated with different geometries
Source: Oke, T.R. (1987). Boundary layer climates. New York, Routledge. After Oke,Pijpers-Van Esch, M. (2015). Designing the Urban Microclimate A framework for a design-decision support tool for the dissemination of knowledge on the urban microclimate to the urban design process. PhD, Delft University of Technology.

In general, the size, form and arrangement of buildings determine the degree of influence on wind flow behaviour. Therefore, a brief explanation regarding airflow patterns in urban canyons will follow.

As far as the wind flow patterns in urban canyons are concerned, three flows, correlated to the wind direction at roof height, can be defined: parallel, perpendicular or at an angle to the canyon axis. When the wind direction is parallel to the canyon axis, the wind flows right through the canyon (van Esch, 2015). In this case, pollutants are easily transported and dispersed. If the wind direction is more or less perpendicular to the canyon axis, three sub-flow regimes can be distinguished: isolated roughness flow, wake interference flow and skimming flow (Oke, 1987, van Esch, 2015). These flow regimes depend upon the geometry of the array, especially from the height to width ration of the canyon.

[H/W < 0.1] - This is the case of isolated roughness flow where there is a very little interaction between the flows of the upwind and downwind area of the canyon (van Esch, 2015). Their flow pattern appears almost the same as if they were isolated.
[0.1 < H/W < 0.67] - At closer spacing, the wake of any building interferes with that of the next downstream leading to a complicated pattern. This is the case of the wake interference flow regime; wind speeds are higher than the ones in the isolated roughness flow.

[H/W > 0.67] - In even narrow canyons, the main flow starts to skim over the building tops and drives a lee vortex in the cavity. The wind speeds in this regime are slower than the ones in the wake interference flow and they might be even slower than wind speeds in the isolated roughness flow – in case of very narrow canyons.

The above-mentioned regimes are found when the wind direction is normal to the urban canyon axis. If the wind has a different angle the vortex takes a corkscrew motion with elongation along the street (Oke, 1987). Overall, proportions of urban tissue play a relevant role in wind flow patterns and in air pollution dispersion as well. Moreover, the study of these proportions can reveal the role of urban forms in air pollution dispersion.

In the following analysis, in order to allow for a more precisely analysis of the site and to improve the accuracy of the software simulations.

The area with the highest pollutant concentration (180m x 180m) from the three sites was selected from the PM10 concentration simulation results for detailed analysis, as described later (the simulation remains 300m x 300m within this section).

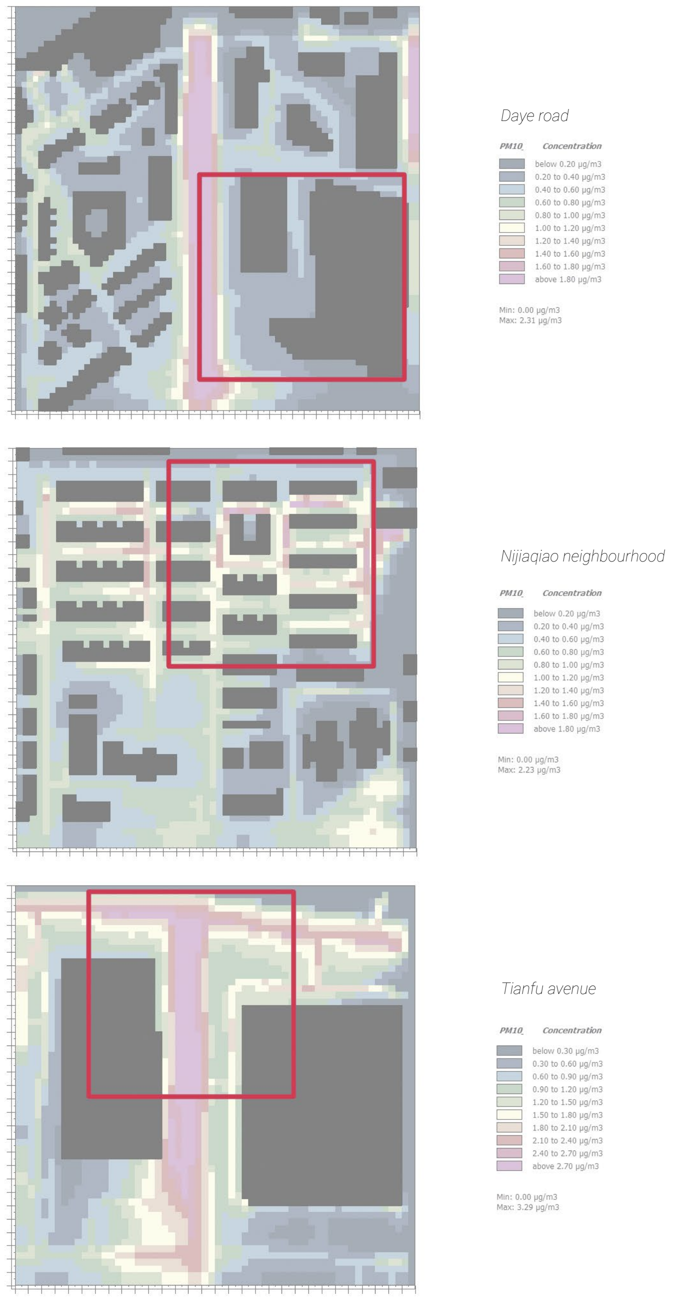
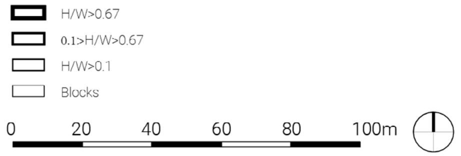


Fig. 5.2.2. Scale down of Daye road, Nijiaqiao neighbourhood and Tianfu avenue.
Source: Author.

Daye Road

Fig. 5.2.3. Daye road.
Source: Author.



Daye Road is built at 20-100 meters and the main street width is about 60 meters.

A large amount of pavement and high building density are factors that increase up the heating. There is quite some shadow from buildings, but that does not eliminate up the heating, and once heated, these areas retain the heat for a long time. On the other hand, the great variety of building heights relatively provides some ventilation.

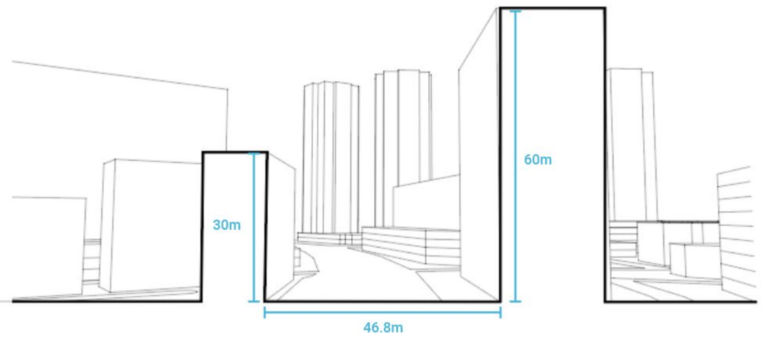


Fig. 5.2.4. Section1 of Daye road.
Source: Author.

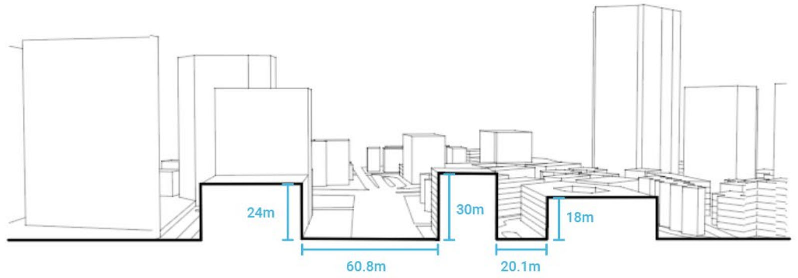


Fig. 5.2.5. Section2 of Daye road.
Source: Author.

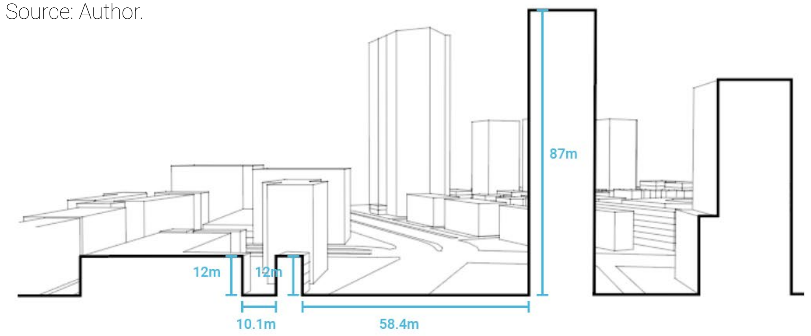


Fig. 5.2.6. Section3 of Daye road.
Source: Author.

Nijiaqiao Neighbourhood

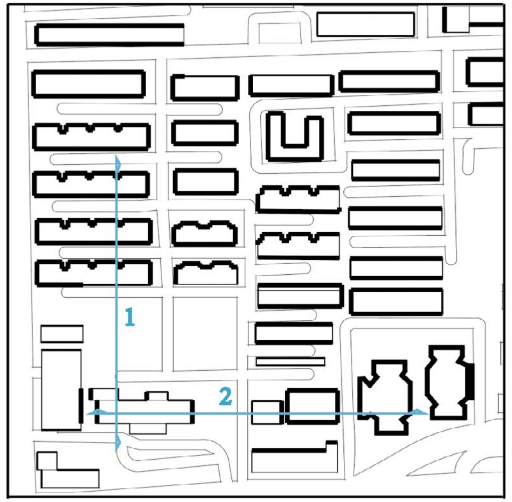
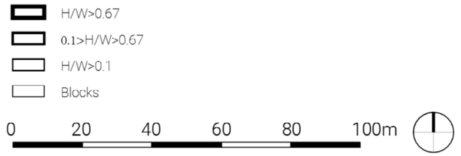


Fig. 5.2.7. Nijiaqiao neighbourhood.
Source: Author.



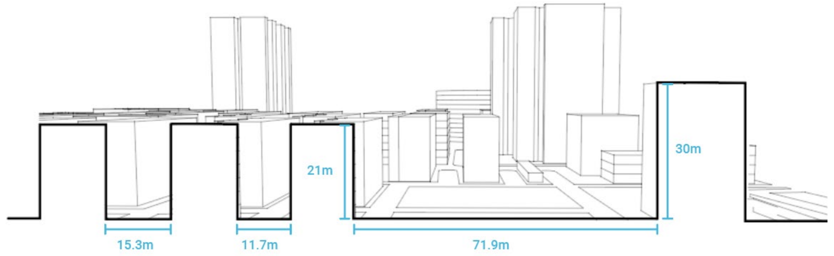


Fig. 5.2.8. Section1 of Nijiaqiao neighbourhood.
Source: Author.

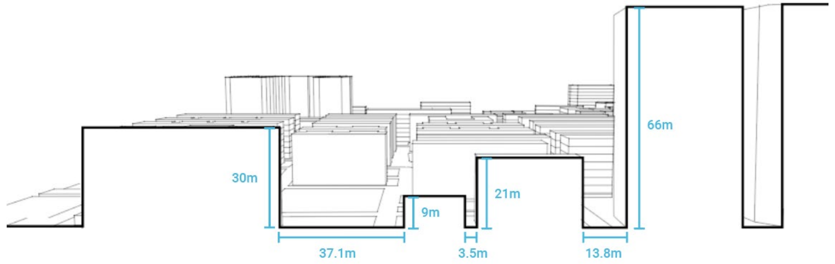


Fig. 5.2.9. Section2 of Nijiaqiao neighbourhood.
Source: Author.

With an H / W ratio greater than 1.5 and the wind direction perpendicular to the street, there is little mixing between the air in the street and the upper floor. Therefore, the fresh air supply here is not good from the H/W ratio aspect. On wider roads, air mixing is reasonable, which also depends on wind speed. In addition, the north-south streets have enough shadows in the morning and afternoon in the narrow street width. At noon due to the large tree canopy on the street, there are some shadows and the space for the trees is smaller. The solar heat load on the south-facing facades of streets in the east and west is relatively large and may increase significantly.

Tianfu Avenue

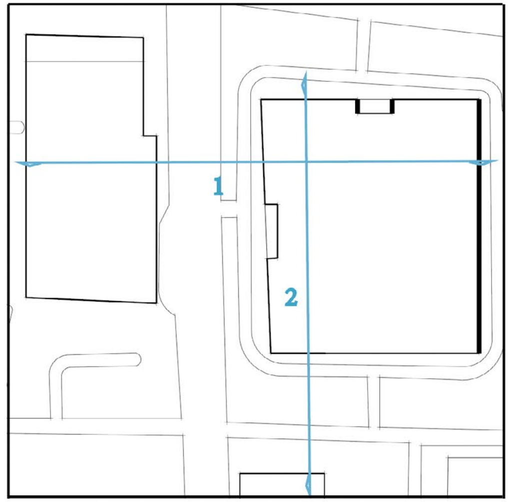
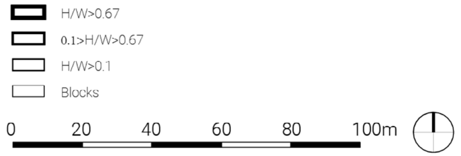


Fig. 5.2.10. Tianfu avenue.
Source: Author.



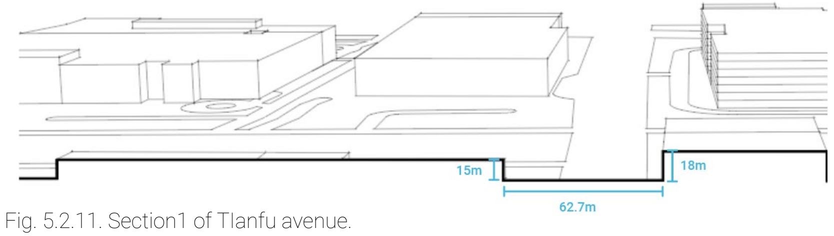


Fig. 5.2.11. Section1 of TIanfu avenue.
Source: Author.

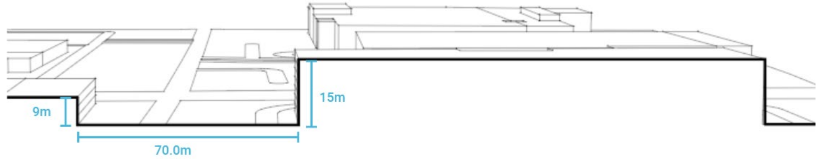


Fig. 5.2.12. Section2 of TIanfu avenue.
Source: Author.

The H / W ratio is close to 0.1, the site is more open, but the wind speed is still low due to climatic factors, therefore the pollution is still high.

Wind Speed/PM10 Concentration Analysis

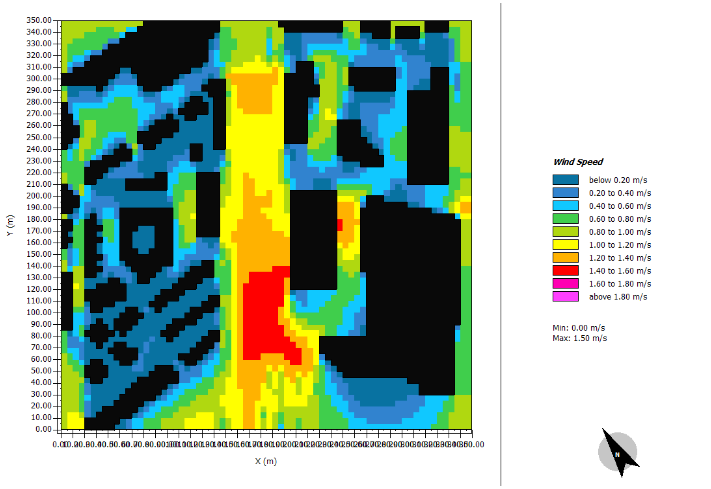


Fig. 5.2.13. Wind speed.
Source: Author.

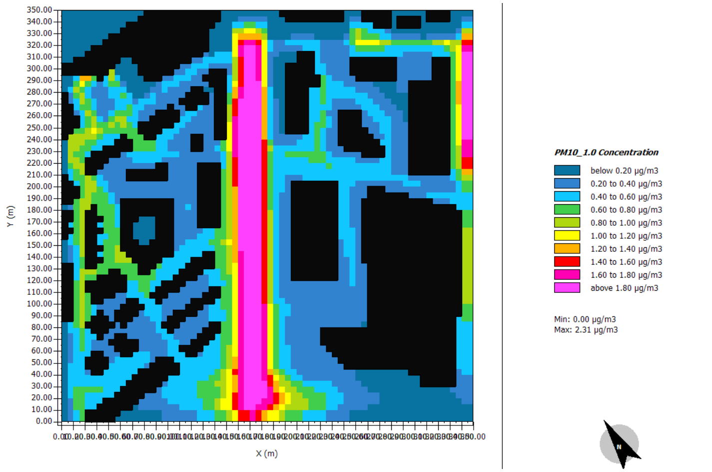


Fig. 5.2.14. PM10 concentration.
Source: Author.

According to the recent years' climate data of Chengdu, the following wind speed simulation conditions use Chengdu's average annual wind speed of 0.9m / s in 2018 and the northeast wind direction.

Through the previous roughness analysis, the building heights on Daye road are more diverse than other sites, while the simulation results show that the Daye road has more ventilation. The vortex of the corner space in the square in front of the high-rise buildings in the south is obvious, and the wind speed is the highest. The enclosed space of high-rise buildings has become a quiet wind area and low wind speed area. Low wind speed areas with different areas also appeared in the surrounding areas of other multi-story buildings.

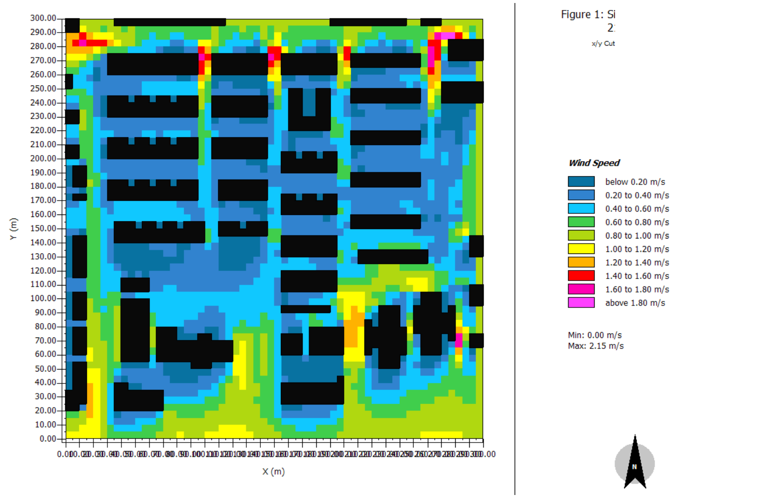


Fig. 5.2.15. Wind speed.
Source: Author.

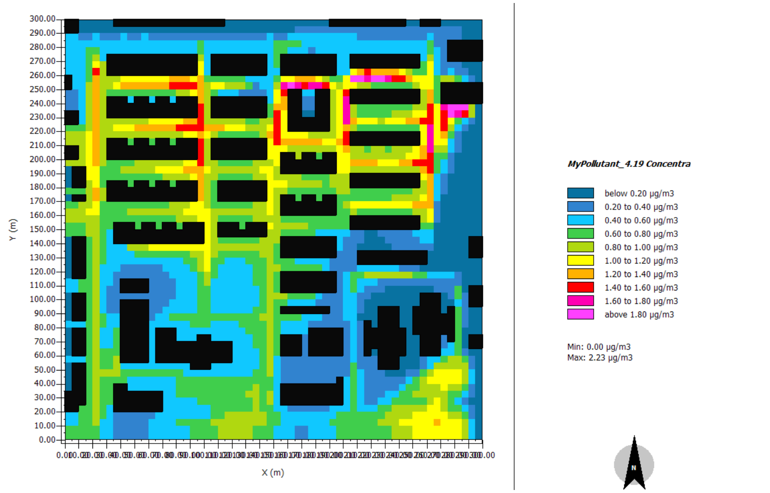


Fig. 5.2.16. PM10 concentration.
Source: Author.

From the simulation results, it can be seen that the wind speed distribution in the Nijiaqiao community is relatively uniform. However, the maximum wind speed at the street opening's corner is higher than at Daye road and the wind speed on the side near the viaduct in the south is relatively high, which is beneficial to the diffusion of pollutants.

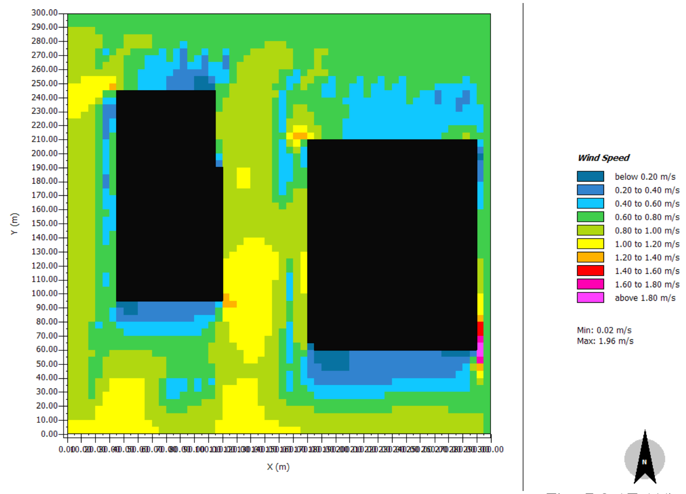


Fig. 5.2.17. Wind speed.
Source: Author.

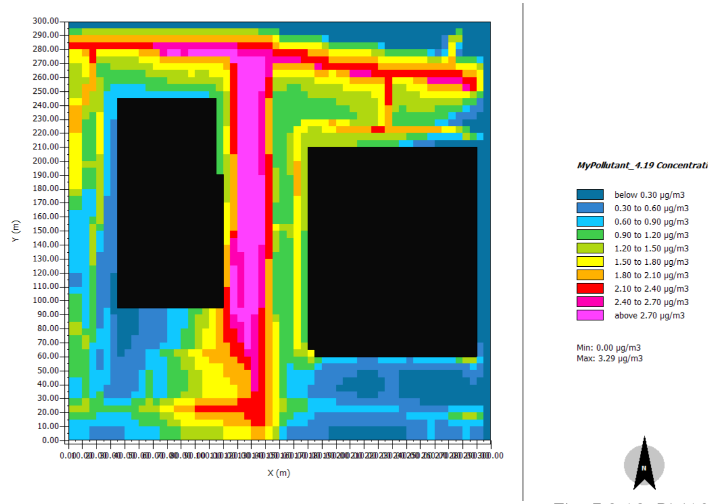


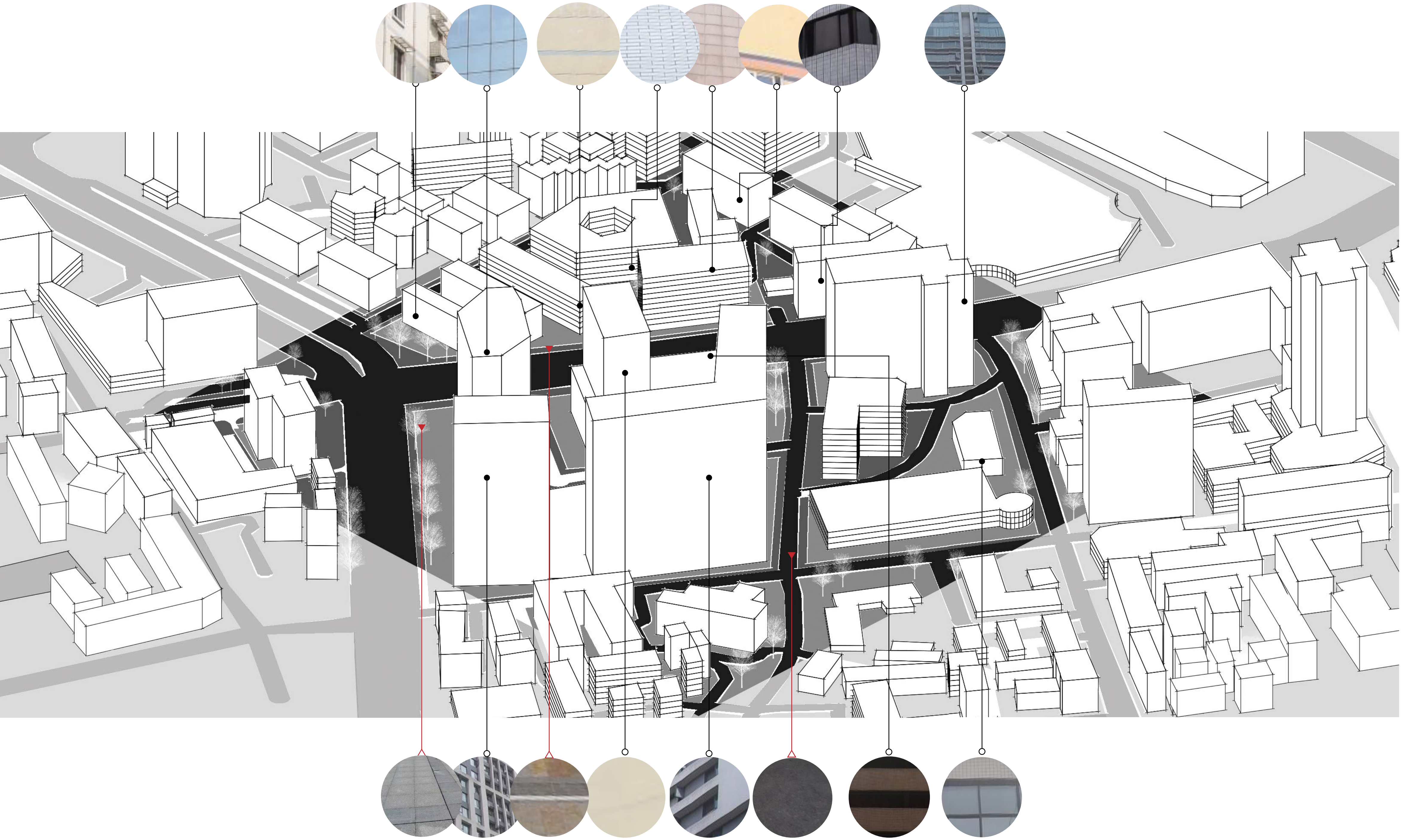
Fig. 5.2.18. PM10 concentration.
Source: Author.

According to the simulation results, there are large areas of quiet or low wind speeds near Tianfu avenue. Pollution concentrations are also highest here.

Surfaces

Different building exterior materials have different solar radiation absorption performance. Increasing the amount of solar radiation energy absorbed by the outer surface of the envelope structure can reduce the building's heating energy consumption in winter, but at the same time it will increase the cooling energy consumption in winter. On the other hand, the solid surface of the building is the boundary of the fluid space and is one of the main heat sources. When there is a difference between the wall surface temperature of the street valley and the air temperature, thermal buoyancy will be formed under the heat of the wall surface. When the prevailing wind speed is small, the thermal effect of the wall surface will have a greater impact on the airflow.

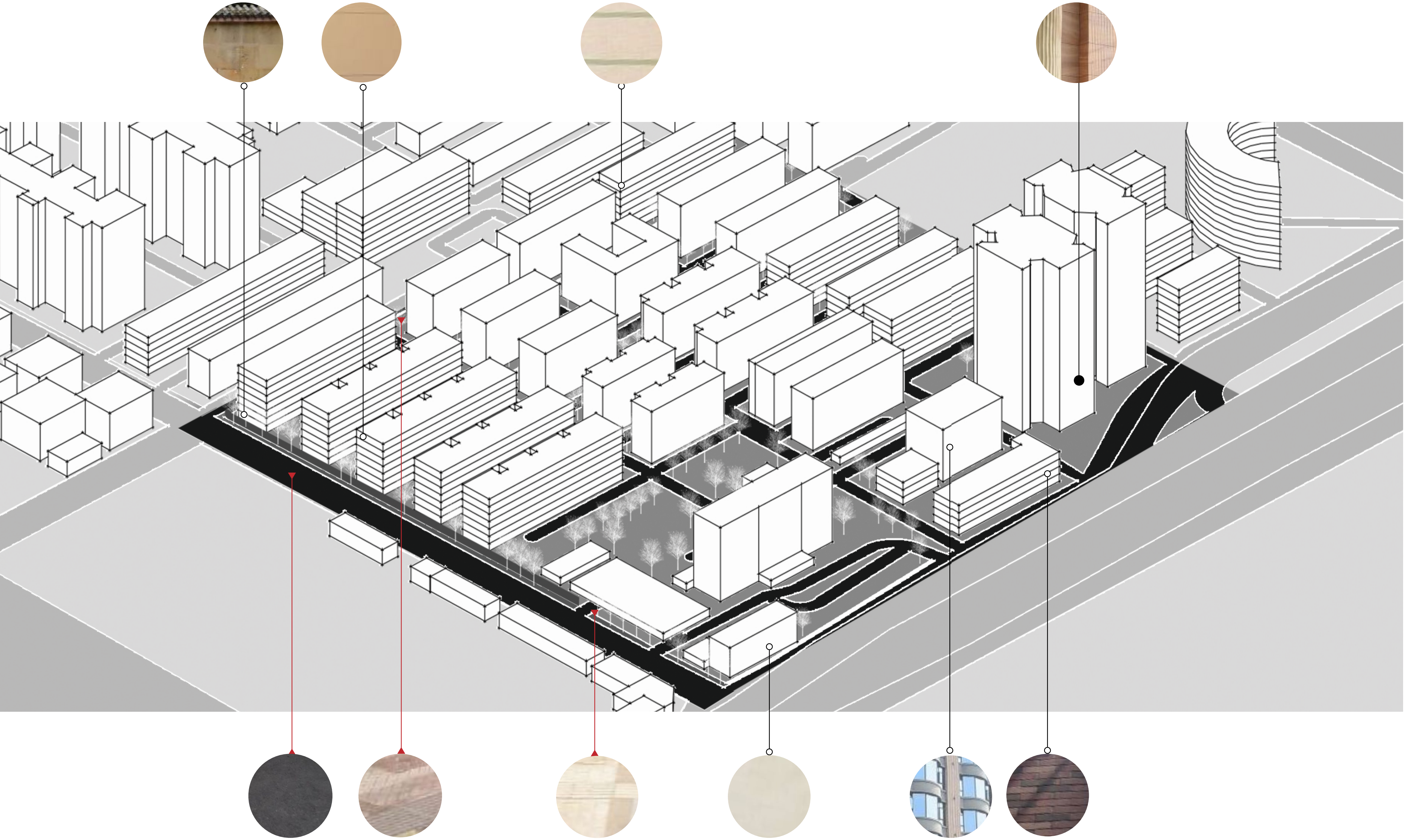
The following will analyze the urban surface materials and colours of the three sites to briefly categorize and attempt to explore the connection between the material colour of urban surfaces and the wind and heat environment as well as the possible thermal effects of the wall.



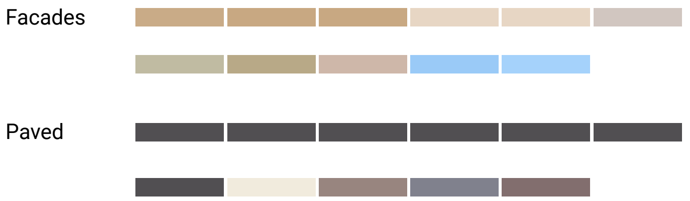
Colour schemes

Fig. 5.3.1. Surfaces analysis of Daye road.
Source: Author(Image from Baidu Maps).

The main streets on the surface of Daye road are composed of asphalt, and the sidewalk covering is almost entirely composed of granite stone, with the main colour being grey-beige. Facades dominate, covering almost 70% of the city's surface. The façade is mainly glass and light-coloured paint. Other materials and colours are used as embellishments in a small area, and the reflectivity is high.



Colour schemes



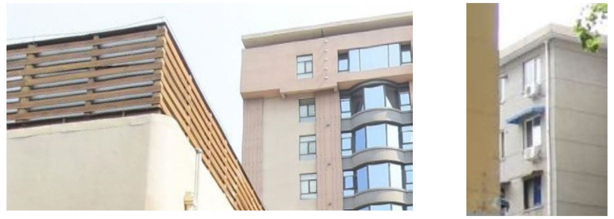
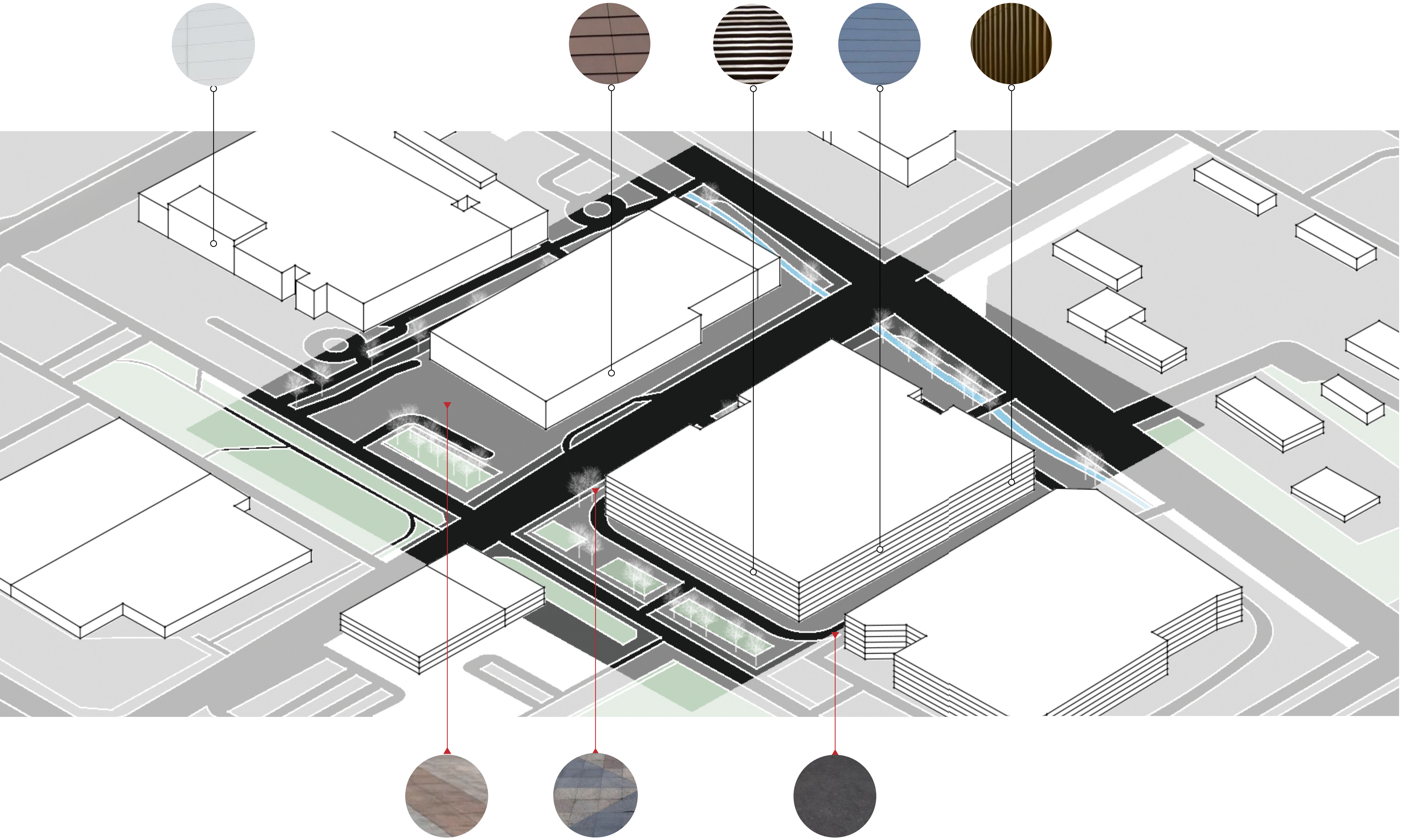
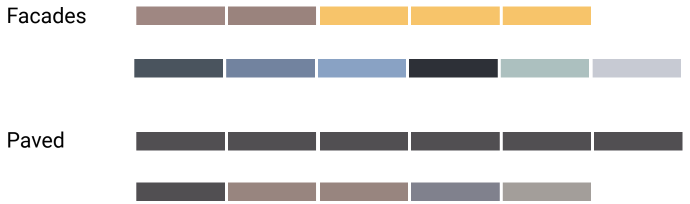


Fig. 5.3.2. Surfaces analysis of Nijiaqiao neighbourhoood.
Source: Author(Image from Baidu Maps).

The surface of Nijiaqiao Neighborhood is dominated by light yellow and white, and the bottom hotel surface is composed of yellow paint and glass. The middle two are made of brick red brick and glass. In general, light-coloured surfaces have higher reflectivity, and the heat storage capacity of traditional materials brick is relatively small and the surface temperature is low. The ground roadway is asphalt, and the sidewalk is dominated by beige granite and red brick. The outer wall of the neighbourhood is made of white cement and wood-coloured cement.



Colour schemes



Yellow Panel Cladding
Red Brick Wall
Glass
Concrete
Stone
Ceramic Tiles

Fig. 5.3.3. Surfaces analysis of Tianfu avenue.
Source: Author(Image from Baidu Maps).

Large commercial buildings on both sides of Tianfu Avenue are mainly brick red veneer on one side, and the white, yellow and dark brown surfaces on the other side are more evenly distributed.

Sunlight hours analysis

Meteorological parameters are one of the main factors affecting the urban thermal environment and the energy consumption of heating, cooling, and air conditioning. Based on the historical observation data of a total of 30 years in Chengdu from 1971 to 2000, the hourly meteorological data files required by the building energy simulation software EnergyPlus were generated. The weather data of summer solstice and winter solstice were extracted using ladybug to compare and analyze the average sunshine hours of the three sites.

Daye road
From the winter and summer simulation results, it can be known that the roof and south facade of the building are the surfaces with the most sunshine hours. In the southern high-rise enclosing building, the podium platform and the inner facade have less sunshine. At the same time, there are many high-rise buildings on the east side, causing shadows on some streets.

Nijiaqiao neighbourhood
From the winter and summer simulation results, it can be seen that the south side of the east-west street of Nijiaqiao Neighborhood can receive a large amount of solar radiation, so it is easy to cause the large-area high-temperature concentration area also there is more thermal buoyancy due to the thermal effect of the wall. Some shadowed areas generated by the building will have a certain cooling effect. The north-south street temperature is relatively low, and the trees are sheltered, which will be beneficial to summer cooling.

Tianfu avenue
From the simulation results of the winter and summer seasons, it can be known that the roof of the site will receive the most solar sunlight. Due to the openness of the site and the street trees will block the building facade, the road will receive more solar radiation than the building facade.

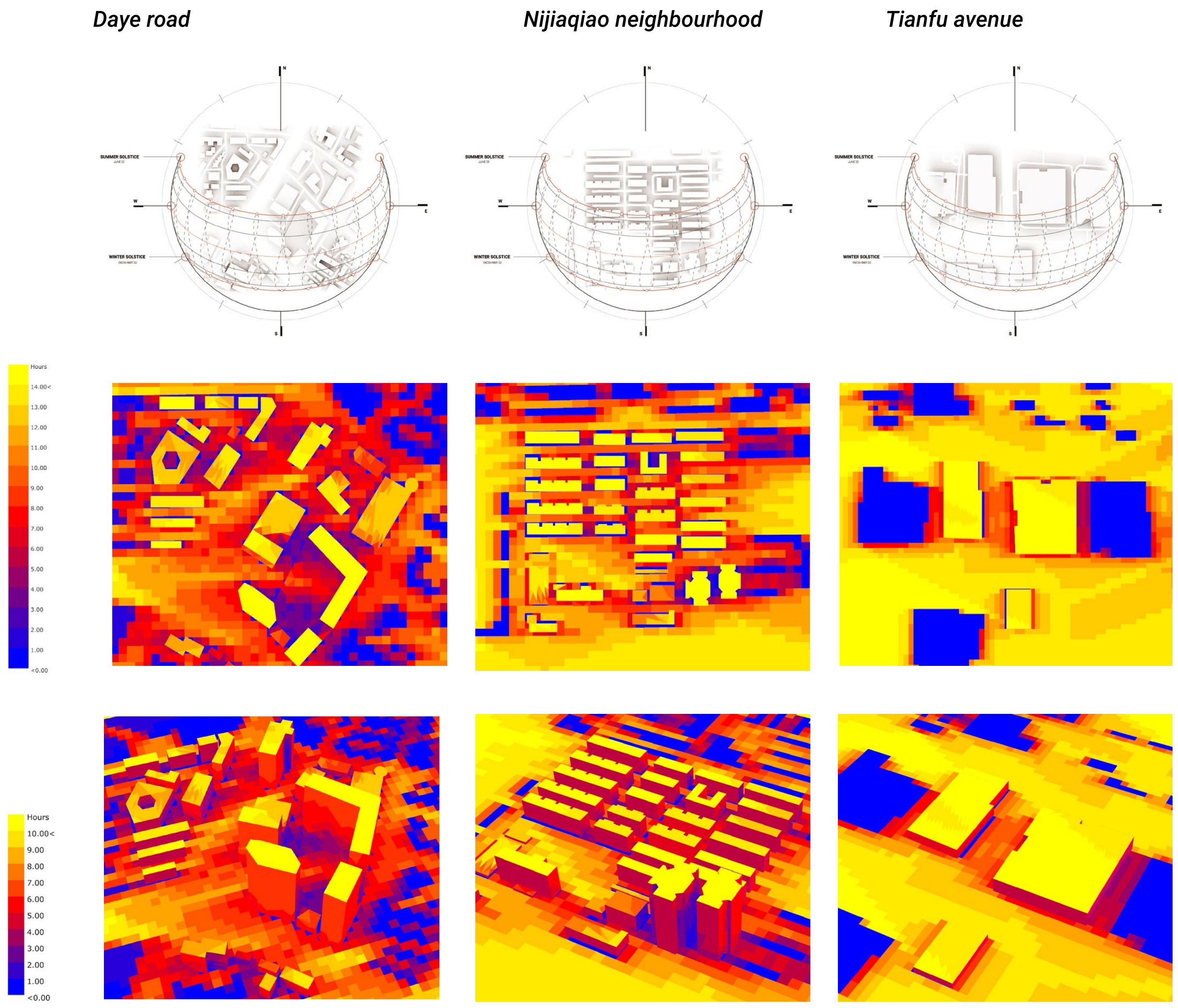


Fig. 5.4.1. Sunlight hours analysis maps(summer solstice 6.23).
source: https://energyplus.net/. Generated by grasshopper ladybug.

Daye road ***Nijiaqiao neighbourhood*** ***Tianfu avenue***

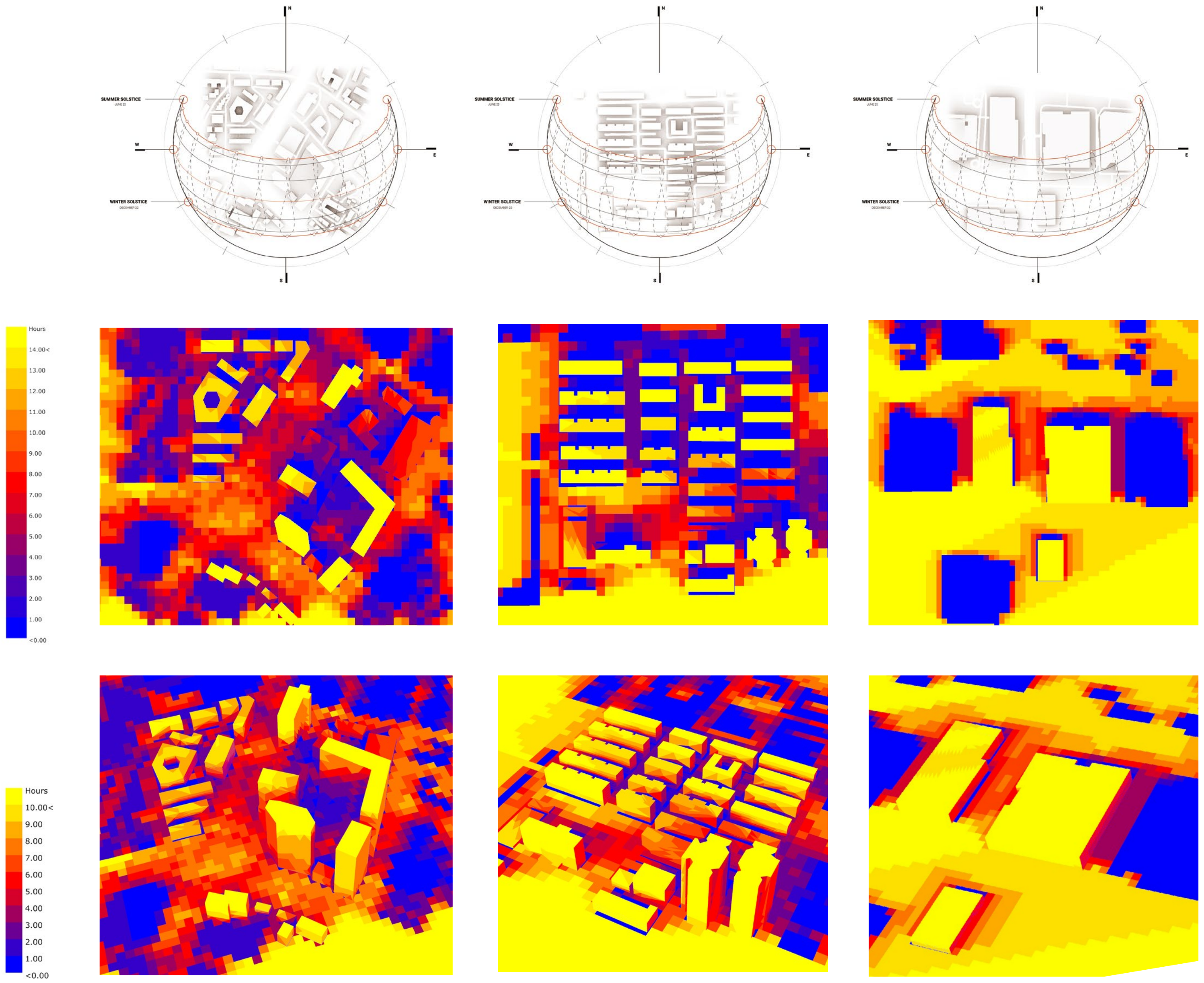


Fig. 5.4.2. Sunlight hours analysis maps(winter solstice 12.22).
source: https://energyplus.net/. Generated by grasshopper ladybug.

Urban green

Daye road ***Nijiaqiao neighbourhood*** ***Tianfu avenue***

Daye Road has a higher building density and a lower road greening rate. Compared with urban greening, the building form has a greater impact on the site's microclimate.

The interior of the Nijiaqiao community has high greenery, and the streets from north to south are narrow. The shadow of the trees on both sides almost completely shields the road.

Compared with other sites, Tianfu Avenue has more open space and more greenery, and the street trees have a higher degree of cover to the building facade.

Fig. 5.5.1. Urban green.
source: Author.

Land use

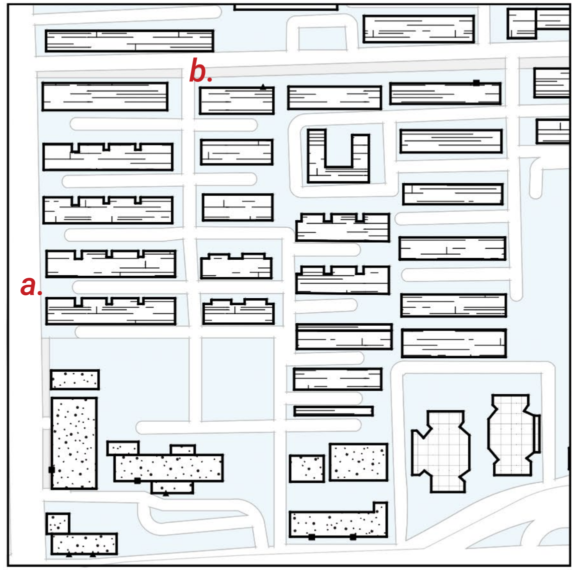
Bus stop
Office
Commercial
Restaurant
Parking building
Residential
Education
Mixed
Services

0 20 40 60 80 100m

Fig. 5.6.1. Land use of Daye road.
source: Author.

The bus stop on Daye Road is crowded, and there is a square in front of the tall building on the south side and a small pool in the middle.

Fig. 5.6.2. Streetscape of Daye road.
a.Bus stop.
b.Public space
source: Baidu maps



Bus stop
Office
Commercial
Restaurant
Parking building
Residential
Education
Mixed
Services

0 20 40 60 80 100m

Fig. 5.6.3. Land use of Nijiaqiao neighbourhood.
source: Author.

Nijiaqiao neighbourhood is a closed community with a wall built-in 1998. The left side of the community is a solid whitewashed wall. Adjacent buildings are divided by the wall. The environmental quality around the wall is not optimistic. People only pass in a hurry during commuting hours. Lack of space for activities, but the plants around the fence which are planted by the residents reflect people's needs for outdoor humanized living space and green.

Fig. 5.6.4. Streetscape of Nijiaqiao neighbourhood.
1.Fitness equipment.
2.Small gardens
source: Baidu maps

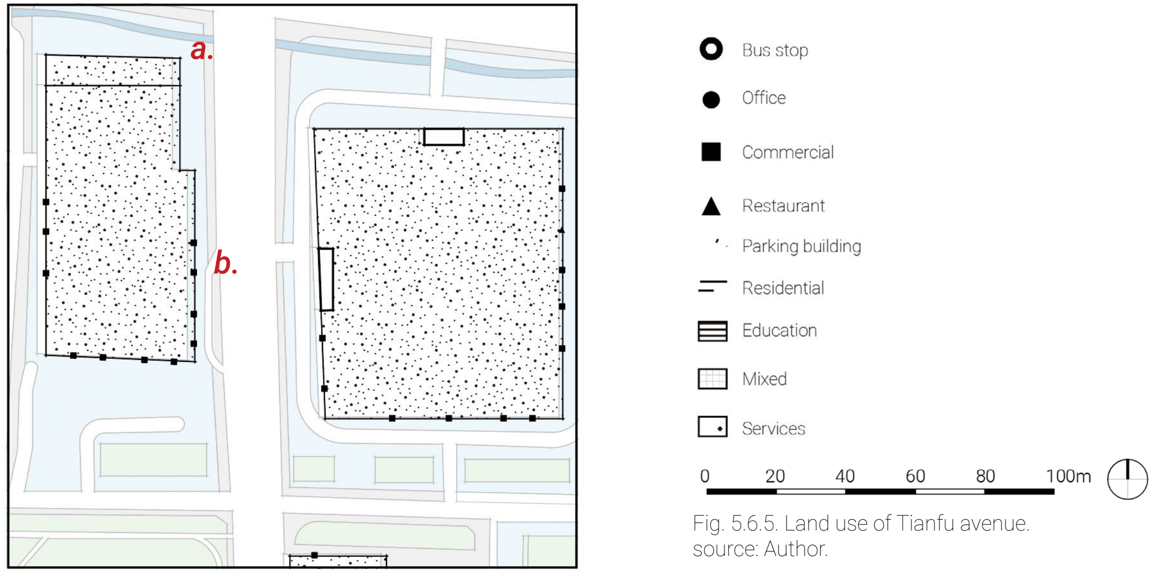


Fig. 5.6.5. Land use of Tianfu avenue.
source: Author.

Site 3 is a large independent commercial building, it is an independent large mass multi-story building, and the external space is non-enclosed space around the buildings are combined with urban squares and green space.

Fig. 5.6.6. Streetscape of Tianfu avenue.
1.Water body.
2.Street trees
source: Baidu maps

5.3 Evaluation

	Daye Road	Nijiaqiao Neighborhood	Tianfu Avenue
Typology	Semi-open	Semi-open	Open
Roughness	$0.67 < H/W$	$0.1 < H/W < 0.7$	$H/W < 0.1$
Roof shape	Flat	Flat	Flat
Colour	Light	Light	Medium light
Facade	Ceramic tile, Glass	Brick	Aluminum gusset
Radiation acceptance	Much	Moderate	Moderate
Pavement	Granite, Brick	Granite, Brick	Granite, Brick
Vegetation	Little green	Moderate green	Much green
Land use	Mixed	Residential	Commercial

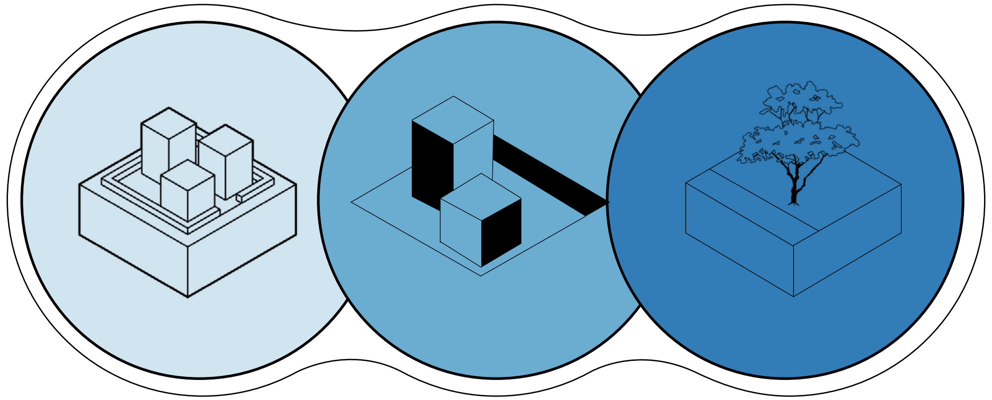
Fig. 5.7.1. Evaluation.
source: Author

The table (Fig.5.7.1) summarizes the effects of each of the small-scale elements on the wind and heat environment, and the microclimate environment they may form.
Regarding the wind and heat environment, the evaluation takes into account the eight elements of urban environments and land use described in the analysis chapter.

+Typology: An open site has relatively little obstruction to airflow and therefore facilitates the spread of hot air and pollution. Tianfu avenue has the highest openness of the three sites.
+Roughness(H/W): The H/W has a large effect on wind speed. Generally, the H / W ratio is inversely related to the diffusion capacity of pollutants (Park S K, 2004). when the aspect ratio is 1, the street valley pollution concentration is the lowest. (Andy T Chan, et al,2001)
+Roof shape: All three sites are predominantly flat-roofed, with potential for roof retrofitting.
+Colour(Building facade and pavement): Buildings with (high albedo) light-coloured surfaces store less heat during the day, have higher canyon air temperatures, and lower nighttime temperatures. Both Daye Road and the Nijiaqiao neighbourhood are predominantly light-coloured surfaces with relatively high daytime street canyons temperatures.
+Materials(Building facade and pavement): Same as colour. Using materials with relatively high reflectivity and lower thermal conductivity results in lower heat storage during the day, but leads to higher street valley temperatures.
+Vegetation: Nijiaqiao neighbourhood has the most trees and vegetation, followed by Tianfu avenue and the least Daye road, which means that the pedestrian height in Nijiaqiao neighbourhood is the most obstructive to airflow.

6 Strategies library

The strategies library refers to which physical elements of urban environments can be modified in order to gain better ventilation and thermal performance to benefit degrading air pollution. Combination of literature review and site analysis, here the strategies can be classified into three main categories: Urban morphology, urban surface, urban green. Through the combination of multiple design strategies that an optimal qualification of spaces can be achieved. Such a variety of physical elements and structures leads to multiple possibilities with respect to design. In the same space, combining measures about wind and heat may produce two results that strengthen or weaken each other. At this time, more appropriate choices need to be made according to specific circumstances and needs.



Urban Morphology

+Height control
+Enclosure degree
+Building porosity
+Orientation
+Roof shape

Urban Surface

+Coloured facade
+Materialization
+Pavement

Urban Green

+Green roof
+Green facade
+Urban tree
+Green wall

6.1 Urban morphology

Height control
As mentioned earlier, the street canyon wind pattern can be divided into isolated rough flow, wake disturbance flow and skimming flow. It is mainly affected by the street canyon's aspect ratio (H / W). Generally, the H / W ratio is inversely related to the diffusion capacity of pollutants (Park S K, 2004).

In this regard, Andy.T.Chan et al conducted a more in-depth study. The relationship between H / W and street valley pollutant concentrations is shown in the figure. Therefore, when the aspect ratio is 1, the street valley pollution concentration is the lowest.(Andy T Chan,et al,2001)

Enclosure degree
The degree of enclosure refers to the ratio of the sum of the side lengths of all external buildings along the road within a certain range to the length of the entire block boundary.

The degree of closure is an important representative of the openness of the building space in the block, reflecting the comprehensive degree of the visibility of the inner space of the block and the public accessibility.

Research shows that the average wind speed of pedestrian height gradually decreases with the increase of the degree of the enclosure; the linear regression of the wind speed ratio between the degree of enclosure and the height of pedestrian shows that there is a strong negative correlation between the two.

Building porosity
To pedestrians, urban ventilation performance mostly depends on the pedestrian-level building porosity. To mitigate the negative wall effects caused by the slab and high-rise buildings, there are many various modification strategies, such as setting back buildings, separating the long buildings, stepped podium, increasing the permeability of podiums, and creating a ventilation bay in the podium,etc.

By adopting different strategies to improve the porosity of buildings, air corridors in the site can be effectively established (Chao Yuan, 2011).

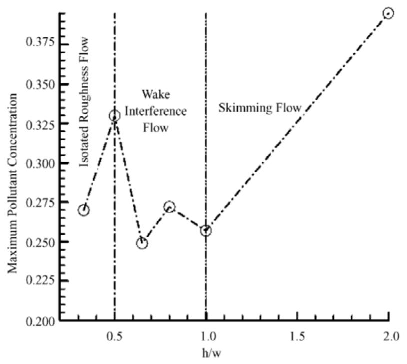


Fig. 6.1.1. Height control.
Relationship between pollutant concentration and h/w
source: Andy T Chan, Ellen S P So, Subash C Samad, Strategic guidelines for street canyon geometry to achieve sustainable street air quality. Atmospheric Environment [J].2001,35:5681-569.

Orientation
Street orientation is a significant param-eter in urban natural ventilation performance. It also influences the moment and amount absorbed solar radiation.

For the orientation of the main streets of the city, it is best to be parallel to the summer prevailing wind or at an angle of less than 30 degrees. In this case, it can promote the penetration of the summer prevailing wind into the entire area, which is beneficial to the diffusion and dilution of air pollutants. At the same time, if the pedestrian comfort requirements in the street space in winter are considered, the direction of the main street may be 30 degrees or slightly larger than the prevailing wind in winter, but a large area of static wind should still be avoided.

Roof shape
Takano and Moonen (2013) performed numerical simulations of pollutant diffusion in urban canyons with slanted roofs. They proved that the roof slope is essential to determine the pollutant distribution field in the urban canyon.

Studies have shown that at higher upstream roof heights, the arched shape of the upstream roof facilitates removal of pollutants from street canyons compared to trapezoidal, sloped, and wedge-shaped roof shapes, with the highest levels of pollution in upward canyons. The wedge-shaped roof indicates that the upward wedge-shaped roof is beneficial to the accumulation of gaseous pollutants in urban canyons (Yuan-dong, H, 2014)

At high roof heights (ZH / H = 1/2), the highest level of near-surface pollution occurs in canyons with upward wedge-shaped roofs, while the lowest pollution levels near streets in canyons with arched upstream roofs occur in canyons .

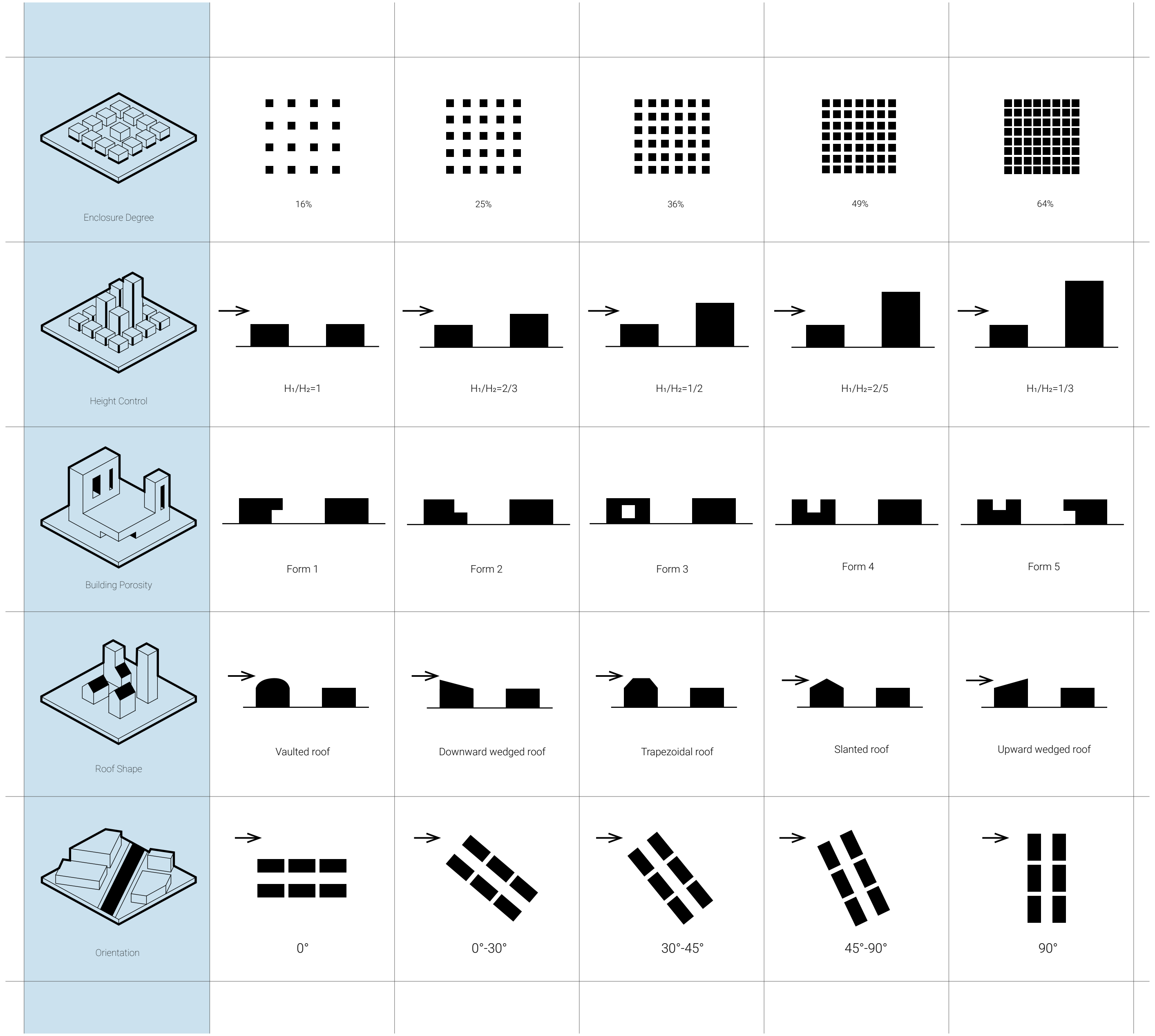


Fig. 6.1.2. The possibility of different types of strategies.
source: Author

6.2 Urban surface

Coloured facade

The color and material of the exterior wall of the building will affect the thermal stratification process in the street canyon. Because different materials and colors have different radiation absorption coefficients to form a temperature difference, dark colors absorb solar radiation, and light colors reflect radiation, so the air will Rise faster along the darker outer wall surface, thereby increasing street wind speed. The stratification of air in street canyons can have a major impact on circulation. In heat waves, when the ambient wind speed is lower than 3-4 m / s, the airflow process is mainly affected by gravity (Santamouris et al., 2001). Stable stratification can reduce air circulation, while convective stratification can enhance air circulation (Bohnenstengel et al., 2004). At the same time, dark colors absorb solar radiation, while light colors reflect radiation. At the same time, it is necessary to consider the impact on the indoor temperature and outdoor thermal comfort, and add additional insulation.

Materialization

In urban areas, the thermal effect is mainly caused by the solar radiation directly generated on the front of the building and on the ground during the day, thereby heating the nearby air. In static wind conditions, downward inertia is usually offset by upward buoyancy (Kim and Baik, 2001; Louka et al., 2002), in this situation the contribution of buoyancy to airflow in street canyons is more important.

Different building exterior materials have different solar radiation absorption performance, and at the same time increase the absorption of solar radiation energy on the outer surface of the envelope structure. When there is a difference between the street wall temperature and the air temperature, the heat of the wall Forms thermal buoyancy.

Pavement

In the past, materials used in urban spaces were designed to combat the heat island effect, reduce power consumption in buildings, and improve outdoor thermal comfort. Studies on wind and heat environment and air pollution have also shown that ground heating has a greater impact on the airflow structure and pollutant transport in street canyons.The distribution of ground temperature affects the distribution of airflow and pollutants in the street canyon.

6.3 Urban green

Green roof

The green roof becomes a new low-temperature area through the transpiration of vegetation and the shielding of solar radiation. Due to the near-ground heating of solar radiation and the existence of artificial heat sources such as cars, the linear pollution source of the road and the green roof will form a temperature difference. If the green area of the roof is large and the amount of green is high, inner ventilation will be formed. Even if the wind conditions cannot be met, the temperature difference will cause local air turbulence and promote the diffusion and dilution of pollutants. For a quiet wind city like Chengdu, the pollution control effect of airflow is even more important. Furthermore, vegetation can also filter the air through dry deposition of particulates.

Green facade

Few studies have compared the effectiveness of different green space types in mitigating air pollution. There is evidence that green walls in street canyons are more effective than green roofs in mitigating air pollution in canyons, and may be better than trees in areas with reduced airflow (Amorim, Rodrigues, Tavares, Valente & Borrego, 2013; Buccolieri et al., 2011; Koyama et al., 2013). A study estimated that the use of green walls can reduce nitrogen dioxide and PM10 on streets by 40% and 60%, respectively, and shows that the potential benefits of green infrastructure on air quality are greatly underestimated (Pugh, MacKenzie, Whyatt & Hewitt, 2012 year).

The green facades can provide an effective environment for indoor comfort during the day and prevent the facade from heating. Especially in the late afternoon and evening, the greening reduces the heat dissipation to the outdoor space, Because the green facade has less heat storage than the original.

Trees

Vegetation has a certain weakening and blocking effect on the street canyon airflow, often reducing the overall ventilation efficiency and contaminants are difficult to spread and the concentration increases. The larger the volume of the street canyon vegetation, the denser the canopy, the stronger the wind attenuation, and the reduction of wind increases, the heavier the pollution. In addition, plant species, distance from the wall, continuity, and spacing will also affect street canyon ventilation and air pollution (Ji W & Zhao B, 2014). On the other hand, the characteristics of the vegetation's absorption of heat radiation will affect the street canyon's thermal environment. In the strong summer, not only can a large amount of heat energy be consumed through transpiration, the canopy can also increase the reflectivity of solar radiation, and produce a climatic effect of reducing the ambient temperature in the shadows appearing on the sidewalk trees. At the same time, the plants convert solar energy into bioenergy, reducing the fluctuation range of the air layer (Zhao J Y, 2019). Vegetation leaves can absorb certain particulate matter to reduce pollution. Particulate matter precipitation is related to factors such as particle size, wind speed, plant species, leaf area, and particulate matter concentration (Gao H L, et al, 2017). Therefore, the current comprehensive impact of vegetation on wind and heat environmental impacts and sedimentation on pollution in the canyon is still controversial. This is caused by different parameters of different scholars' observations or simulation objects.

Fig. 6.3.1. Junglefy Breathing Wall
Source: https://www.architectureanddesign.com.au/projects/2016/green-building-project/junglefy-breathing-wall-by-junglefly#

Green wall

Green walls are usually used on both sides of heavily polluted roads to effectively isolate pollutants and noise. In addition, the type of plant has become the key to filtering pollutants. The picture shows the Junglefy breathing totem with 72 plants, can produce 140 cubic meters of clean air per hour and remove 62 litres of carbon dioxide. It is more efficient than ordinary plants in filtering pollutants and has an independent irrigation and ventilation system.

A plant scientist at the University of Technology Sydney has demonstrated that this Junglefy breathing wall has a faster ability to clear air pollutants than any other plant on the market. With a high degree of durability, durability and sustainability. Its system provides airflow between plants and growth media through fan peaks. This active ventilation increases the rate of carbon dioxide absorption and increases the amount of air that each module can filter and cool. But its high cost makes it less likely to be widely used. The portability and efficiency of this breathing wall deserves further study for widespread use.

6.4 Guidelines

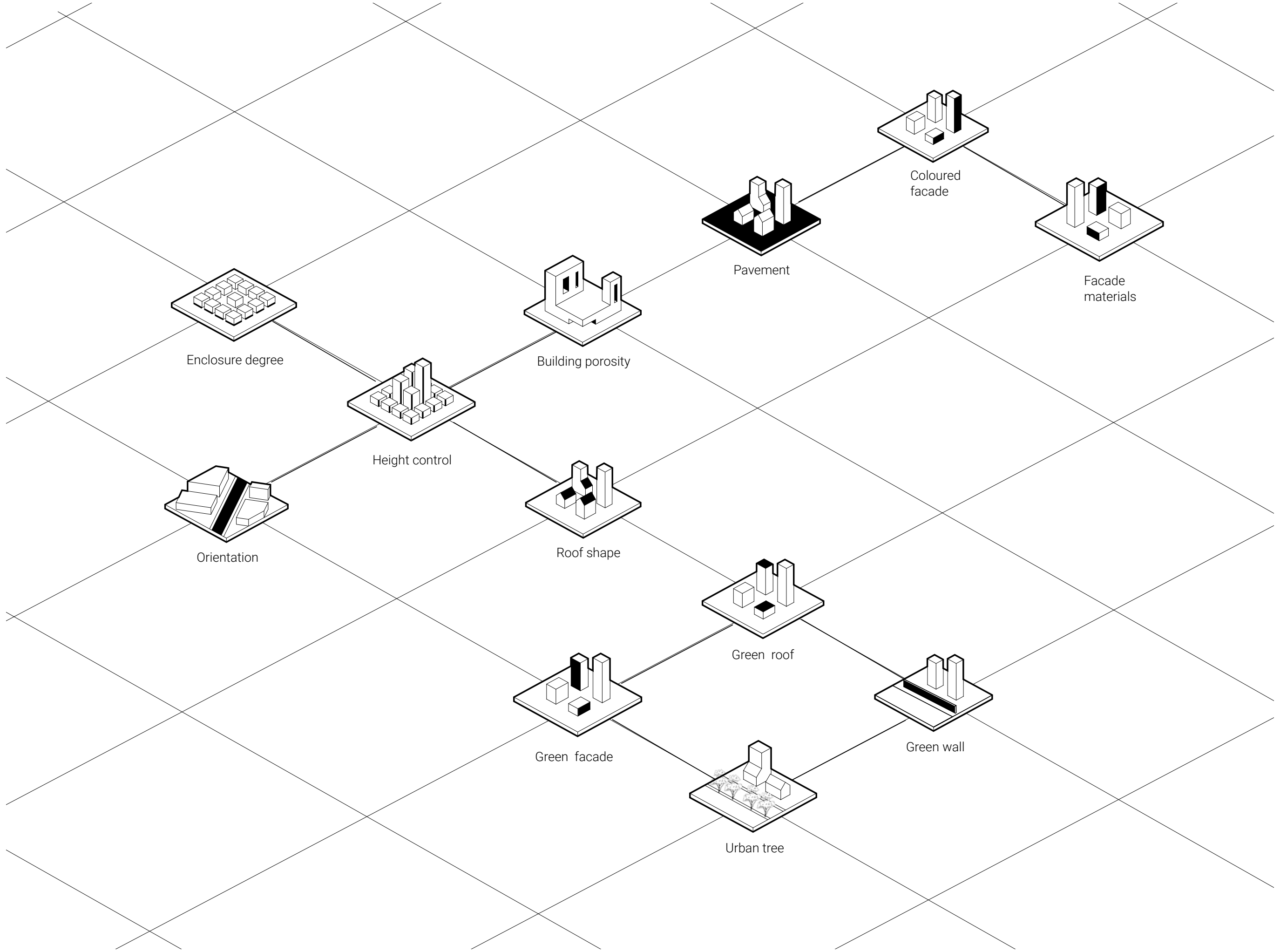


Fig. 6.4.1. Main strategies.
source: Author

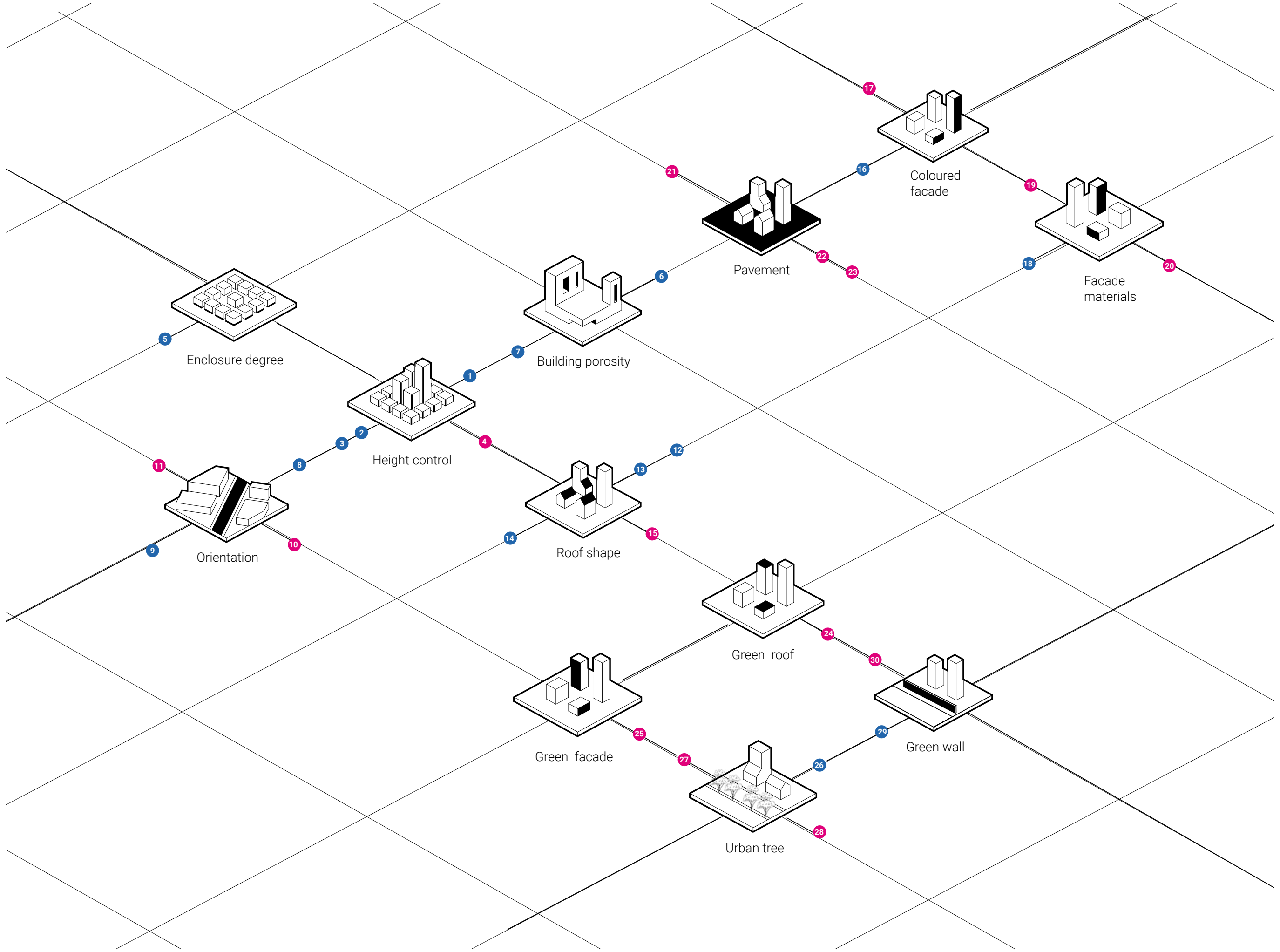


Fig. 6.4.2. Principles based on main strategies.
source: Author

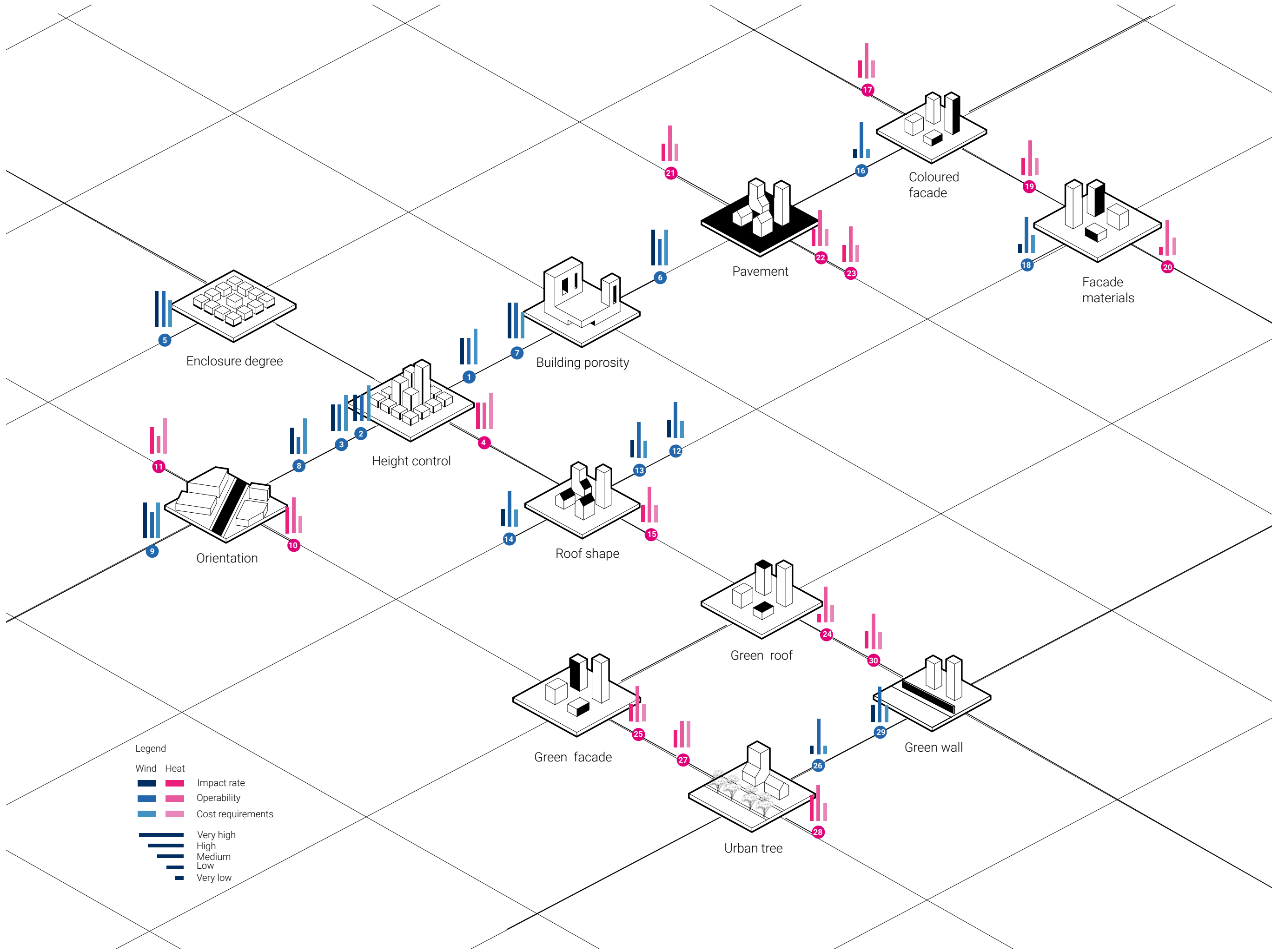


Fig. 6.4.3. Impact rate, operability and cost requirements.
source: Author

1.When designing high-rise buildings, if the heights of buildings are similar, and the distance between each other is less than 0.7 building heights, there will be no high wind speed downwash and the skimming flow regime shows.

2.Buildings that are twice or more than 15 meters taller than surrounding buildings will occur downwash of high wind speeds.

3.In the case of perpendicular flow, a stepped building height profile is recommended, in which case the pollutant concentration is lower.

4.The difference in building height will increase the average and maximum daylight factors.

5.On busy roads, it is better to have short intersections or alleys (L <6H) to promote ventilation; strong vertical flow will occur in streets parallel to the wind direction.

6.Building setback, separation, and building permeability are helpful in improving the pedestrian-level wind environment. They are favourable for natural outdoor ventilation and greening.

7.Air passages and the openings on the facade should be arranged as close as possible to the ground level. Increase ground zone air volume。

8.For higher buildings, if the longest side is parallel to the prevailing wind direction, the frontal vortex and corner steams are the lowest.

9.The wind corridor is preferably parallel to the prevailing wind or at an angle of up to 30 degrees to maximize the penetration of the prevailing wind.

10.East-west streets are best facing south because the amount of solar in winter is the largest and the smallest in summer.

11.For east-west streets, the H/W aspect ratio of the building has the greatest impact on solar radiation absorption and shadows. To maximize sunshine time, widening east-west streets is an option.

12.The leeward single-slope roof form is the most conducive to the diffusion of pollutants in the traffic canyon. It should be adopted as much as possible in the street-front architectural design.

13.A higher H/W ratio usually decreases ventilation within a street, different building heights will increase turbulence so that pitched roofs have a preference above flat roofs.

14. (under a high upstream roof height the vaulted shape of upstream roof is beneficial for pollutant removal from the street canyon compared with the trapezoidal, slanted, and wedge-shaped roof shapes)

15.The buildings on the east-west street are best to have a single pitched roof facing south, because this benefits both outdoor and indoor solar access.

16. use coloured facades to enhance an increase of wind speed to mitigate air pollution in urban spaces on hot days with a prevailing low wind speed.

17.For east-west streets with a high H / W ratio, the shadow area in winter is the largest, so surface colors with high albedo should be used.

18.use low emissity material facades to enhance an increase of wind speed to mitigate air pollution in urban spaces on hot days with a prevailing low wind speed.

19.For east-west streets with a high H / W ratio, the shadow area in winter is the largest, so surface materials with high albedo should be used.

20.Reflective roofing materials will result in relatively little heat storage. High-reflectivity building materials or light-colored finishes will result in relatively little heat stored in the building (but increased radiation to the street surface) and reduced pedestrian thermal comfort.

21. Roads with low albedo / high thermal conductivity materials or colors should be shaded as much as possible in summer to reduce heat storage and lower night temperature. Or increase the use of solar energy.

22. On roads with relatively low thermal conductivity and high reflectivity, the heat storage during the day is lower, but it will cause the street valley temperature to increase. Therefore, when using this material, the cooling of the street valley should also be considered.

23. Use permeable flooring to cool down by evapotranspiration

24. Green roofs are planted green patches in the city and should be used whenever possible.

25. The green facade facing (southwest) will be cooled by shading and evapotranspiration when it is most needed, and further reduce the penetration loss of the building.

26. On roads with high traffic flow and high pollutant concentration, plants or trees can absorb pollutants and reduce the temperature by transpiration, but at the same time, it will reduce the wind speed and trap the remaining pollutants.

27. In high-density urban centers, spaces with high SVF should be prevented to help dissipate pollutants and heat, and provide shade as much as possible during the day to reduce heat storage.

28.Deciduous trees on the north side of the east-west street or the east side of the north-south street will provide shade for the most needed facades and provide additional shade for the street surface in summer and provide sunlight in winter.

29.On roads with high traffic flow and high pollutant concentration, the green wall can block pollutants, and at the same time have the adsorption capacity and evapotranspiration of plants. Cool down the road.

30.When the wind direction is 45 degrees to the street, a four-meter-high green barrier can effectively reduce the PM10 pollution concentration in the traffic canyon

Source:Esch, M. P. (2015). Designing the Urban Microclimate. https://doi.org/10.1007/978-94-007-5631-1
Yuan, C., & Ng, E. (2012). Building porosity for better urban ventilation in high-density cities - A computational parametric study. Building and Environment, 50, 176–189. https://doi.org/10.1016/j.buildenv.2011.10.023

Impact rate, operability and cost requirements

In the analysis matrix, the impact rate of layers is briefly mentioned. In the section on strategies, the 12 categories of measures were refined into 30 feasible guidelines through a literature review. The impact rate, operability and cost requirements were also compared between them and classified as very high, high, medium, low and very low five levels. The main objective is to compare and discover their relative importance and to identify initially which guidelines play a role in mitigating air pollution and optimizing microclimates (wind-thermal environments).The first categorization is made in wind and heat, for example, building height has a greater impact on wind environment, so its impact on wind environment is mainly judged in the impact rate. The next consideration is the impact rate of each principle in relation to its scale, here mainly based on its impact rate at the block and building scale. Green roofs and surfaces, for example, may have a stronger systemic effect at the large scale, but at the block and building scales their impact rate is defined as Medium. At the same time, the use of each principles in different areas and to different extents is related to its impact rate and therefore cannot be assessed very rigorously.

In addition, each guideline was judged on its operability, which means that modifications can be made to the building or block and ease of change. These values can help determine which guideline can be prioritized during the design phase, For example, the form and orientation of a building both have a large impact on the wind environment, but the operability is different. The cost requirements also affect the operability of the guidelines to varying degrees. Overall, those with higher impact rates and operability and lower cost requirements will be prioritized in the design phase.

7 Design

Design method

In the design chapter, the results of all the preceding chapters provide input for the development of urban development strategies to reduce air pollution through urban microclimate design. In order for climate adaptation measures to become part of the 'standard' design process, urban designers and policy makers need to have clear guide (Pijpers-van Esch, 2015). The guidelines related to urban microclimates and air pollution were presented in the previous chapter. This chapter attempts to integrate the corresponding guildelines into the planning or design process for the area, answering sub-question 6: How to integrate microclimate design and air pollution issues into the urban design process?

All three sites selected aim to improve air pollution through microclimate design. Air pollution and microclimates constitute some degree of maximization in the urban planning or design process. The maximization method developed by Duijvestein (2002), shown in Figure 7.1.1, is an urban design method, which aims to elucidate the choices in processes related to a specific environmental theme. In this study, the maximizing theme is air pollution. Using the maximisation approach, environmental and urban space issues can be included alongside the maximisation theme design. The three site studies in this chapter follow the same integration process and have the same questions as listed in Table 7.1.2.

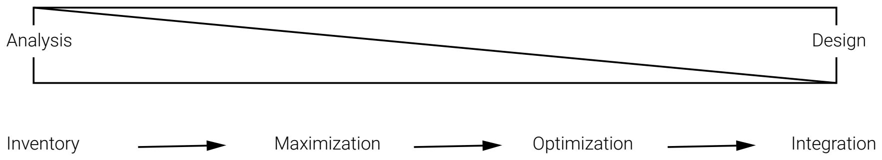


Fig. 7.1.1 Environmental aspects provide structure and direction in the transition between analysis and design (Duijvestein, 2002).

Design process		Daye road	Nijiaqiao neighborhood	Tianfu anvenue
Analysis	Built environment	High density, large building height difference, high reflective walls, enclosed high-rise building group unit	Medium density, average building height, determinant residential area, semi-enclosed multi-story building group unit	Low density, average building height, much green, non-enclosed large mass multi-story building unit
	Microclimate condition	High temperature, relatively low wind speed, higher wind speed in the corner flow area	Moderate reflective walls, slab type multi-story building that are nearly perpendicular to the wind direction form a large still wind area	Still wind zone
	Livability	High traffic flow, high human flow, low greening rate, lack of public space	Community with low accessibility and low vitality	Low outdoor attraction, high greening but low accessibility
Maximisation	What are best options in relation to air pollution(wind/heat) and urban character-istics(density typologies)?	Change the material and color of urban surfaces, reduce frontal area, coordinate the urban cold and heat sources	Change urban mophology, slab type multi-story building are arranged in a scattered manner to form an air corridor that matches the prevailing wind direction in summer	Adjust the form of urban road greening to reduce air pollution in outdoor exposed areas of the popula-tion
Optimisation	What are the options to build a better microclimate (wind-heat environment)?	Reflective and green roofs, the fountain installation on the square serves as cooling and dust retention, adjust building function according to air quality	Use insulation and sunscreen, add extra layers and trees to provide shadows for the sidewalk, add spaces with high SVF such as squares	The dark facade promotes ventilation and the building adds extra insulation, permeable pavement for water infiltration.
Integration	What are the options in combination with other context ?	Use building ground floor to shade, vegetation and higher permeability surfaces, mental benefits provided by green roofs	Add additional public space and improve residents' vitality, mental benefits provided by green roof, improve the use of solar energy,	Use urban canvas and urban trees to shade, Increase solar energy supply, increase attractive-ness business to add vitality to public spaces, redesign of square

Fig. 7.1.2 Overview of results per step within the integrated design process of the three sites.(Maximumsation)

7.1. Daye Road

In order to more accurately simulate the wind and heat environment and air pollution of the site, combined with the size of the site simulated by ENVIMET, the design site is down to 180 × 180 meters. Here, the high-rise building area is selected. The area has lower wind speeds and higher pollution.

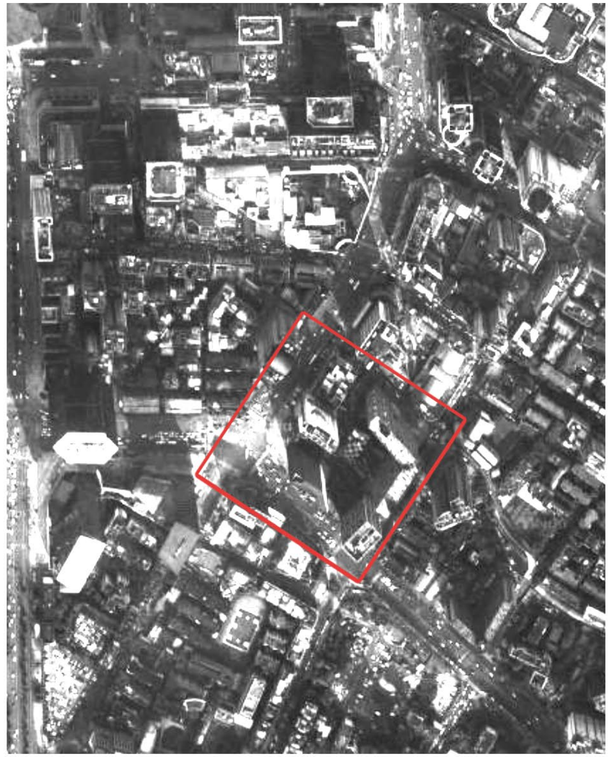


Fig. 7.1.1 Satellite map of Daye road.
Source: Baidu maps.

Design objectives

Analysis

High density, large building height difference, high reflective walls, enclosed high-rise building group unit

High temperature, relatively low wind speed, higher wind speed in the corner flow area

High traffic flow, high human flow, low greening rate, lack of public space

Maximisation 6 16

Change the material and color of urban surfaces, reduce frontal area, coordinate the urban cold and heat sources

Optimisation 3 7 15 24 25

Reflective and green roofs, the fountain installation on the square serves as cooling and dust retention, adjust building function according to air quality

Integration

Use building ground floor to shade, vegetation and higher permeability surfaces, mental benefits provided by green roofs

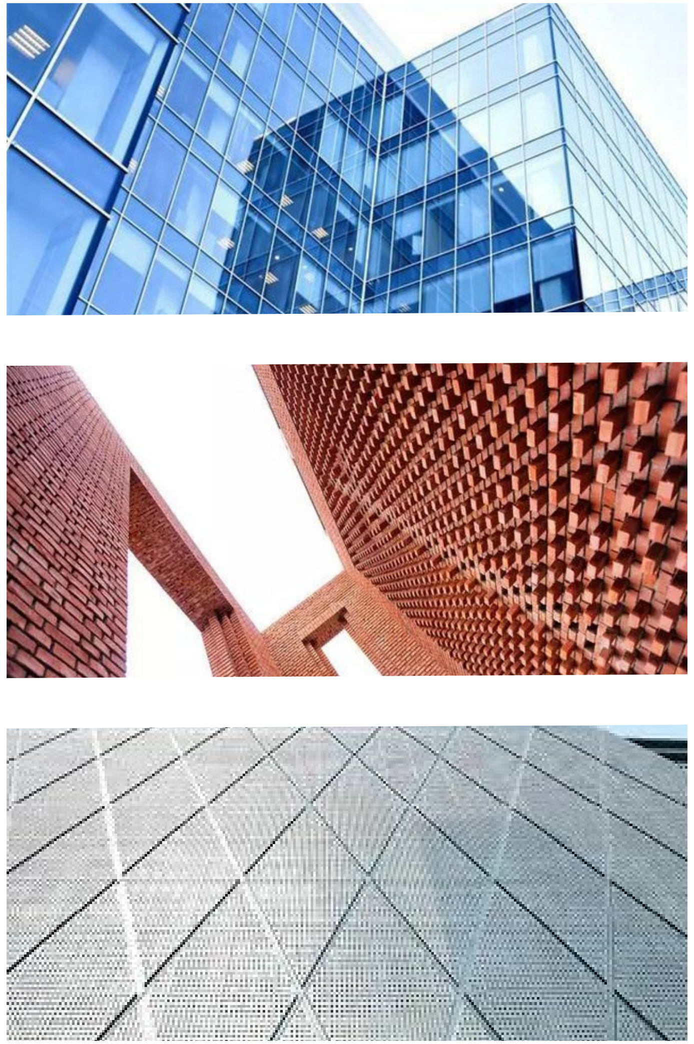


Fig. 7.1.2 Glass, brick and aluminum veneer curtain wall building.
Source: https://www.hotbak.net/key/%E9%AB%98%E5%B1%82%E5%BB%BA%E7%AD%91%E7%8E%BB%E7%92%83.html
https://dy.163.com/v2/article/detail/D7LB3UH20520CIDT.html
http://www.024cai.net/product/717.htm

In addition to changing the building porosity, another operatable method is to use the colour of the facade to speed up the wind speed, especially in a city centre with a large building facade. The use of temperature differences and accelerate the process of thermal stratification could be used to accelerate airflows, although in an uncontrolled way. Three different materials are used for simulation here, which initially shows that different surfaces have effects on wind, heat environment and air pollution. The hypothesis tested in Daye road and design proposals are as follows:

The colour and material of the facade will affect the thermal stratification process in the street, so when using dark or low emissivity materials' facades, the air will rise faster along the facade surface, thereby increasing the wind speed and increasing the increase the mixture of air between the canopy layer and the boundary layer.

-Glass(all the building surfaces)
-Brick
-Aluminium (grey)

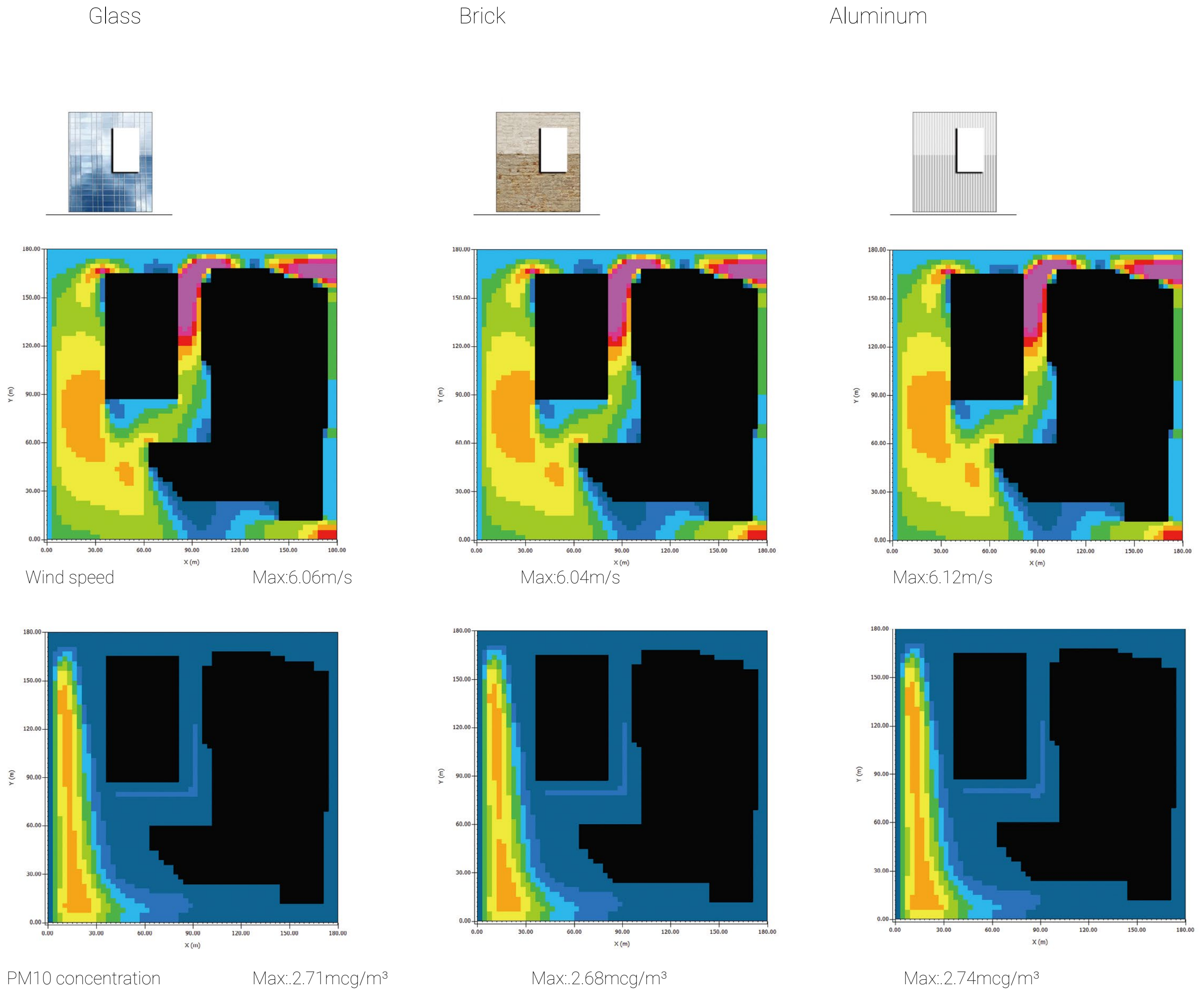


Fig. 7.1.3 Simulation results for wind speed and PM10 concentration under three building materials(Glass, Brick, Aluminum).
Source: Author

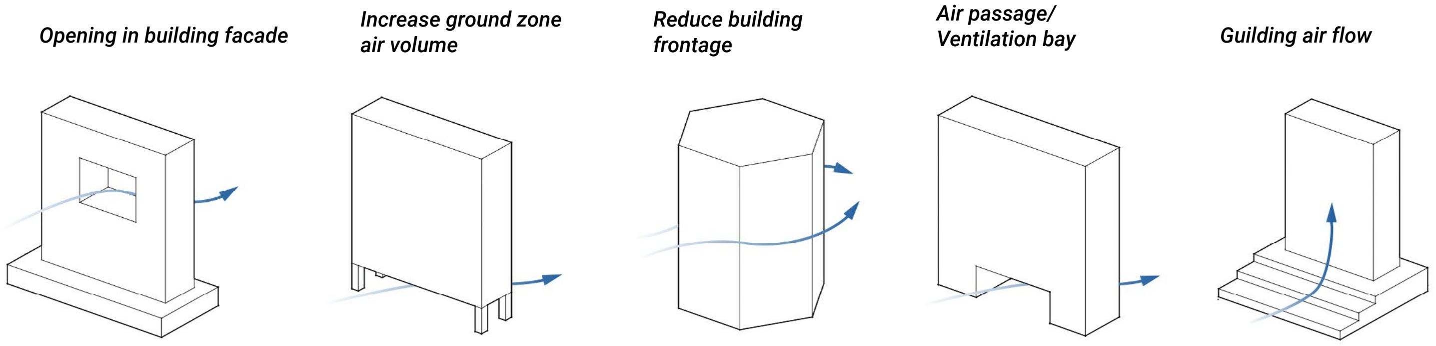


Fig. 7.1.4. Different ways of building porosity.
Source: Author

Building morphology

For high-rise or large mass platform buildings, it will seriously hinder urban ventilation and form a large wind shadow area on the back of the building. For a single building form, opening in the building facade, increase ground zone air volume, reduce building frontage, air passage/ventilation bay and guiding airflow are advantageous design methods.

The impact on the above-ground buildings should be reduced by controlling the building quality as much as possible, reducing the size of the windward surface, optimizing the building form, destroying large buildings or developing underground spaces, and thus reducing the impact on ventilation.

When looking at the simulation of the test proposal, it appears that building covered by brick has the lowest concentration of PM10(maximum: 2.68mcg/m3) but the difference is very minimal. Concerning Windspeed values, test aluminium has the largest wind speed. Although it can be seen that the low-reflection material (aluminium) will produce greater wind speeds, the difference between the three is not obvious, and it may not be sufficient to obtain reliable results at the current scale. Considering the negative impact on thermal comfort and cost, the impact of the materials and colours of the building facade on air pollution needs further verification.

On the other hand, this measure may cause the indoor up-heating effect and reduce thermal comfort, requiring additional heat insulation measures and cost.

Design description

Porosity

The site is designed by combined with green space, squares, building porosity and building setback space to form a ventilation path along summer prevailing wind direction, enhance the permeability and greatly improve the wind environment in the outdoor space in high density area.
Reduce the windward size by optimizing the form of the building, breaking down and reduce the frontal area to make the airflow near the ground smooth.
A stepped podium design to increase the inlet air volume of the street canyon, and help to dissipate the heat and air pollutants to the sky.

Green

Greening is provided in pedestrian areas, public squares and rooftops and the greening coverage should be accessible to all residents and citizens.
Plants can produce significant cooling effects through canopy shading and transpiration, and help decrease the urban heat effect. At the same time provide shadows in the pedestrian area to improve thermal comfort. In the urban central area, more shrubs or lawns should be planted, and tall and lush trees should be scattered to avoid obstructing ventilation.

Public space

Place squares, parks and green spaces in the windward position where the wind prevails in summer, so that open public spaces have a good ventilation environment. Set high SVF space or squares at road intersections to accelerate the transfer of airflow in different directions, to avoid the formation of vortex zones, and to promote airflow into leeward streets.

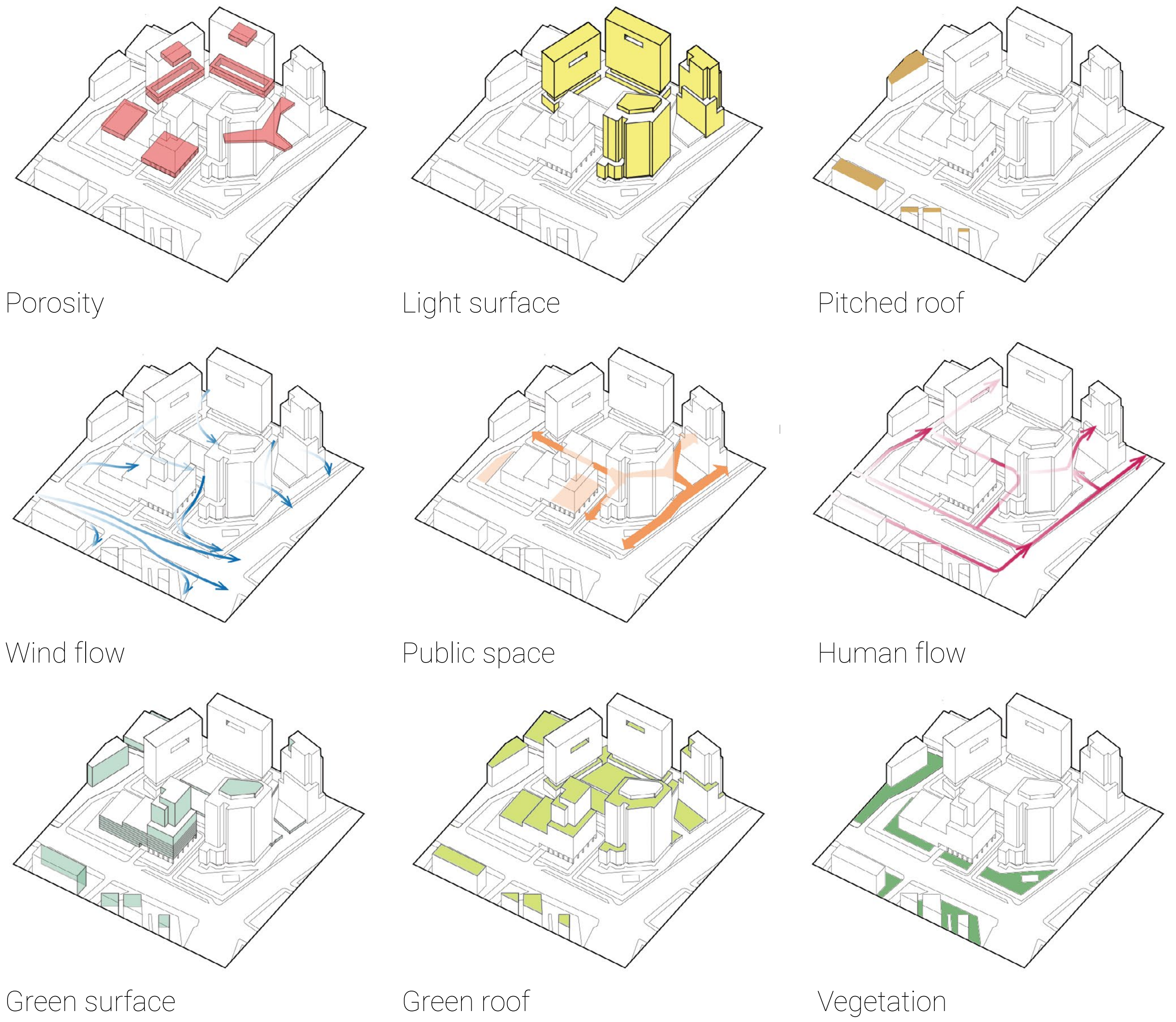


Fig. 7.1.5. Design proposals.
Source: Author

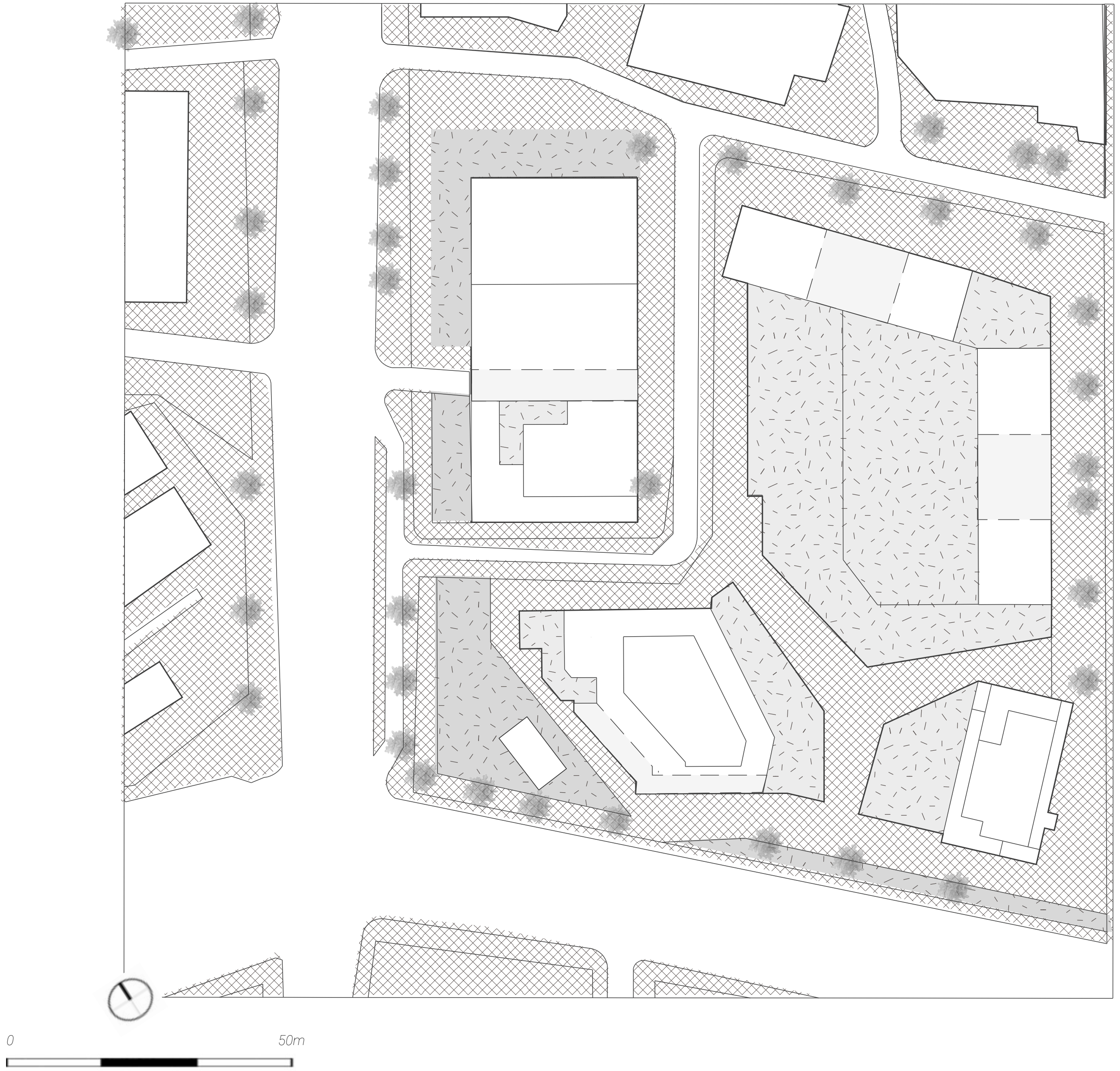


Fig. 7.1.6. Daye road design plan.
Source: Author

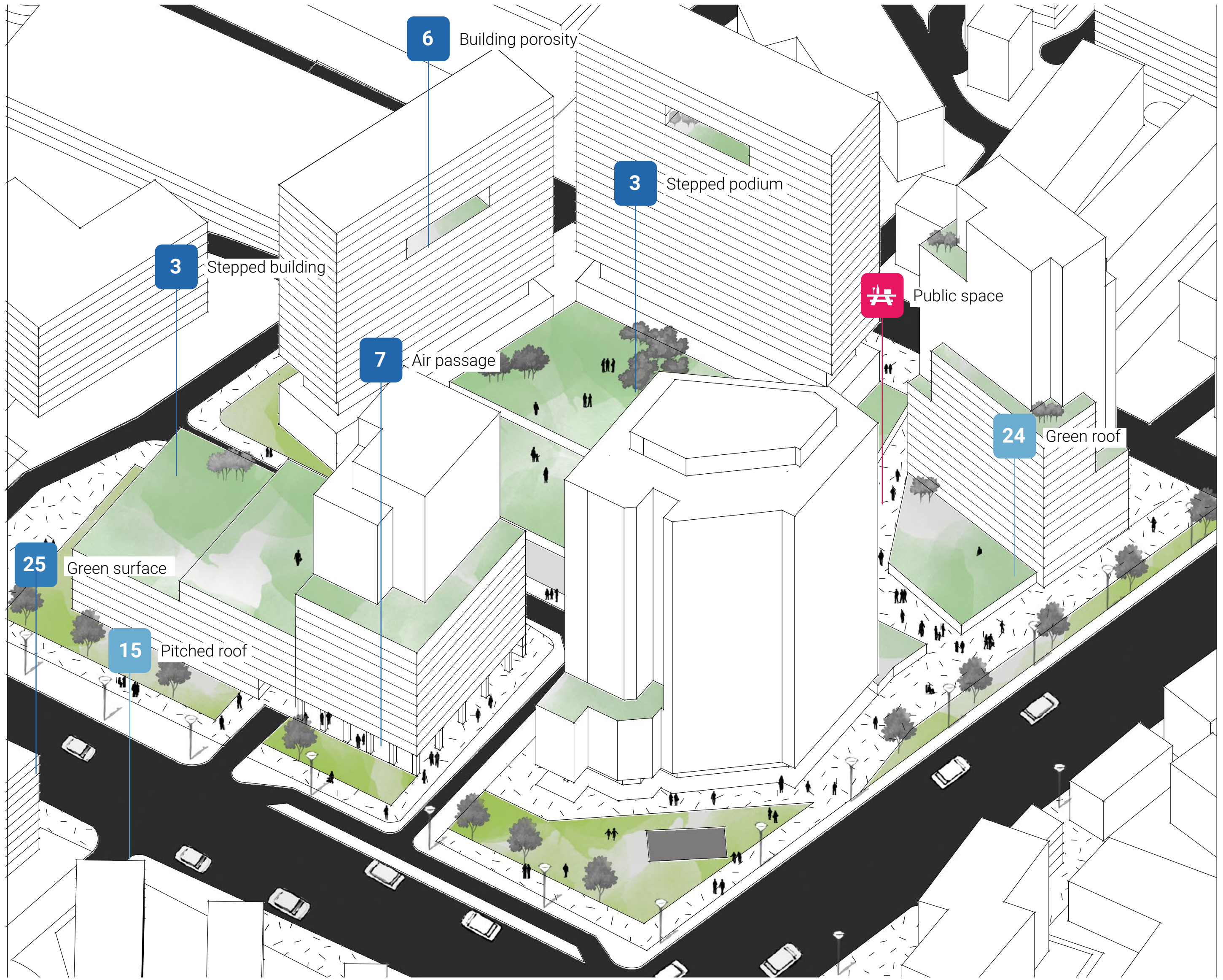


Fig. 7.1.7. The overview of Daye road design principles.
Source: author

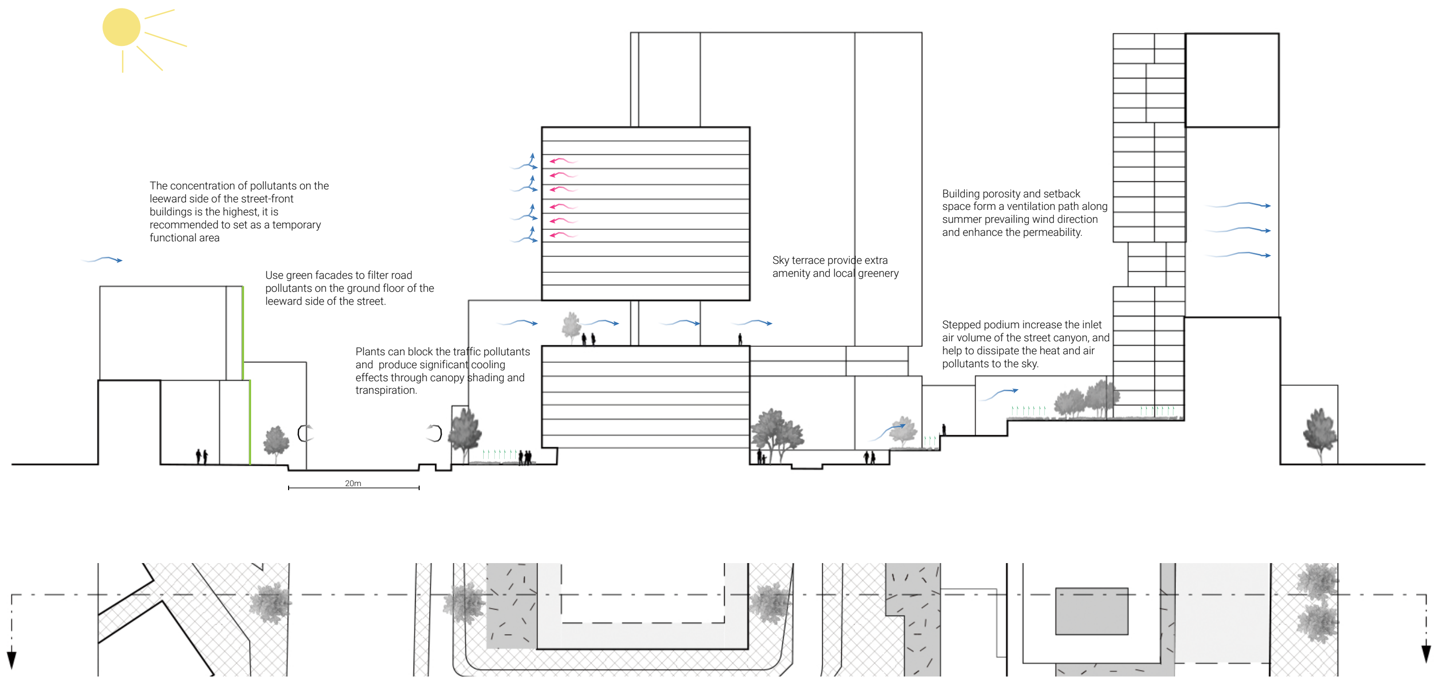


Fig. 7.1.8. The section of Daye road.
Source: Author

Fig. 7.1.9. Daye road.
Source: Author

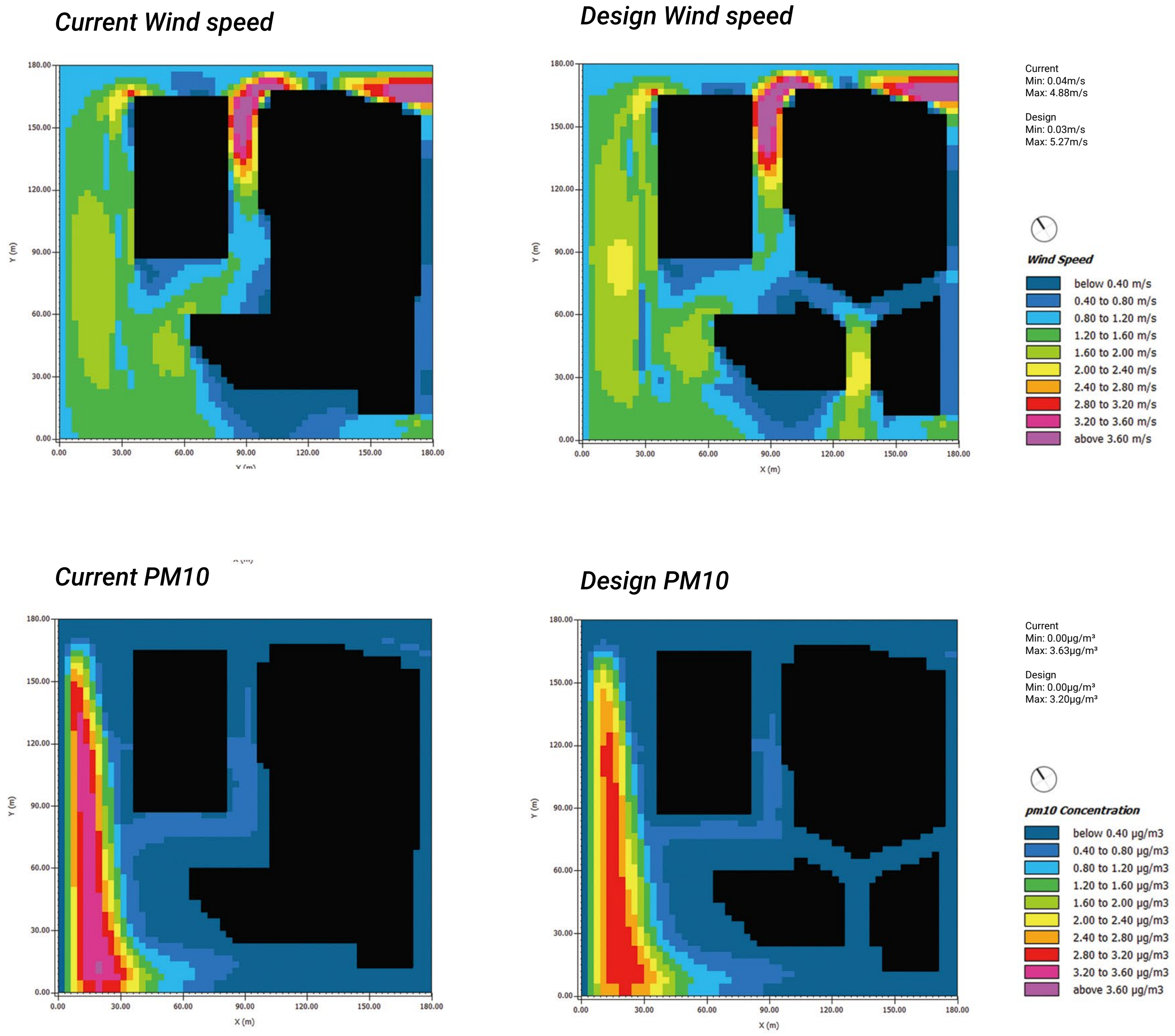


Fig. 7.1.9. Wind speed and PM10 concentration simulations of Daye road.
Source: Author

Evaluation

In the ENVI-met model, due to technical issues, some design principle are not taken into account, such as single pitched roofs, ground ventilation corridors, etc. Therefore, the simulation results are only valid for trees, surfaces and some building porosity. When comparing the simulation results, in general, the pollutant concentration at the pedestrian height (1.625m) around the high-rise large platform area is low, and no difference can be seen. The concentration of pollutants on the main road has been reduced. The overall maximum pollutant concentration decreased from 3.63mcg / m³ to 3.20mcg / m³, and the maximum wind speed at pedestrian height increased from 4.88m / s to 5.27m / s. The buildings next to the main road enhance permeability, increase the wind speed of the main road, At the same time, the division of the large podium increases the ventilation of the ground floor, reducing the area of the wind shadow formed by the high-rise area, while providing new public spaces for pedestrians.

7.2.Nijiaqiao Neighbourhood

Most of the residential communities in China are easily over 500 meters in diameter. Within the residential community, there are only a large number of repeating dwellings, and no high-quality shops and changing urban life can be seen. After the community was closed, outsiders could only enter through a limited number of entrances. In addition, air pollution also endangers the health of residents. Creating vital community spaces, and reducing pollution, forming semi-open spaces, open spaces, and closed private spaces become the key to this area. Here the areas with the highest pollutant concentrations within the neighbourhood are selected for intervention. The design plan aims to reduce air pollution while providing comfortable and healthy public spaces for nearby residents and citizens.

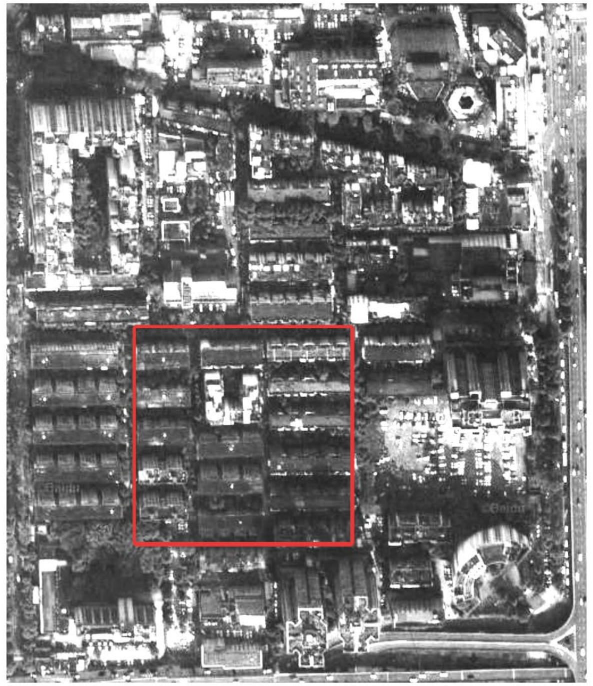


Fig. 7.2.1. Satellite map of Nijiaqiao neighbourhood.
Source: Baidu maps.

Design objectives

Analysis

Medium density, average building height, determinant residential area, semi-enclosed multi-story building group unit

Moderate reflective walls, medium heat island effect, low wind speed, slab type multi-story building along the street that are nearly perpendicular to the wind direction form a large static wind area

Community with low accessibility and low vitality

Maximisation 6

Change urban morphology, slab type multi-story building are arranged in a scattered manner to form an air corridor that matches the prevailing wind direction in summer

Optimisation 3 7 15 17 24 29

Use insulation and sunscreen, add extra layers and trees to provide shadows for the sidewalk, add spaces with high SVF such as squares

Integration

Add additional public space and improve residents' vitality, mental benefits provided by green roof
improve the use of solar energy,

Form operation

As mentioned earlier, some small gardens outside the wall of the Nijiaqiao community can see that the residents here have a demand for green and more vibrant public spaces.

Due to the differences in air pressure caused by changes in height contours can be used to induce airflow, promote ventilation, and provide wind permeability, buildings are strategically distributed in different heights. At the same time, combining with landscape elements to shape a better residential landscape.

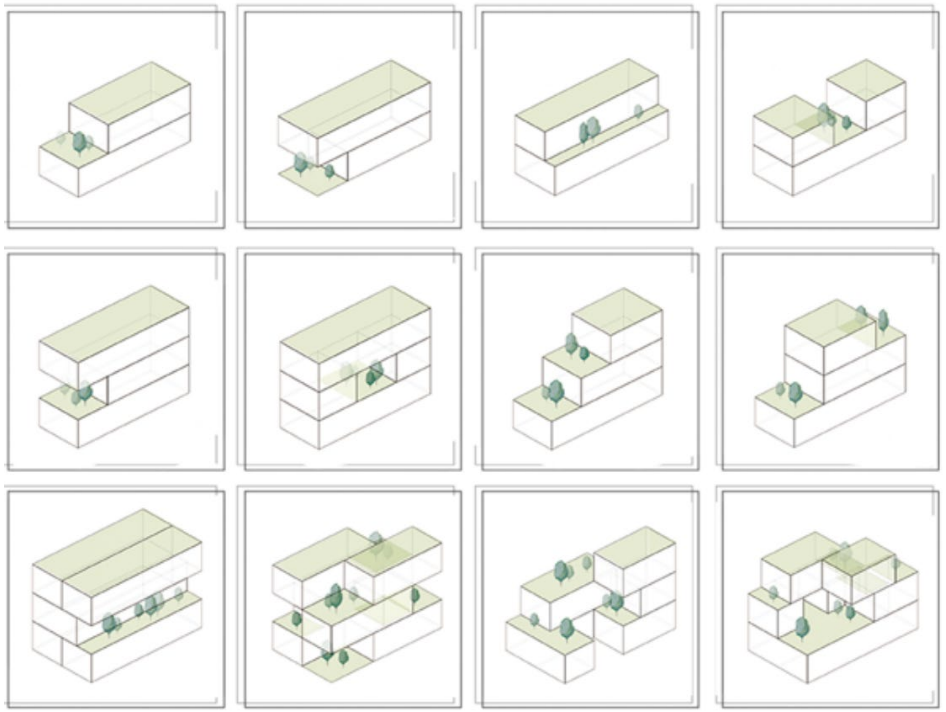
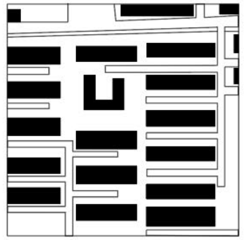
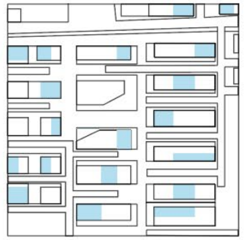


Fig. 7.2.2. Design proposals.
Source:: Author

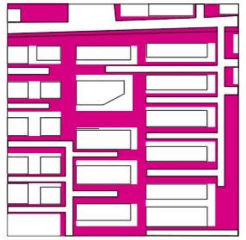
Current



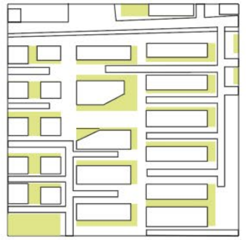
Porosity



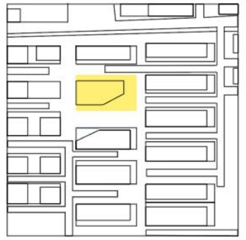
Pavement



Green space



Public space



Design description

The largest public space inside the Nijiaqiao neighbourhood is a green space, which includes a small pool. The area is likely to be transformed into a community square. In order to create more public space, a small part of the building will be renovated, while increasing the height difference of the building to create better ventilation conditions.

Building porosity
Appropriately widen east-west streets, and reserve a part of the opening space to add local buildings along the street, increase the building height appropriately to improve summer ventilation. Some buildings on the south side treat the roof as a sloping roof to improve the sunshine in the street.

Green
Renovate the roofs and walls of some buildings and add roof greening. Introduce small-area, fragmented greening forms, increase the greening area inside the community, reduce the summer ambient temperature, and form convection of hot and cold air.

The combination of different building porosity has created more visually shared spaces, retaining the original plants, the accumulation of cooling elements (plants, green roofs and green walls), plus high and low buildings, results in a heterogeneous space with multiple spatial qualities.

Although these interventions understand and take into account the difficulties of cooperating with privately owned spaces, changing building ventilation patterns to add more public areas can still be seen as a potential plan.

Public space
Plant green plants with a larger canopy in the square (the entrance and exit space of the main public buildings) provide a comfortable leisure space in summer. Organize and arrange various outdoor activities according to the change of seasons, arrange facilities with more flexibility, and enhance the vitality of the street. The surrounding wall of the community can effectively isolate pollution and transform itself into a multifunctional wall for activities.

Redesign of the external wall of the Nijiaqiao community, the original small gardens are retained on the outside, and the internal structure is changed to different forms of structures for different purposes. It can be used for internal use and can also be used for commercial purposes, increasing the vitality of the community boundary.

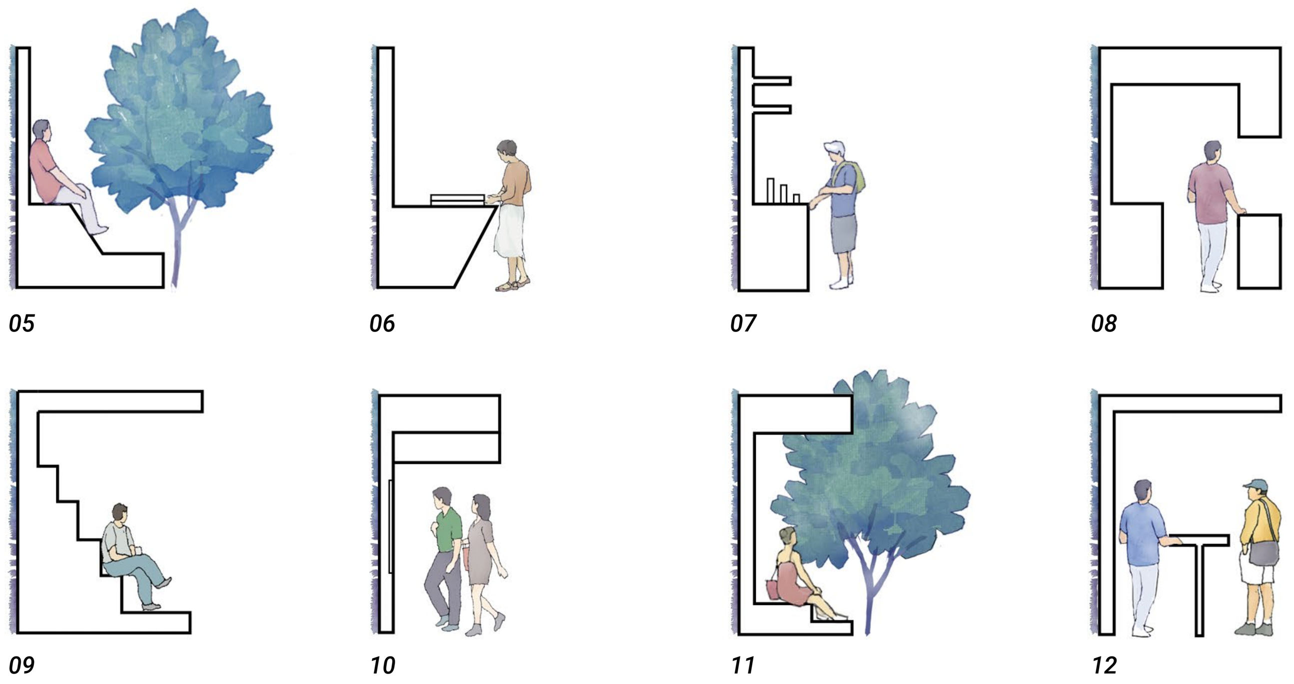


Fig. 7.2.3. Wall design proposals.
Source: Author

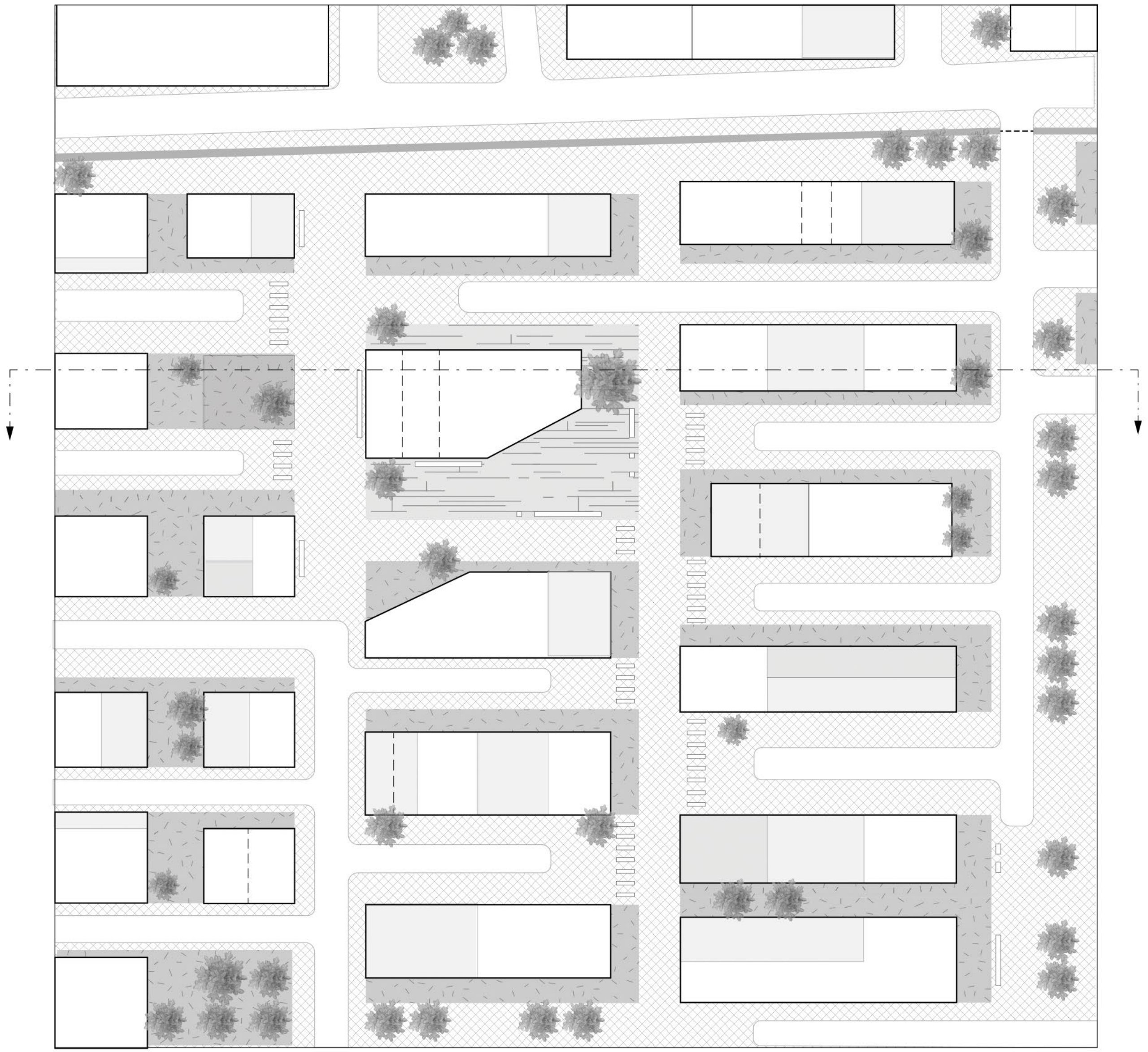


Fig. 7.2.4. Nijiaqiao neighbourhood design plan.
Source: Author

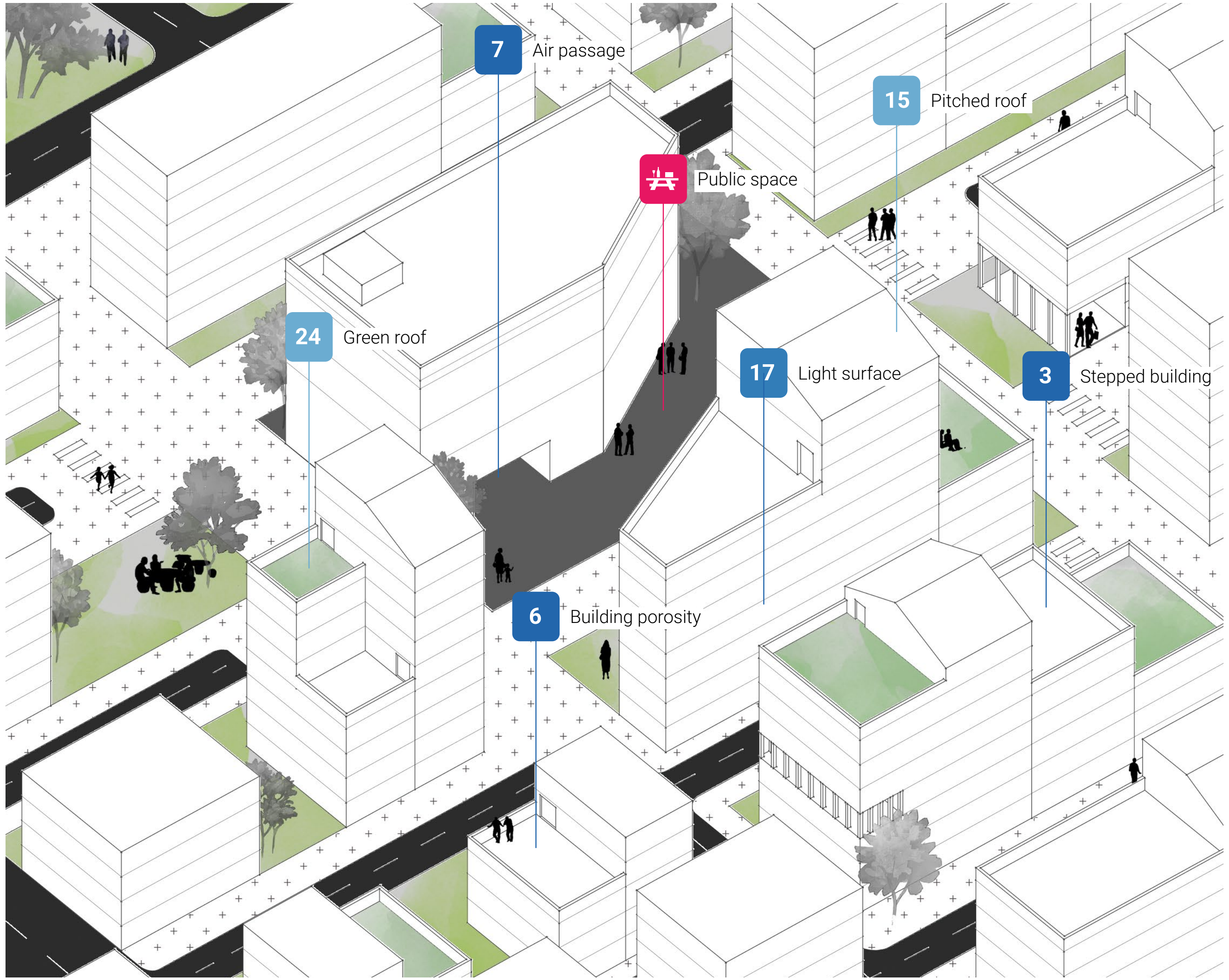


Fig. 7.2.5. The overview of design principles on Nijiaqiao neighbourhood.
Source: Author

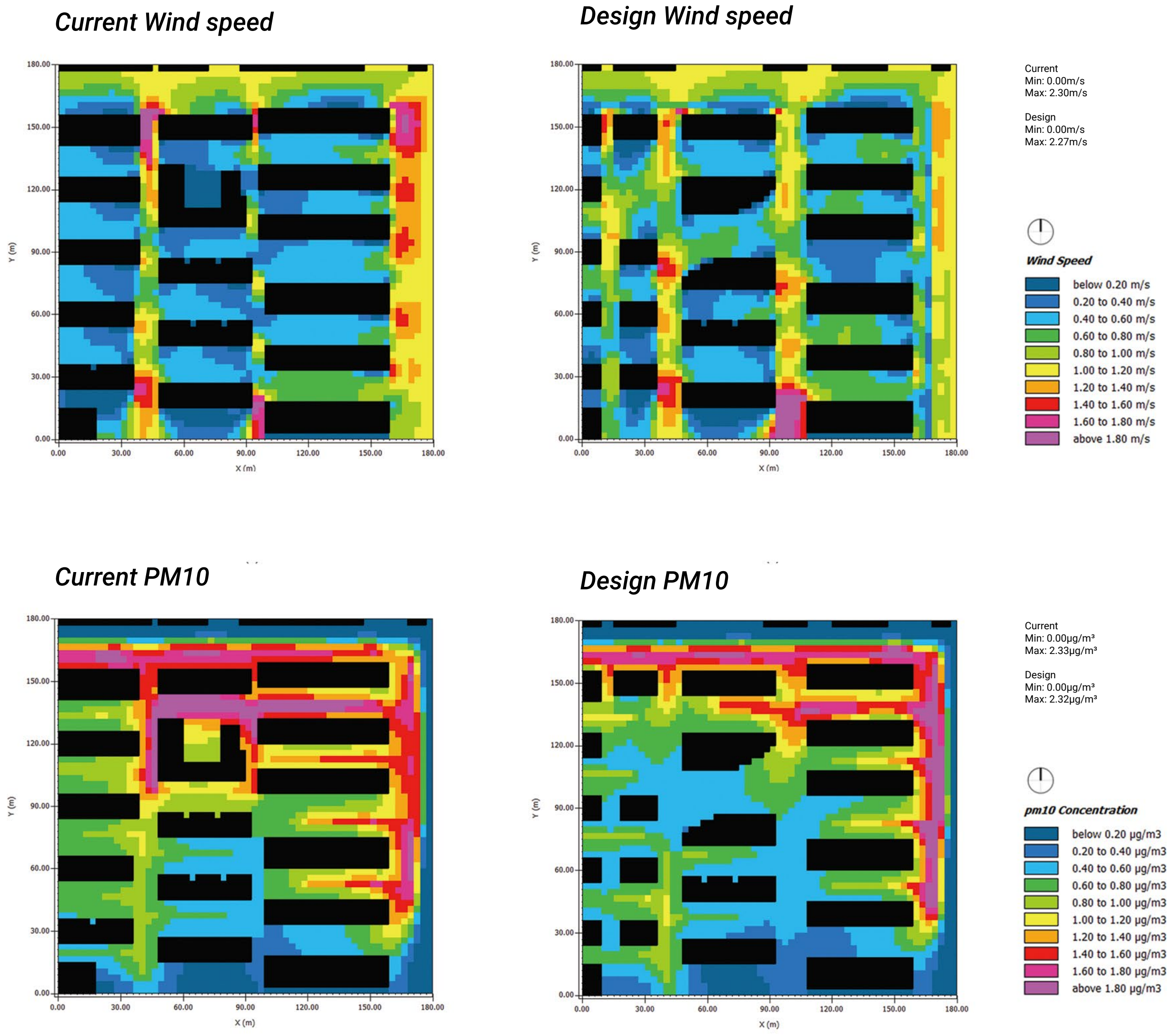


Fig. 7.2..6. Wind speed and PM10 concentration simulations of Nijiaqiao neighbourhood.
Source: Author

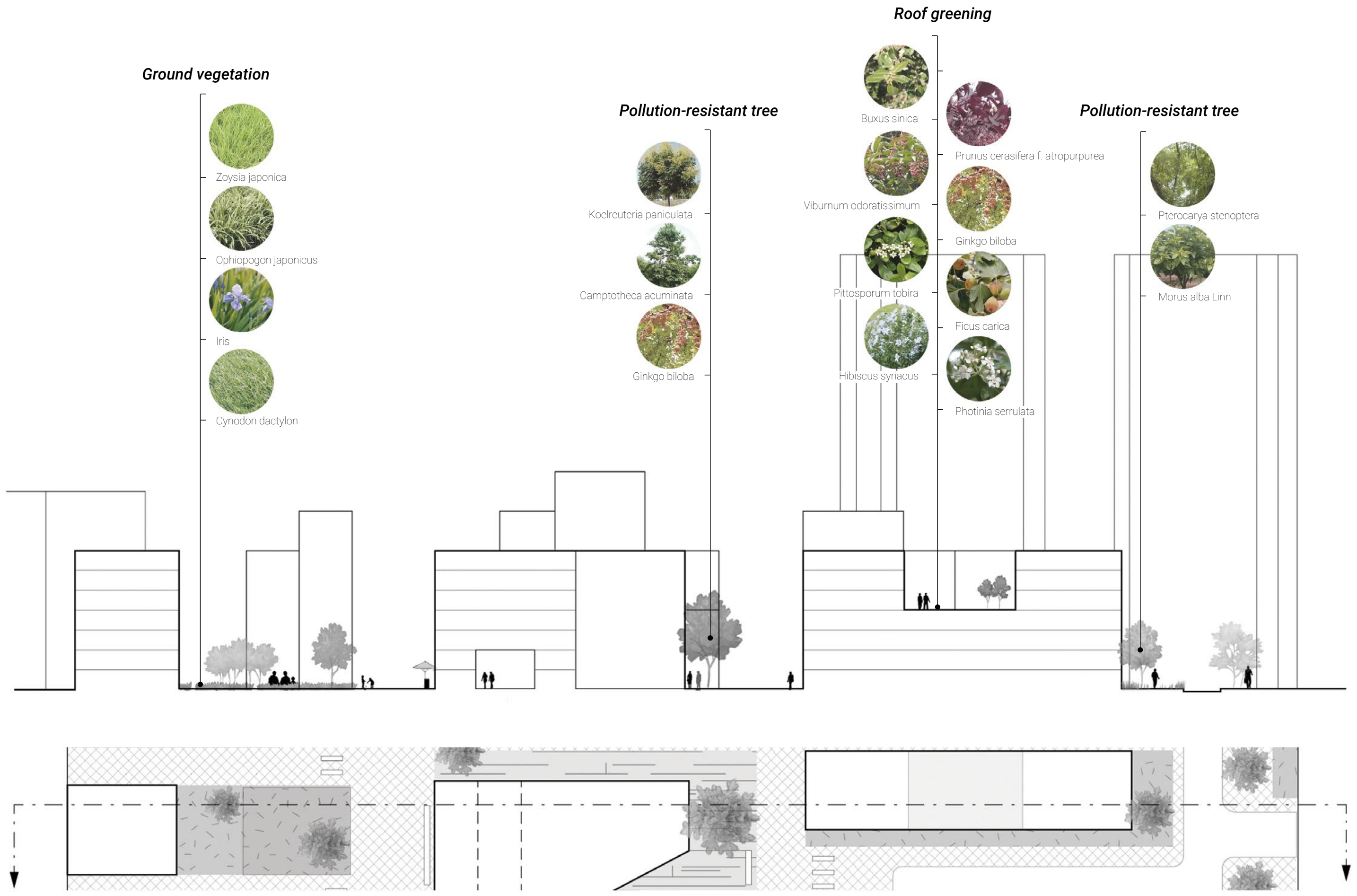


Fig. 7.2.7. Vegetation configuration profile of Nijiaqiao neighbourhood.
Source: Author

Fig. 7.2..8. Nijiaqiao neighbourhood.
Source: RUIS studio(Synthesis, moscow).

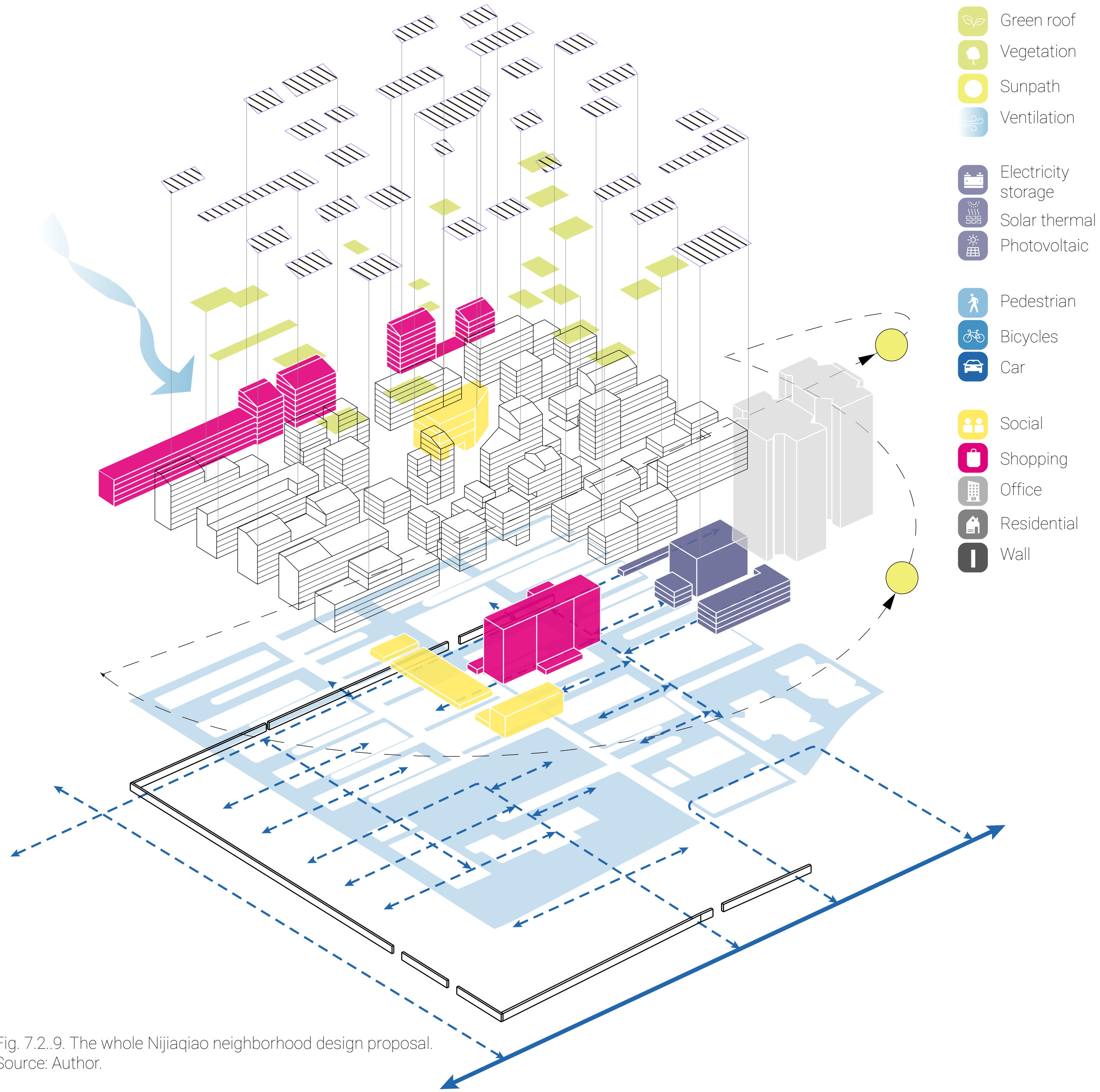


Fig. 7.2..9. The whole Nijiaqiao neighborhood design proposal.
Source: Author.

The simulation results show that increasing building porosity is an effective measure to increase wind speed.

When simulating current conditions of the chosen area in Nijiaqiao neighbourhood, higher values can be founded on corners of buildings, and residences close to external streets are exposed to pollution. The designed wind speed is 3.27mcg / m³, which is slightly lower than the current wind speed. The concentrations of pollutants are 2.33mcg / m³ and 2.32mcg / m³, which are almost the same, but it can be noticed that the reduction of pollutants infiltrated into the community. Because in the design plan, more trees were planted next to the fence, the wind speed on the right was significantly reduced, and pollution was more trapped in the street. so pollution concentrations were higher in the street but lower in the rest of the neighbourhood.

On the other hand, in the entire community, in addition to the green roof, the sloped roof in the south can also increase the utilization of solar thermal energy, and install a cogeneration plant and electricity storage inside the community.

7.3.Tianfu Avenue

As mentioned before, as a major north-south traffic artery in Chengdu, Tianfu Avenue is outside the Third Ring Road, inside the Ring Expressway and near the South Railway Station. High pollution levels in areas near the viaduct. Here the intersection of two main roads in the site is selected for intervention.

Research shows that the impact of urban vegetation on air quality is more complex. Sometimes the vegetation on the roadside may lead to an increase in the concentration of pollutants. The effect of different vegetations on dust absorption is also far away. The vegetation stock of Tianfu Avenue is much higher than in other areas, so the local vegetation has the greatest transformation potential.

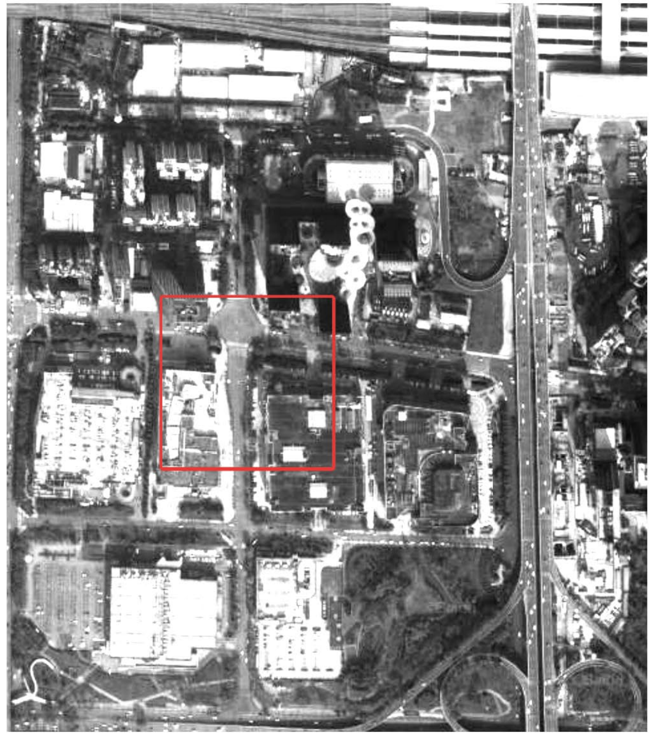


Fig. 7.3.1. Satellite map of Tianfu avenue.
Source: Baidu maps.

Design objectives

Analysis

Low density, average building height, much green, non-enclosed large mass multi-story building unit

Static wind zone with low heat island effect

Low outdoor attraction, high greening but low accessibility

Maximisation 26

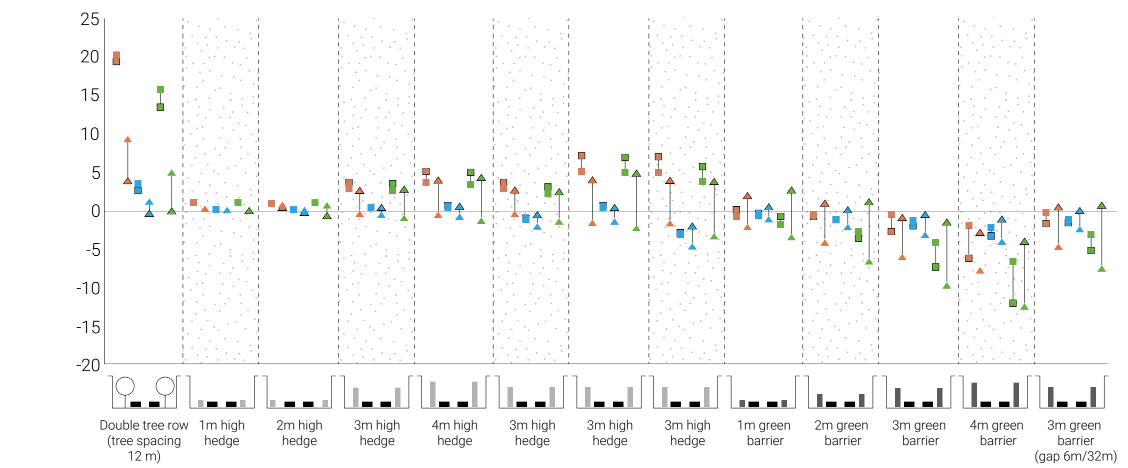
Adjust the form of urban road greening to reduce air pollution in outdoor exposed areas of the popula-tion

Optimisation 7 16 21 23 25

The dark facade promotes ventilation and the building adds extra insulation, permeable pavement for water infiltration.

Integration

Use urban canvas and urban trees to shade, Increase solar energy supply, increase attractiveness shopping streets to add vitality to public spaces, provide more shade, redesign of square



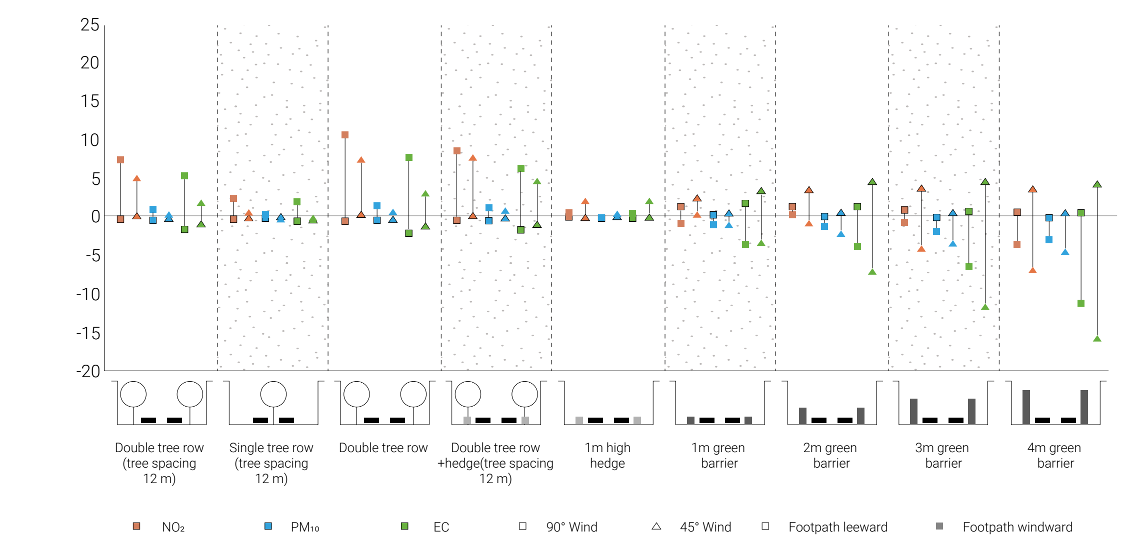


Fig. 7.3.2. Effects of urban vegetation in urban canyons
Source: VOS, P., MAIHEU, B., VANKERKOM, J. & JANSSEN, S. (2013). Improving local air quality in cities: To tree or not to tree? Urban Environmental Pollution, 183, 113-122

According to relevant literature, trees on both sides of the road may significantly increase the concentration of pollutants, and hedges and green barriers may improve air pollution. For trees, the deceleration of the flow causes air pollution to increase. Hedgerows and obstacles can also reduce street-level wind speeds, but low-permeability trees or green barriers can effectively reduce the concentration of pollutants on sidewalks or squares at intersections (Peter E.J. Vos, et al).

In addition to reducing wind speed, trees can play a role in shading, reducing the heat island effect, reducing noise, etc. in the urban environment. Green vegetation is also beneficial to reputation and mental health. Therefore, planting trees on both sides of high-pollution roads needs more scientific considerations.

The current layout of Tianfu avenue has been already described: a double tree-line.
The design proposals try to test different layouts which are derived from the research.
-Loose
-Dense
-One line
-No trees
-4m green barrier

According to the simulation results, the previous analysis can be confirmed that the wind speed around the planted trees is reduced, since the maximum value of the pollutant concentration is slightly higher than the current status (2.17ug / cm3), in which the maximum value of the pollutant concentration is lowest in the case of no trees . The average value of pollutants has increased (but whether this aerodynamic effect exceeds the filtering capacity of vegetation remains to be further studied). The dense trees and 4m green barrier can effectively reduce the pollution on the sidewalk through isolation. Both of them reduce the pollutant concentration in the downwind direction (right side). But the average pollutant concentration of 4m green barrier is lower.

All in all, the simulation results show that the more trees, the smaller the wind speed. Considering the range of pedestrian activity, the most effective measure is the 4m green barrier, so the 4m green barrier is used in the site plan.

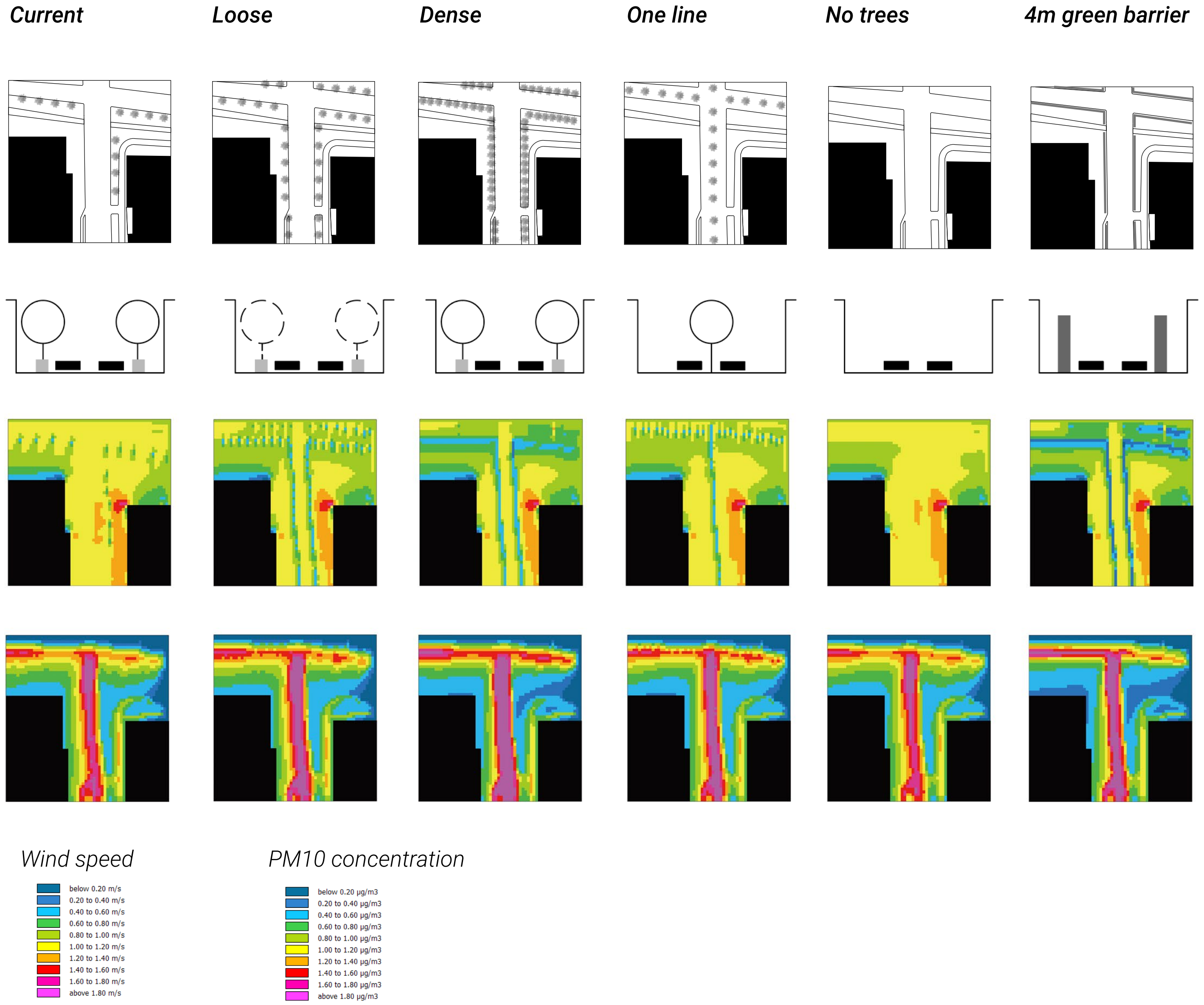


Fig. 7.3.3. Wind speed and PM10 concentration simulation results for different plant layouts on Tianfu avenue.
Source: Author

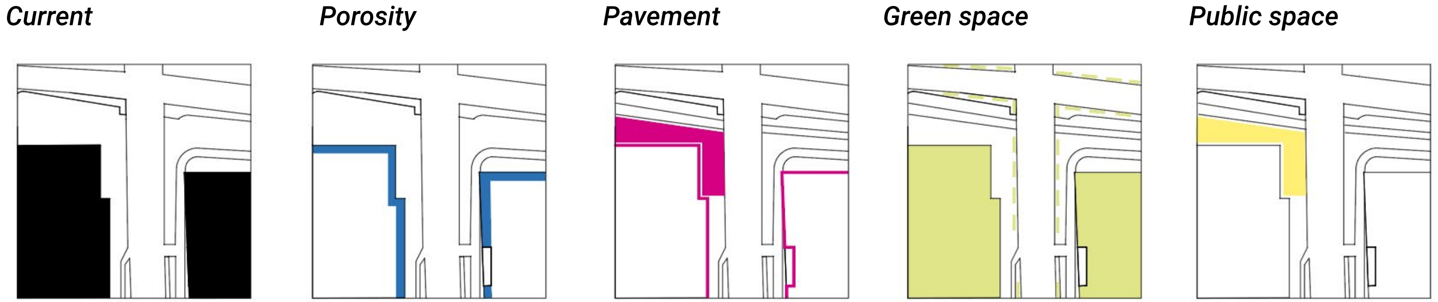


Fig. 7.3.4. Design proposals.
Source: Author

Design description

Building porosity
Partial overhead design of the ground floor of the building to promote air circulation while reducing the need for higher wind speed.

Green
Low-rise buildings or large mass platform buildings is more suitable than high-rise building to improve thermal comfort through roof greening.
Use a 4m green barrier to effectively isolate the pollution in the road from spreading to the sidewalk.Reconfigure the surrounding plants and adopt vegetation that is suitable for local climate conditions and has a strong ability to absorb pollutants.
Around the square, by increasing the coverage of green vegetation and providing shaded hard and soft spaces, it improves human thermal comfort in the urban environment

Public space
Place squares, parks and green spaces in the windward position where the wind prevails in summer, so that open public spaces have a good ventilation environment.
Set high SVF space or squares at road intersections to accelerate the transfer of airflow in different directions to promote airflow into leeward streets.

Fig. 7.3.5. Functional zoning map of Tianfu avenue.
Source: Author

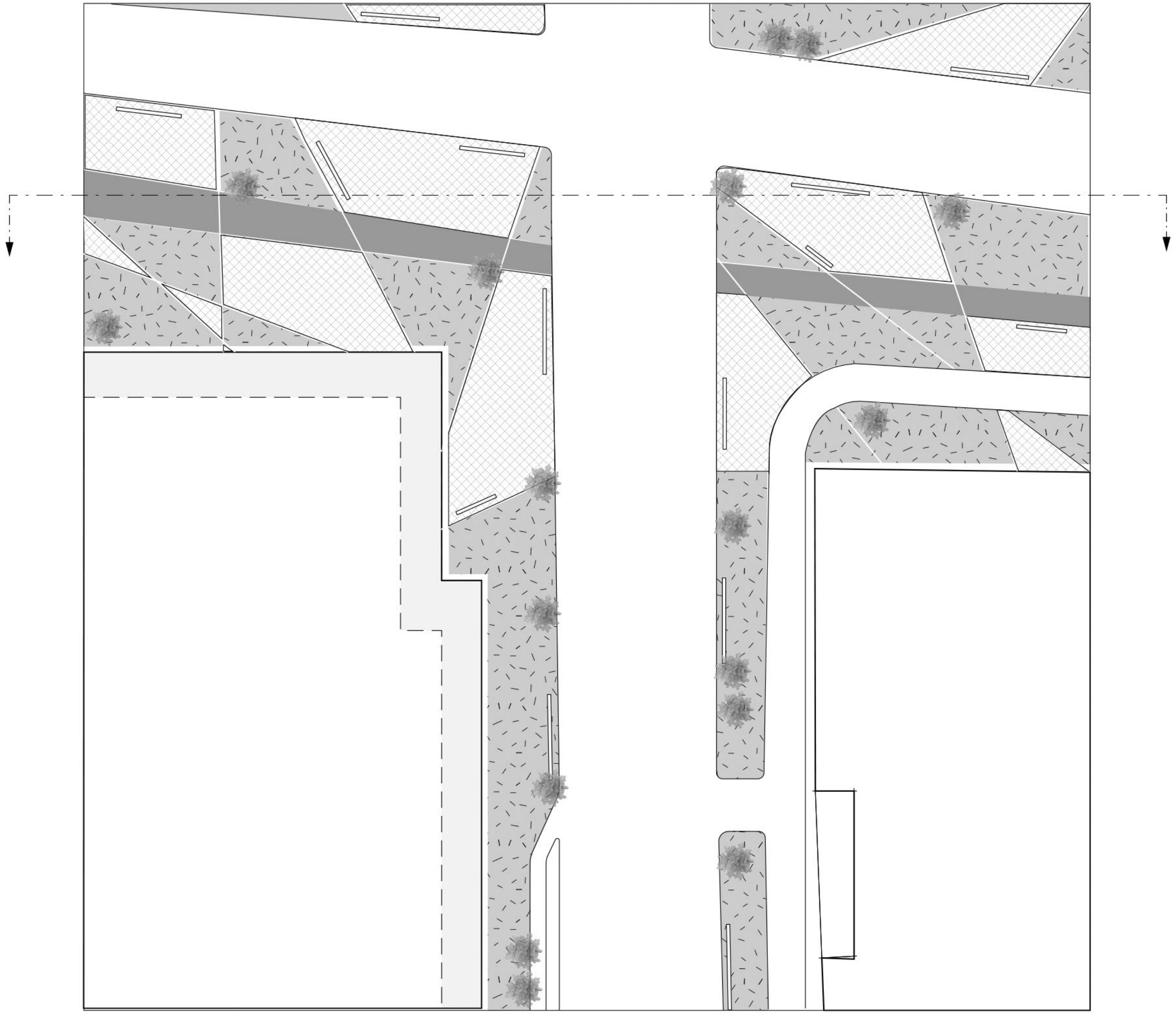


Fig. 7.3.6. Tianfu avenue design plan.
Source: Author

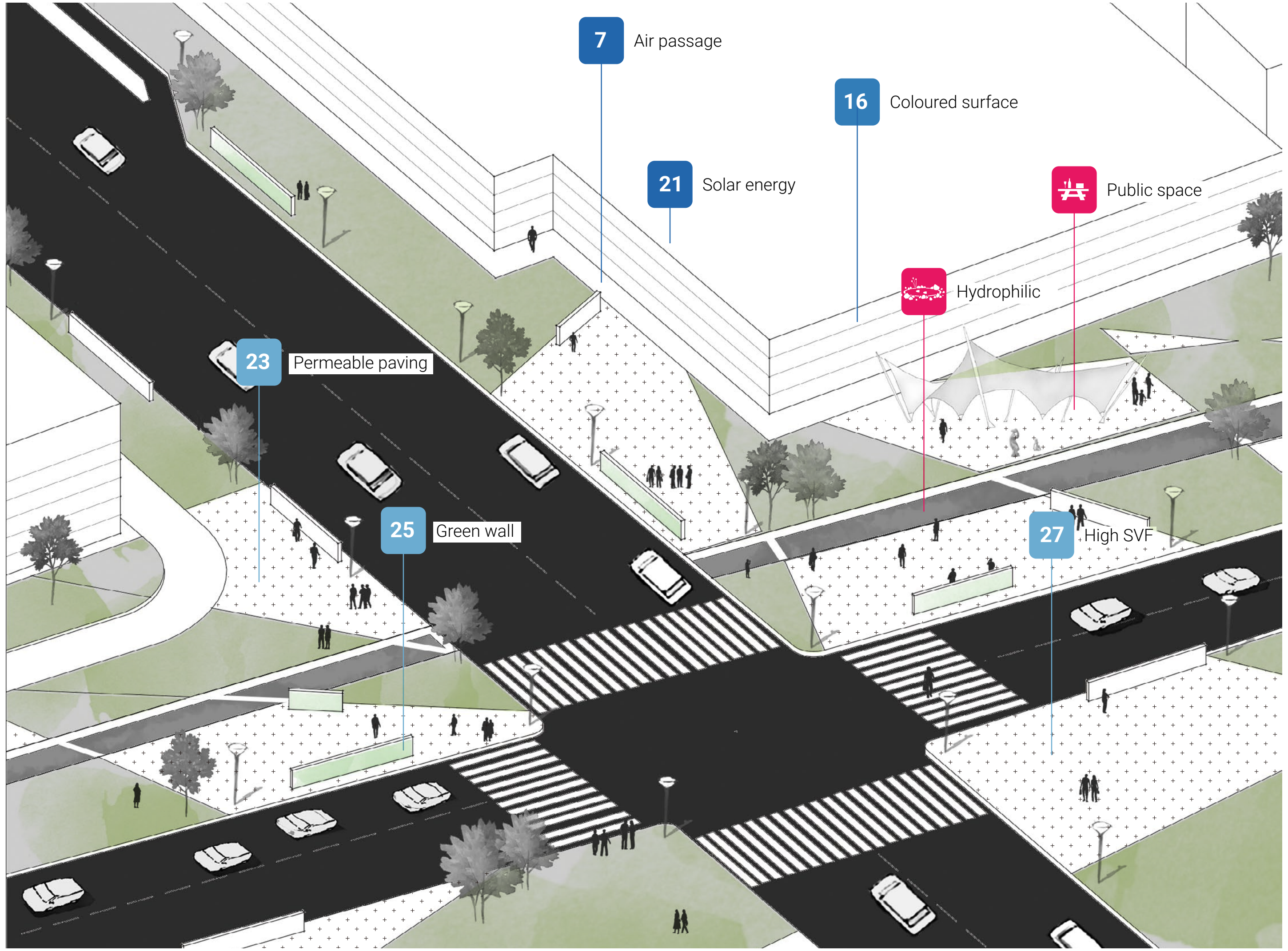


Fig. 7.3.7. The overview of design principles on Tianfu avenue.
Source: author

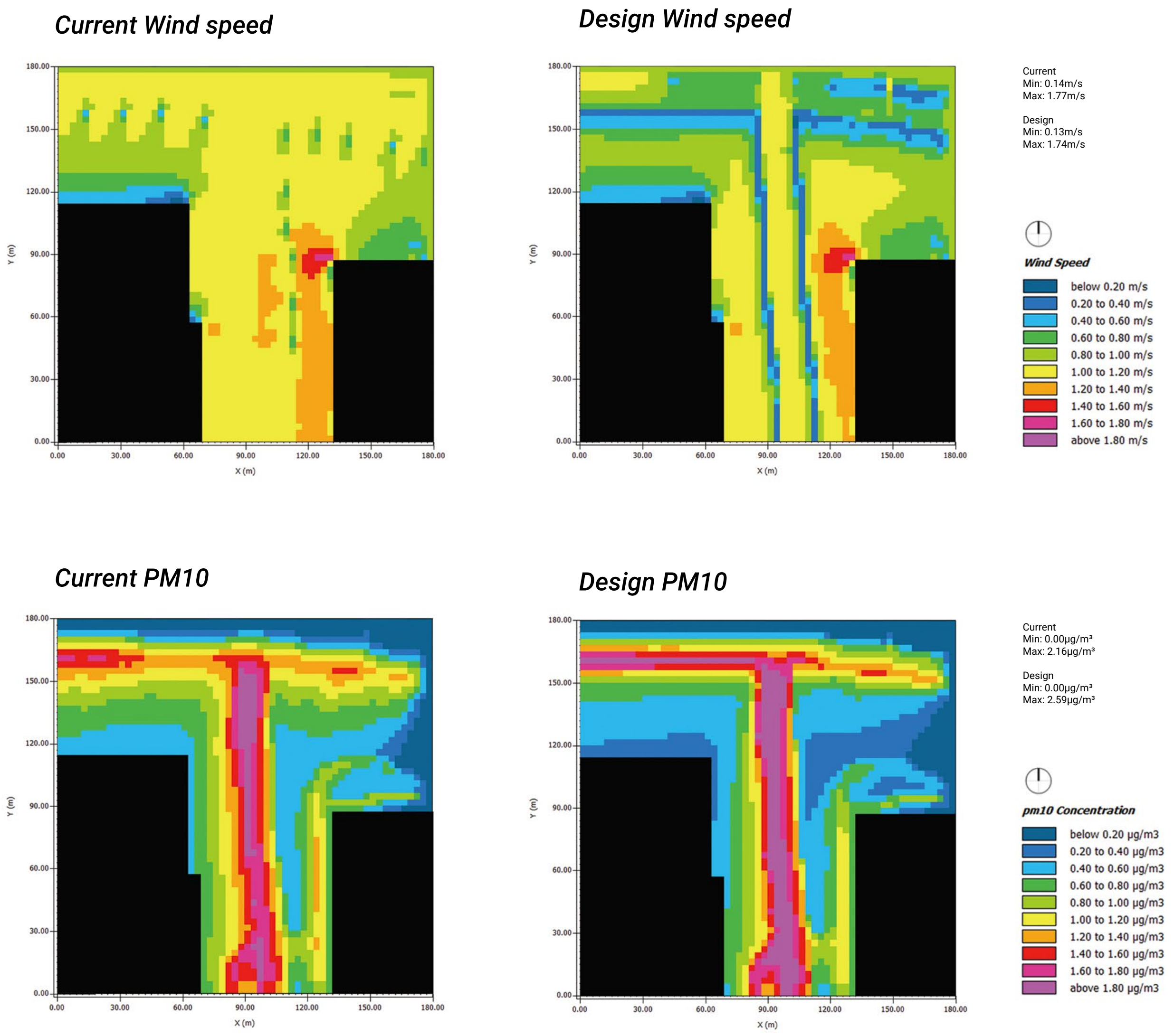


Fig. 7.3.8. Wind speed and PM10 concentration simulation results for current and design on Tianfu avenue.
Source: Author

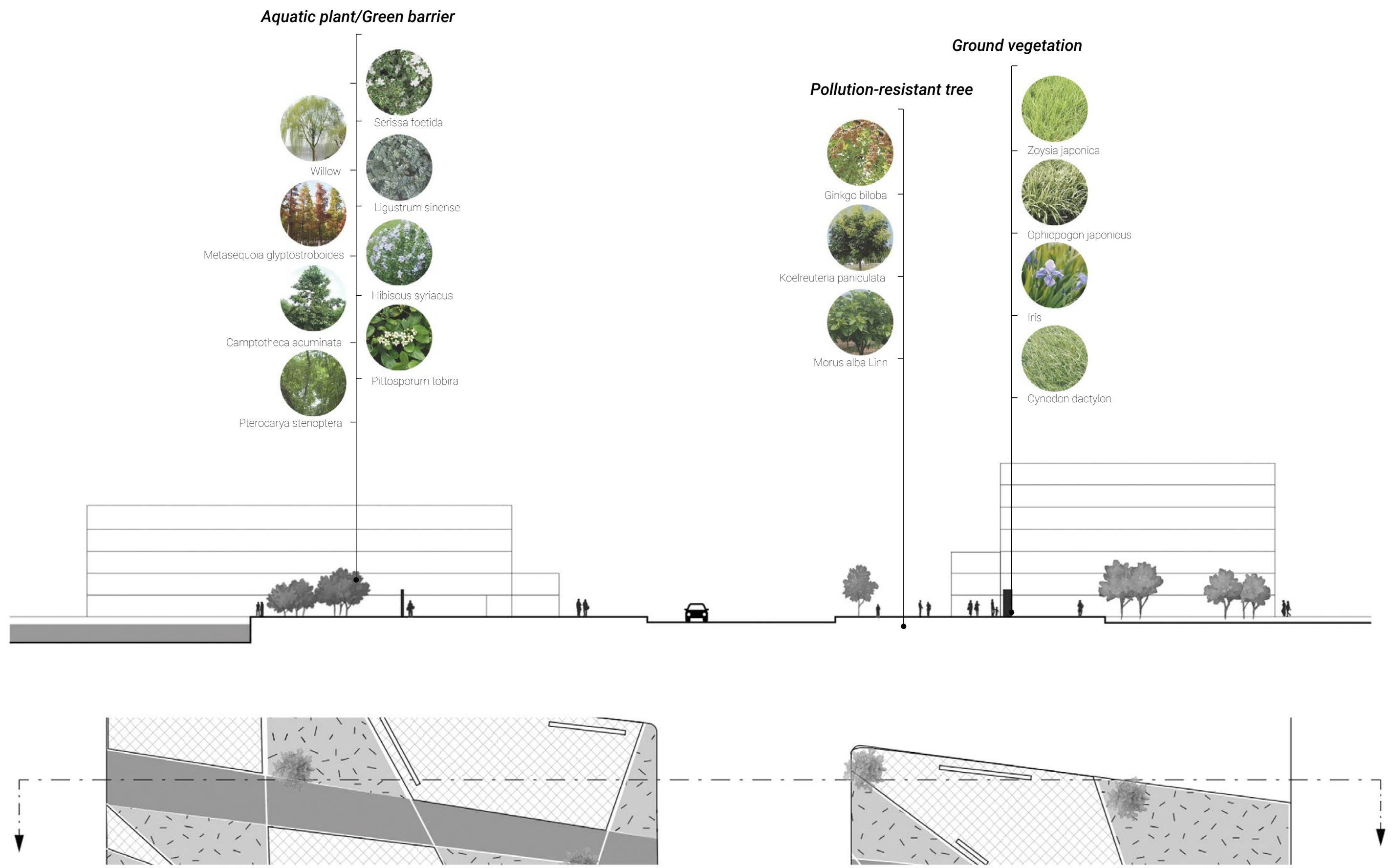


Fig. 7.3.9. Vegetation configuration profile of Tianfu avenue.
Source: Author

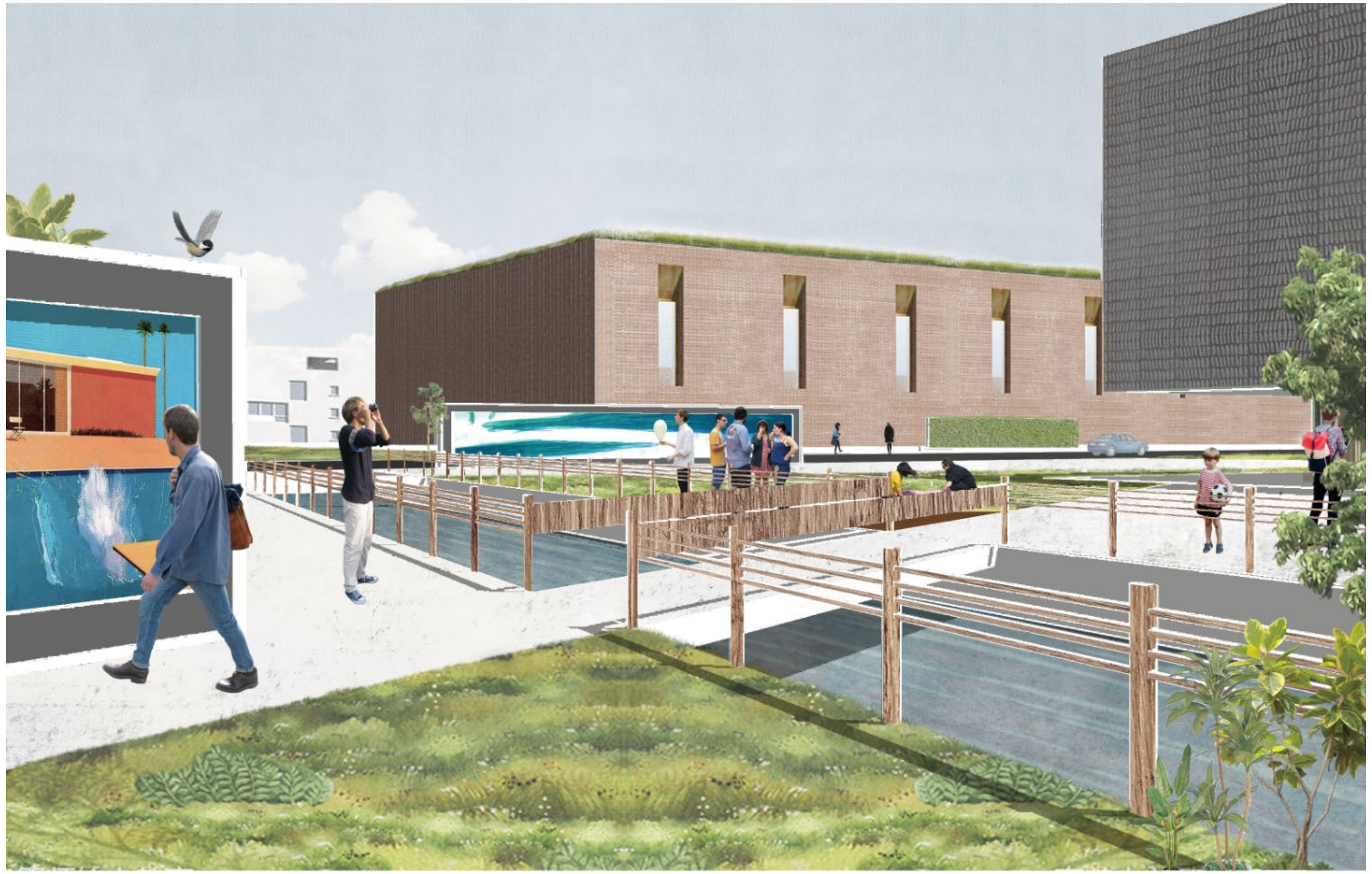


Fig. 7.3.10. Tianfu avenue.
Source: Author

8 Feasibility

Transferability

During the development of the design approach on the block and building scale, the specific characteristics of each site resulted in different principles used and very particular design interventions.

According to the maximization design approach, not only for density parameters (FSI or GSI) analyzing the possibility of transferability, other variables should also be considered, such as the physical characteristics of each area and the resultant microclimate environment, as well as the local socio-economic and public space conditions, the merging of these variables, are inherently very different, leading to a comprehensive consideration of local conditions. This forms the basis for determining the degree of transferability of a particular design approach to other areas of the city. In this respect, the creation of a second typology can facilitate the visualization of this possibility.

Therefore, the conclusion of the transferability is that the degree of transferability of the intervention is only partial. Some guidelines can be widely used. The typological research in this study is to aim to select the intervention area. The intervention measures for the site are combined through a variety of design principles, site characteristics determine the trade-off between measures.

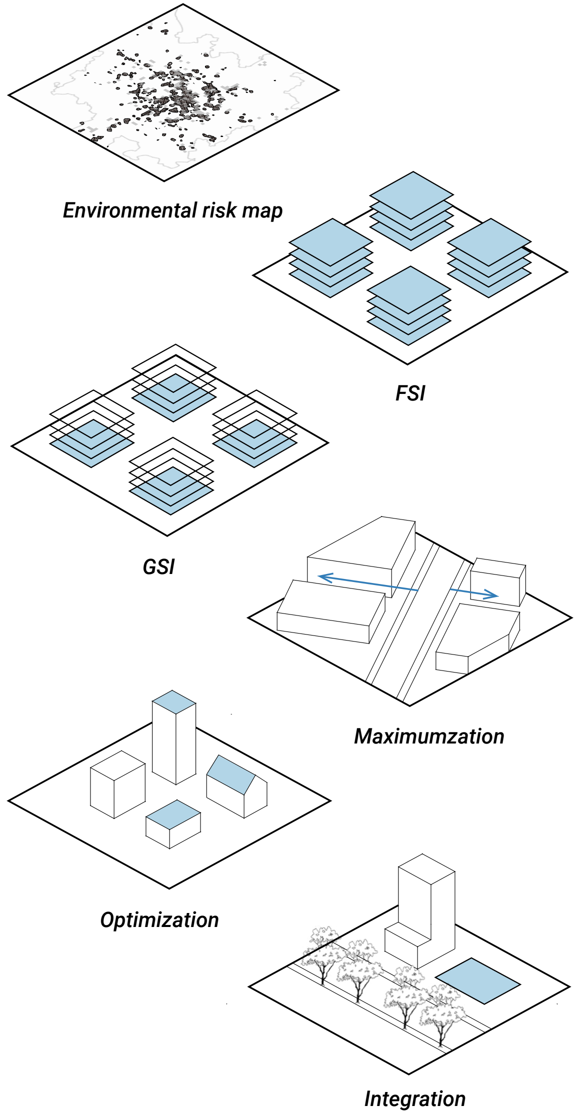


Fig. 8.1. Different variables that are suitable for determining the transferability of different design principles.
Source: Author.

Policy support

1 Adhere to the gas to define the form, combined with ecological green partition and the city's internal roads, rivers, parks to delineate urban ventilation corridors, the central city and new areas of the eastern city, a total of 8 primary ventilation corridors and 26 secondary ventilation corridors are planned, and strictly control the land, industry and building form within the scope of the ventilation corridors.
—— «Urban Master Plan of Chengdu(2016-2035)»

2. Carry out urban design for the whole area and key regions and important nodes, strengthen urban space control and optimize urban form.
—— «Urban Master Plan of Chengdu(2016-2035)»

3. The building colors in Chengdu are mainly guided by gray, warm yellow, and brick red.Specifically to "black-led building colors need to be used carefully, gray-led supplemented by colored embellishments, warm yellow-led high-rise office buildings, and warm yellow-led office buildings. The yellow dominated residential buildings reinforce the comfortable and pleasant feeling, while the brick-red dominated buildings reinforce the contemporary character and lively atmosphere". Delineate urban color zoning, strengthen control requirements, and exert the important role of urban color in shaping the city's appearance.
—— «Guidelines for Architectural Planning and Design in Chengdu (2013)»

4. Strengthening urban greening construction, combining urban development and industrial layout, and striving to raise the level of urban greening and enhance the environment's self-cleaning capacity. Ecological vegetation and landscapes will be created to curb the generation of dust.
—— «The Twelfth Five-Year Plan for the Prevention and Control of Air Pollution in Key Regions»

5. Greening the whole area, building "park cities", strengthening the ecological protection and restoration of ecological zones, greening ecological corridors, greening parks, greening roads, greening neighborhoods and three-dimensional greening.
—— «Urban Master Plan of Chengdu(2016-2035)»

6. Build an ecological system that connects urban and rural areas, effectively increasing wind speed and volume, diluting air pollution and reducing the heat island effect. Strictly protect existing green spaces in the central city.
—— «Action Plan for the Prevention and Control of Air Pollution in Chengdu (2014-2017)»

7. Encourage public participation in atmospheric governance, and actively carry out various forms of activities focusing on the prevention and control of respirable and fine particulate matter. Popularizing scientific knowledge of air pollution prevention and control, and continuously enhancing the public's ability to participate in environmental protection.
—— «The Twelfth Five-Year Plan for the Prevention and Control of Air Pollution in Key Regions»
—— «Action Plan for the Prevention and Control of Air Pollution in Chengdu (2014-2017)»

Collection of planning and policy support at different scales, mainly including the Chengdu Urban Master Plan, the Chengdu Air Pollution Prevention and Control Action Plan ((2014-2017), etc.For air pollution, in addition to source control such as motor vehicle traffic restrictions and bans, rectification of key industrial sources, and construction site restrictions, In terms of climate, national and provincial plans focus on the construction of eco-regions, while in Chengdu, the concept of wind-defining, combined with the optimization of spatial layout and greening of the whole area to improve the urban environment。 Planning recommendations based on mitigation and optimization of urban microclimates, based on existing policies and knowledge of existing policies, are presented and include the following.

City scale
Strengthen the protection of open space, control the intensity of land development, and optimize the layout of urban buildings.The construction of ventilation corridors.

Block scale
Control urban height and building layout according to local microclimate. Consider the impact on pollution when laying out urban greenery.

Building scale
The targeted optimization of the building form through building porosity to enhance ventilation. Avoid large-area demolition and construction, consider the distribution of pollutants to set building functions, reduce the impact of air pollution on human health, and encourage the public to participate in green roofs and facade greening.

Air pollution and urban microclimatic conditions directly affect the health of the public, the planning and design of the city of Chengdu in the past is more functional, aesthetic and other angles as the goal, ignoring the importance of urban microclimates and its influence on air pollution. Work on urban microclimate and urban form design is still in its infancy, and in addition to integrating key disciplines and technologies such as urban planning, climate, and information, there is a need to promote collaboration between government management, policy, and the public in order to be more effective.

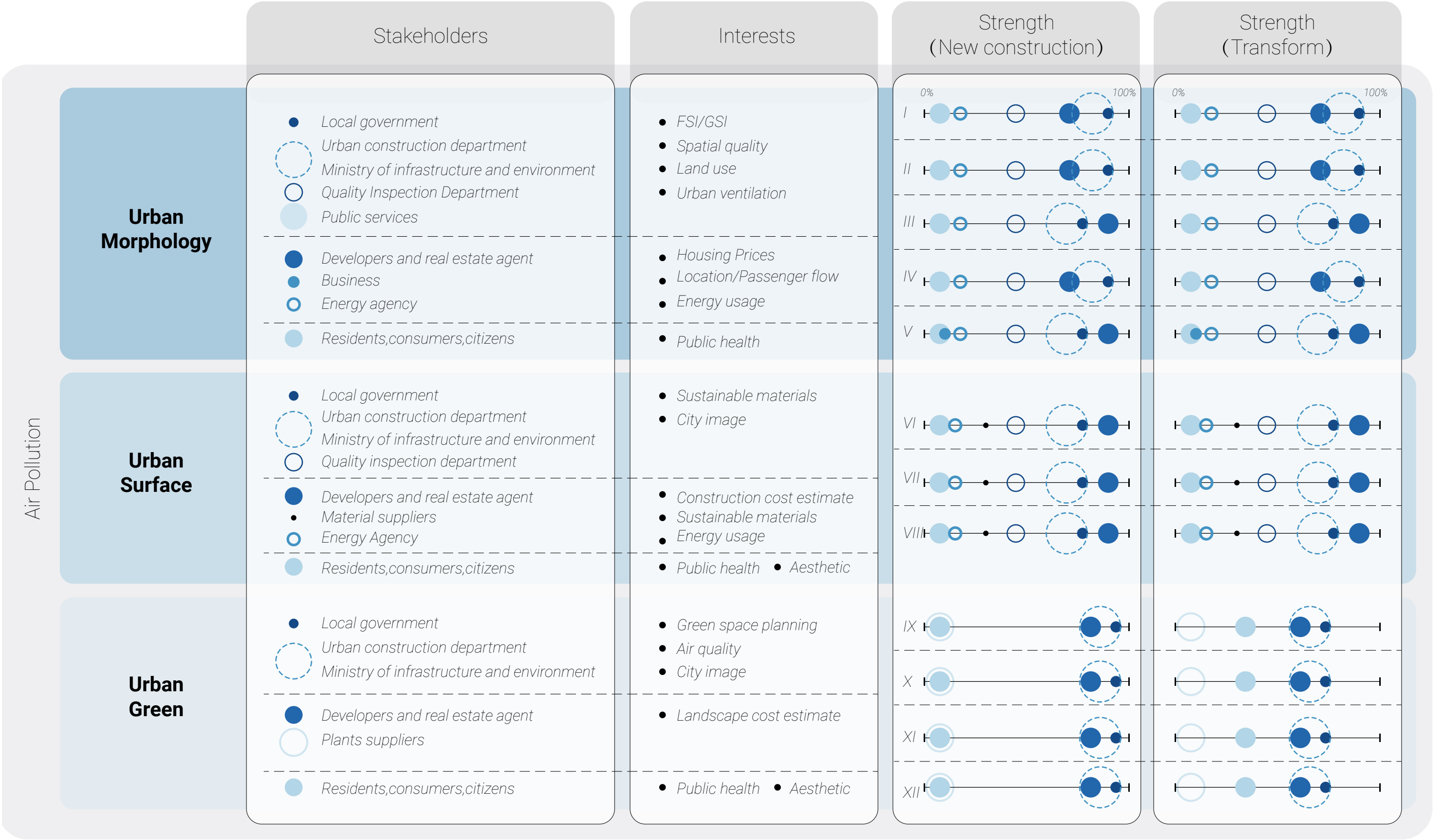


Fig. 8.2. Stakeholders analysis.
Source: Author

Stakeholders

The government, developers (real estate) and urban residents are the three main stakeholders of this project, including the Ministry of Urban Construction, the Ministry of Infrastructure and Environment, the Energy Agency and suppliers, etc(represented by different circles in the Fig.8.2). They have different importance at different levels of urban form. Through analysis, we know that in the newly built area, the urban form is mainly controlled by the government, and the planning and design are carried out under the conditions that meet the basic specifications such as its plot ratio, greening rate, and land use red line. Developers are driven by interests and use the location of the land, the flow of people and the stock of housing as the standard to obtain higher profits. Urban residents and consumers pay more attention to public health and the aesthetics of public spaces. In the transformation, the urban form is usually negotiated and funded by the local government, residents, and administrative organizations. Among them, the residents are more operable in terms of urban greening.

Financial considerations

Combined with the Chengdu Urban Master Plan (2012-2020) and related environmental function zoning. It is necessary to reasonably control the development intensity and improve the functional layout in urban development and community renovation, so as to form an urban spatial layout conducive to reducing air pollutants.

In terms of funding, Chengdu's relevant plans as well as pollution prevention programs are given in response, which can be divided into four ways: government-led capital compensation, financial share of urban construction, introduction of social capital and market-based fund raising. Provincial, municipal, district (city) and county governments and relevant departments have provided financial support for the construction of ventilation corridors in Chengdu and set up special funds for air pollution prevention and control. In terms of ecological greening, municipal finances have been increasing investment in the construction of ecological zones.There is an annual special fund for ecological construction, healthy greenways, and green infrastructure, which generally provides financial and factual guarantees. At the same time, it attracts large groups such as Baoli, Wanke and Huaqiaocity to participate in thematic construction such as land consolidation and ecological environment projects. In addition, a sound diversified investment mechanism has been established in community renovation, with the model of government and residents investing jointly in the early stages and residents raising their own funds to complete maintenance and renewal in the later stages. This range of funding modalities supports the implementation of projects to enhance the control of air pollution in vulnerable urban areas.

Projects time-lines

For the three types guidelines of urban morphology, urban surfaces and urban green, they have different priorities and application times. As far as reducing air pollution is concerned, the most effective approach is to increase building porosity, but this requires high capital investment and a long planning and implementation time (usually 3-5 years). For its implementability, developers and real estate companies have the most power, and it can be implemented better and faster in new areas. Long periods of planning and implementation between developers and government are required in built-up areas. The renovation of residential areas requires a much longer period of coordinated communication and financial preparation by the government, community organizations and residents.

Urban surfaces are the easiest and least expensive to implement, and unfortunately the impact on air pollution at the building scale of this project has not been effectively demonstrated. Further research is needed. In this case, measures that are beneficial for microclimates can be implemented, such as permeable pavements and highly reflective light-colored facades.

Urban greening is implemented over a short period of time with moderate investment, but is less efficient than porosity in terms of aerodynamic effects on reducing air pollution. Urban greening can start more easily at the Daye road and Tianfu avenue sites, with the creation of green walls and 4m green barriers and the replacement of vegetation. This can be done very quickly and efficiently, relying heavily on relevant sectors such as urban infrastructure and the environment. In the Nijiaqiao neighborhood greening needs to begin after building porosity is complete. And increase resident participation and achieve strategies such as green roofs and green spaces.

Projects time-lines

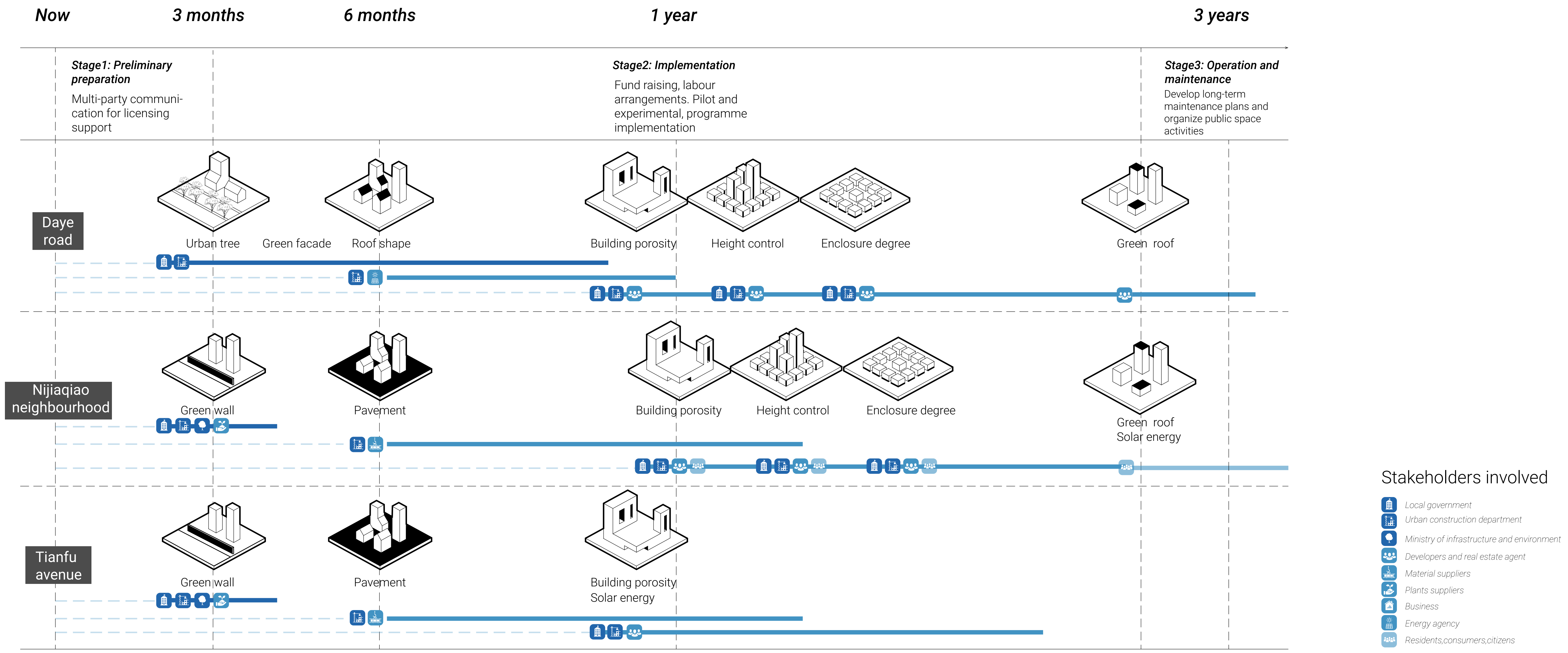


Fig. 8.3. Projects time-lines.
Source: Author

Conclusion

The population growth and the rapid expansion of the city have brought a series of environmental problems to Chengdu. According to the Chengdu Statistical Yearbook, the air quality standard days and AQI statistics of Chengdu in 2006-2015, the air quality of Chengdu after 2011 is remarkable. Declining, the number of days in which air quality reached Level 2 and above in 2013 was only 139 days, which seriously threatened the health of the public. In response to the negative impact of urban expansion, urban planners in Chengdu have focused on environmental protection in recent years. While controlling the development of urbanization, density and urban microclimate are closely related to urban air quality, while optimizing Chengdu's microclimate by regulating urban form is a complex multidisciplinary project with great potential. Therefore, the research question of the graduation project is: How to mitigate air pollution through urban microclimate design in Chengdu?
First of all, it is very important to understand the relationship between the urban built environment, urban microclimate and air pollution. Among them, the wind is a key factor affecting the dilution and diffusion of pollutants. At the city scale, the frontal area index, building height, and green space have become the main factors of urban wind. Chengdu is located in a basin with a large static wind area. In 2016, it had a still wind frequency of 40%. According to the frontal area index, its static wind areas are mainly located in the city centre and the southeast axis. Considering more that air pollution is harmful to expose human bodies, more areas of air pollution and crowd gathering are designated as vulnerable areas. Mainly located on the southern axis of Chengdu.

At the street-canyon scale, the porosity, enclosure degree and height of buildings are the main factors affecting the wind environment, in addition to urban trees. In the urban canyons with different densities, the formed urban microclimate has certain representativeness to some extent. For example, high-density areas are generally located in the centre of the city, and high-rise buildings hinder ventilation, forming a large number of wind shadow zones, using more high-reflection building facades, and high city temperatures. The slab type multi-storey residential area represented by site 2 also occupies a large proportion in Chengdu. This old-fashioned community usually has an external wall, which can isolate the pollution of external streets to a certain extent, but the pollution of internal roads is difficult to spread(when the wind direction is not parallel to the street). Finally, low-density buildings located in open areas are usually located in the suburbs of Chengdu, and buildings are not the main reason for affecting urban ventilation. Generally speaking, the higher the wind speed, the lower the pollutant concentration, and the urban temperature also affects the diffusion and dilution of pollutants by affecting or forming urban winds.

In this project, it is found that at the street-canyon scale, the impact of the building surface on air pollution is minimal, and the building porosity can effectively increase wind speed and reduce pollution. This principle can be applied in other places according to the specific site characteristics. In addition, it has been confirmed that a 4m green barrier can reduce the concentration of pollutants in pedestrian areas by blocking air pollutants in the street.
At the same time, this project uses the maximisation method to integrate microclimate design into the urban design process. The first step is to select the principle that may have the greatest impact on air pollution according to the site characteristics. The second step of optimization is mainly aimed at the microclimate environment of the site, and the third step is to optimize the public space according to the needs of the people. Although the impact of the design criteria used on air pollution cannot be confirmed one by one, the ENVI-met simulations have shown that the overall plan is effective in mitigating air pollution.

9. Reflection

The air pollution is a problem that must be considered in healthy city planning and construction. It threatens the health of citizens. As a central city in southwestern China, Chengdu has been under tremendous pressure in air pollution in recent years, so that its image of livable cities is declining. This graduation project has the aim of understanding the relation between air pollution and the built environment through urban microclimate mechanism. To this extent, the main objective is that of investigating how to mitigate air pollution through microclimate design in the city of Chengdu in order to provide a better urban environment.

The relationship between the graduation lab (UM) and the graduation project

The project requires a morphological method related to the urban microclimate, and a method based on research and design is required. Meanwhile, the urban microclimate (wind and heat) and air pollution can be considered as a part of urban metabolism. And it can be used to shape the urban environment in a more sustainable way. In urban metabolism, creating an effective urban microclimate environment and reflecting the impact of the urban built environment on the urban microclimate and air pollution is a challenge. To this extent, the graduation lab gives the necessary tools, approaches needed and techniques to carry out a thorough project.

In the field of urbanization, urban microclimate is one of the important components of the urban ecological environment. Together with air pollution, it affects many city performance indicators such as livability and sustainability. At present, scholars in China have less research on microclimate strategies that can be used to guide urban planning. Microscale often lacks the interaction with large- scale regional environment in a large- scale study. To this extent, the graduation project can contribute to the field of urbanism by providing more physical and cross-scale interventions to mitigate air pollution towards urban microclimate design.

The relationship between research and design

Air pollution can be discussed through different disciplines and different perspectives. It is very complicated to use microclimate as an intermediate mechanism to connect air pollution with the urbanization field.

The main research can be divided into two parts. The first part focuses on the relationship between the three systems of air pollution, microclimate and urbanization. The knowledge gained can define the theoretical and analytical framework of the project. At the same time, for more consideration of ethic, this thesis uses the risk mapping method in environmental risk management (which includes population vulnerable map) and using areas of population exposure and the most polluted areas as priorities. Then density is selected as the main indicator of urban morphology to find the intervention sites and discover comprehensive solutions.

The second part of the research is helpful to discuss the joint reaction of the wind and heat environment as well as air pollution mitigation plans. This section focuses more on discovering design principles which cope with air pollution. This stage from research to design is not linear and needs to make decisions based on site characteristics, so the relationship between research and design can be seen as continuous parallelism.

The role of density

As mentioned in the development of theoretical and analytical frameworks, the parameters of density and morphology are highly correlated with the urban microclimate and are indirectly related to the spread of air pollution. This phenomenon has led to the emergence of a typology, which helps to define different types of density and different corresponding microclimates. For this type of generation, two main indicators FSI and GSI are selected.

First of all, for the built area, it is not necessary to change the physical density for every intervention. The project is more concerned about the impact of different types of the physical environment and the existence of microclimate phenomena on air pollution.

In short, Density typology in this article has not played a real role in relation to air pollution. Instead, it explores different physical built-up characteristics and microclimate types through density. For instance, lower FSI may increase the potential for direct solar irradiation, which related to the ventilation(heat wall effect) and the urban thermal environment.

Limitations of Transferability

When discussing the possibilities to generalize the results of research, first, The design interventions have mostly been based on maximum air pollution mitigation principles. Social factors will be integrated to shape the spatial interventions after applying the principles, these factors sometimes play a greater role in defining the design intervention.

Second, as mentioned earlier, density typology is to initially explore urban physical morphology and microclimate typology, and due to the complexity of urban microclimate systems, revealing that urban microclimate patterns that can reduce air pollution still require a lot of simulation and measured work.

Third, more factors need to be taken into account. For instance, beyond the diffusion and dilution of air pollution, it is also worthwhile to consider the implications of density regarding emissions of air pollution.

Therefore, the conclusion of the transferability is that the degree of transferability of the intervention is only partial. Some guidelines can be widely used. The typological research in this study is aim to select the intervention area. The intervention measures for the site are combined through a variety of design principles, as the result of the conflict or coupling effects between different principles, site characteristics determine the trade-off between measures.

Methodology

Throughout the methodology, there are a large number of references on the study of wind and heat separately with urban morphology, but it is difficult to draw more accurate conclusions due to its complexity, but it still provides the possibility to study wind and heat coupling optimization measures on air pollution mitigation. On the one hand, the analysis matrix are from the literature review. On the other hand, in the environmental risk assessment method, the population vulnerability map reflects the distribution of the population that is more likely to be affected when exposed to pollution. Contributed to the consideration of social justice. Finally, considering the feasibility aspects of the intervention, stakeholder analysis will help identify investors, decision-makers, or implementers involved in urban planning or urban design. Help predict the extent to which the project can be implemented. Therefore, through the above-mentioned multiple methods, the three systems of urban form, urban microclimate, and air pollution can be interconnected. In the design stage, the main concern is that air pollution may lead to the limitation of the design plan. In the design stage, design by research and research by design become the biggest challenges, and the main focus on air pollution and the complexity of research may lead to design limitations. In this part, the best plan will be selected using the method of maximization and comparison combined with the site characteristics.

Societal and Scientifical Relevance

The air pollution is a problem that must be considered in healthy city planning and construction. Its impact on the city is mainly reflected in the comfort of public space, urban air quality and building energy conservation. Air pollutant accumulation caused by static wind frequency will induce respiratory diseases. It limits outdoor activities and causes great harm to people's health. Excessive urban climate due to dense super-tall buildings can also cause damage to cars and pedestrians. As a central city in southwestern China,

Chengdu has been under tremendous pressure in air pollution in recent years, so that its image of livable cities is declining. This project would bring a better urban environment to Chengdu by improving in combination with microclimate and air quality.
The urban microclimate is one of the important components of the urban ecological environment, which directly affects many performance indicators and livability of the city, and is closely coupled with other environmental factors (such as thermal environment, pollutants, etc.). At present, scholars in China have less research on microclimate strategies that can be used to guide urban planning. Micro scale often eliminates the interaction with large-scale regional environment in a large-scale study (Mingyuan, 2018). To this extent, the graduation project can contribute to the field of urbanism by providing more physical and cross-scale interventions to mitigate air pollution towards urban microclimate design.

Ethical considerations

In designing interventions, while reducing pollution, it also brings about social and spatial externalities that are worthy of reflection. By changing the external space of the city, new functions and values can be added to the space, providing citizens with a new way of life . In addition, related urban programs may change the structural order between social neighborhoods and bring higher population exchanges and economic income to the region. In short, when addressing air pollution by creating a better urban microclimate, the impact of changing and modifying the urban form is not only reflected in one aspect, but a comprehensive consideration of society and space.

Limitation

1. Due to the lack of data, some easier methods need to be adopted. For example, when calculating the frontal area index (FAI), since the data of local wind conditions are missed, consequently, this thesis uses the method of agglomerating adjacent buildings (aggregation distance is 1m), to relatively simplify the calculation process. Another example is that in the population vulnerability map, Baidu heat map is used to represent the exposed areas of the population. It does not take into account that the vulnerable population (old and young) use mobile phones less frequently than young people, so there are certain limitations.
2. When some parameters from urban form, microclimate and air pollution are extracted, they may not be comprehensive enough. For instance, in microclimate research, wind and thermal environment are only a part of it, there are other factors that have important effects on air pollution such as humidity and seasonal changes. On the other hand, air pollution is only one of the factors that need to be studied when designing urban spaces.
3. In addition to the above limitations, the simulation limitations (site size, for the large-scale site, huge simulation time may be spent) and reliability of the Envi-Met program still need to be considered. When testing for conflicts or couplings between interventions, the final decision depends on the simulation results of the program. But due to the unfeasible of simulating and analyzing on an urban scale, it may not be possible to pass simulations to ensure continuity and mutual feedback at various scales after defining the scope and scale of the study. When the street canyon model is built, the cube is often used as a model, the actual street canyon form is difficult to restore; therefore, its reliability is influenced by simplification of the model and parameters.

Further study

Air pollution often associates with not only urbanization and climate factors, but also many other socio-economic factors, such as population growth, economic development, traffic density, and commuting transition. In future studies, beside the aforementioned research area, researchers could also continue to find out the determinants of patterns of air pollution and microclimate in terms of expansion of land can be also considered. In addition, urban design lacks the consideration of microclimate, especially temperature and ventilation. There is little information that can be queried during the evaluation stage of the relevant urban design. However, monitoring the impact of existing projects on the urban microclimate will play a great role in design decisions. Therefore, more practice and monitoring are necessary.
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10. Bibliography

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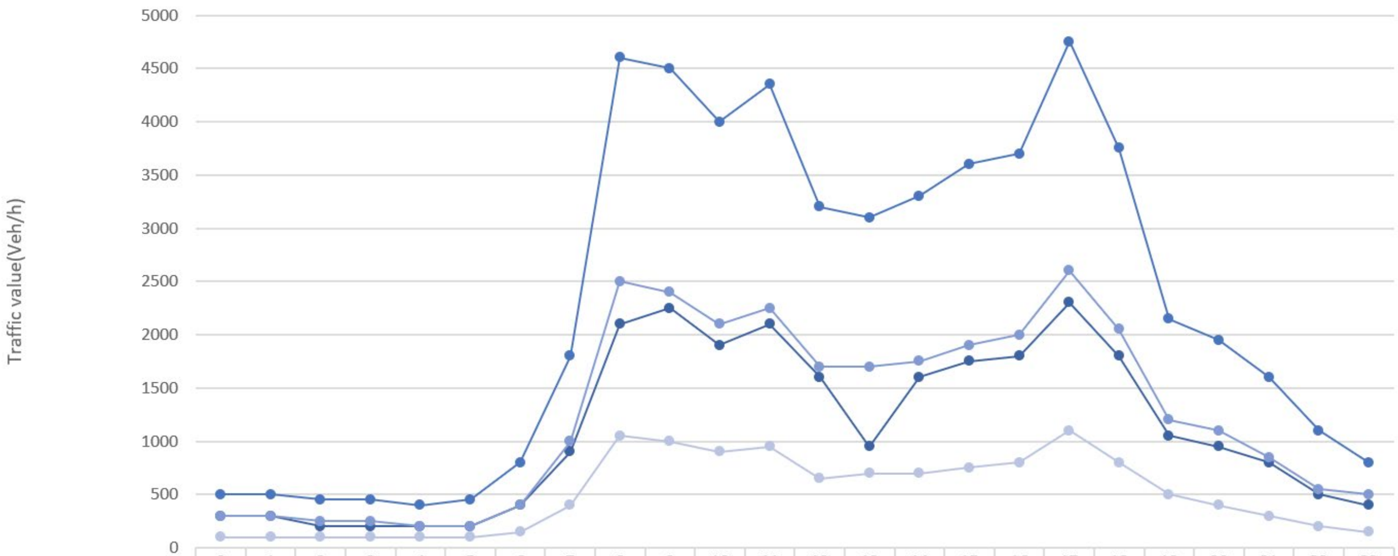
11. Appendix

The daily traffic flow of various road types



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
High way	300	300	200	200	200	200	400	900	2100	2250	1900	2100	1600	950	1600	1750	1800	2300	1800	1050	950	800	500	400
Main road	500	500	450	450	400	450	800	1800	4600	4500	4000	4350	3200	3100	3300	3600	3700	4750	3750	2150	1950	1600	1100	800
Secondary road	300	300	250	250	200	200	400	1000	2500	2400	2100	2250	1700	1700	1750	1900	2000	2600	2050	1200	1100	850	550	500
Branch road	100	100	100	100	100	100	150	400	1050	1000	900	950	650	700	700	750	800	1100	800	500	400	300	200	150

Period (h)

High way — Main road — Secondary road — Branch road

Source: Zhou Z H, Deng Y, Wu K Y,et al. 2018. On-road mobile source emission inventory and spatial distribution characteristics in Chengdu[J]. Acta Scientiae Circumstantiae, 38(1):79-91

Numerical simulation of specific input parameters in ENVI-met

Category	Parameter definition	Value
Meteorological	Wind speed (10m)	1.2m/s
	Wind direction	NNE
	Roughness length	0.010
	Temperature (℃ min-max)	26-29
	Humidity (% 2m min-max)	76-86
Simulation settings (Meteorological)	Start date	21.06.2016
	Start time	00.00
	Total simulation time (h)	24
	Boundary condition	Simple forcing
Pollutants source	Pollutants	PM10
	Source geometry	Line
	Height	0.15m
	Type of street segment	Inner-urban road
Daily traffic value (Veh/24h)	High way (6 lanes)	26550
	Main road (8 lanes)	55800
	Secondary road (4 lanes)	30050
	Branch road (2 lanes)	12100
Simulation settings (Pollutants)	Start date	21.06.2016
	Start time	00.00
	Total simulation time (h)	24

The table lists some parameters that need to be input in the ENVI-met simulation file, mainly including basic settings, meteorological parameters, pollution sources etc.
The basic meteorological data adopts the weather monitoring report of Chengdu Shuangliu International Airport on June 21, 2016
The traffic flow data of road-mobile pollution sources come from the monitoring points of the central urban intelligent transportation system constructed by the Chengdu Traffic Management Department in 2016, covering part of the roads such as the Second Ring Road and the Third Ring Road. Synchronous collection of road traffic was conducted also through manual research, and a total of more than 350 different types of roads were collected.
The remaining parameters keep the system default values, and the model adopts the system's default open boundary conditions.

Source: Zhou Z H, Deng Y, Wu K Y,et al. 2018. On-road mobile source emission inventory and spatial distribution characteristics in Chengdu[J]. Acta Scientiae Circumstantiae, 38(1):79-91. https://zh.weatherspark.com/

Recommended table for roof greening tree species with strong ability to degrade pollutant

Category	Particulates	NOx	SO_2
Arbor	Euonymus hamilionianus, Photinia serrulata, Trachycarpus fortunei, Gingo biloba, Ficus carica, Prunus Cerasifera Ehrh.cv.Atropurpurea Jacq.	Bauhinia blakeana	Osmanthus fragrans, Podocarpus macrophyllus, Magnolia denudata, Citrus maxima, Euonymus hamiltonianus, Hibiscus mutabilis, Photinia serrulata, Trachycarpus fortunei, Phoenix canariensis, Chrysalidocarpus lutescens.
Shrub	Viburnum Odoratis, Pittosporum tobira, Hibiscus syriacus, Euonymus japonicus, Buxus sempervirens, Syringa pubescens, Fatsia japonica, Berberis thumbergii cv. atropurpurea	Excoecaria cochinchinensis, Pittosporum tobira, Hibiscus syriacus, Euonymus japonicus, Lagerstroemia indica.	Viburnum Odoratis, Ilex cornuta, Chaenomeles speciosa, Camellia japonica, Excoecaria cochinchinensis, Pittospporum tobira, Ligustrum quihoui, Rhododendron indicum, Gardenia jasminoides, Michelia figo, Hibiscus syriacus, Euonymus japonicus, Buxus microphylla

Source: Li Zhengsheng, Urban garden green space planning and design[M]; China Construction Industry Press, 2006