Piloting Nature-based Urban Cooling Solutions for Urban Regeneration and New Town Development in Guangzhou, China

BUILDING A COOLER GUANGZHOU

Guangzhou YongQingFang Pilot and China-Singapore Guangzhou Knowledge City

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Energy Sector Management Assistance Program

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Citation
Please cite the report as follows: World Bank. 2022. Piloting Nature-based Urban Cooling Solutions for Urban Regeneration and New Town Development in Guangzhou, China. Washington, DC: World Bank.

Acknowledgments
This technical report was coordinated by a World Bank Group team led by Xueman Wang. Research was conducted by Guangzhou Urban Planning & Design Survey Research Institute, Guangzhou Urban Planning Association. Technical support was jointly provided by Guangzhou Climate and Agrometeorology Center, Sun Yat-Sen University, South China University of Technology. Valuable comments were received from Serge Salat, Kurt Shickman and Xiang Xu.

Cover/back cover photos: Guangzhou Municipal Planning and Natural Resources Bureau.
Design: Ultra Designs, Inc.

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Background

Global Climate Change

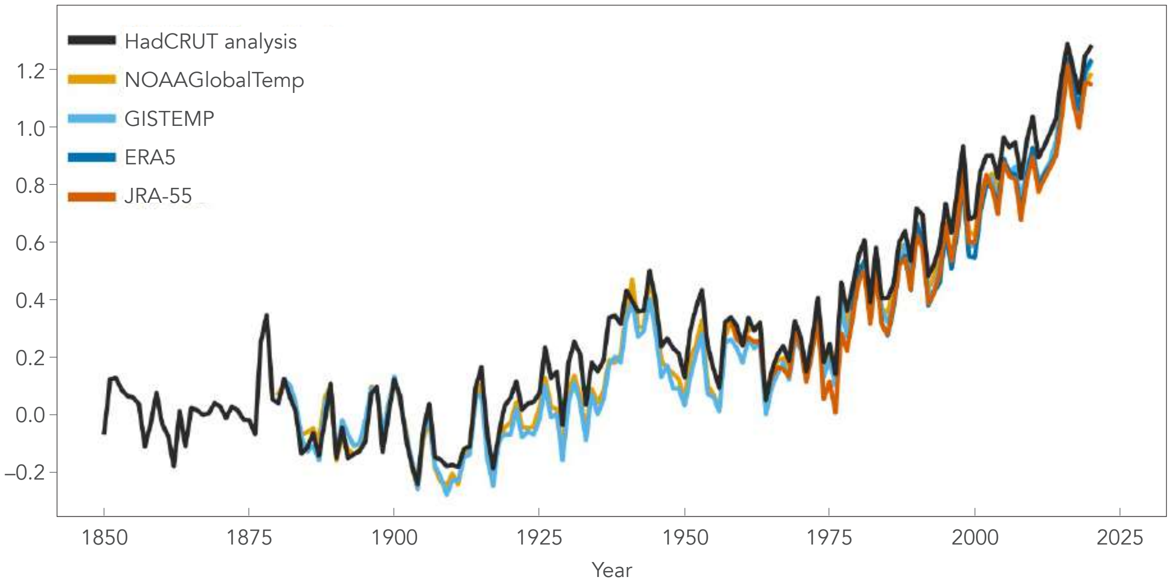
Climate change poses a profound threat to the survival and development of humankind, presenting myriad challenges that confront the entire globe. Achieving sustainable development and mitigating climate change are urgent, long-term tasks that necessitate international collaboration

Global climate change is accelerating. The past six years have been the six warmest years on record. 2020 was one of the warmest years with an average global temperature 1.2±0.1 °C above the pre-industrial (1850-1900) level. (WMO, 2021)

Global climate change has become a direct, major threat to mankind. In the past 20 years, over 475,000 people lost their lives as a direct result of more than 11,000 extreme weather events globally. Economic losses amounted to approx. US$ 2.56 trillion (in purchasing power parities) (Eckstein, 2020).

According to IPCC's prediction, global temperature is expected to reach or exceed 1.5°C of warming, averaged over the next 20 years, (IPCC,2021). A persistent increase in average global temperature by 0.04°C per year, in the absence of mitigation policies, will reduce global real GDP per capita by more than 7 percent by 2100 (Kahn, 2019) .

Figure 1 // **GLOBAL ANNUAL MEAN TEMPERATURE DIFFERENCE FROM PRE-INDUSTRIAL CONDITIONS (1850–1900) FOR FIVE GLOBAL TEMPERATURE DATA SETS.**



source: WMO, State of the Global Climate 2020

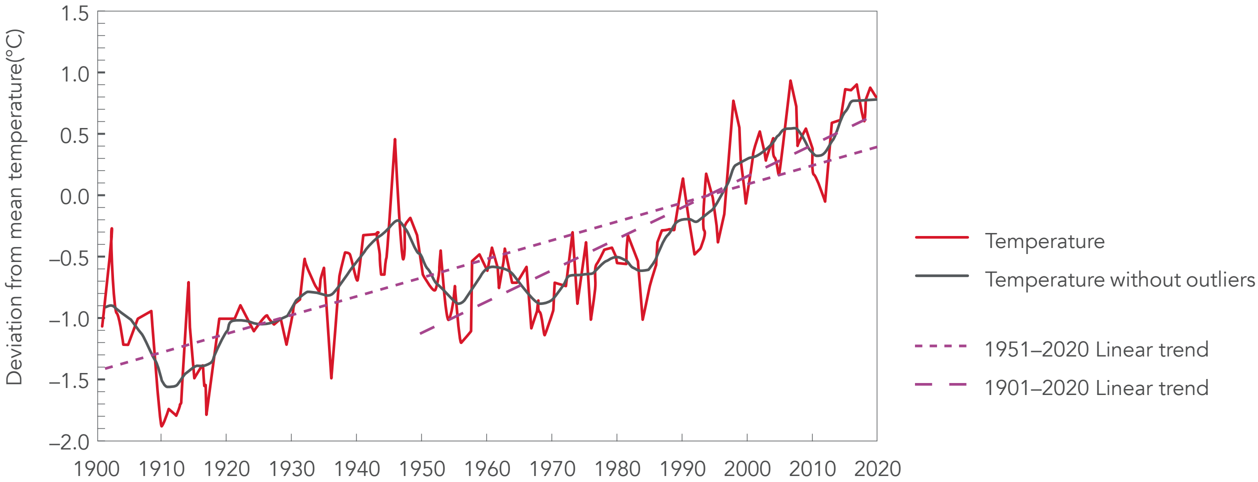
Climate change in China

China is particularly sensitive to climate change. Between 1951 and 2020, the average temperature in China rose 0.26°C every 10 years. (China Meteorological Administration, 2021). This warming rate is significantly higher than the global average during the same period. Between 1998 and 2017, extreme weather events caused the deaths of 25,000 people in China, resulting in 730 billion USD in economic losses (Global science, 2019).

The projected temperature increase in China due to climate change is expected to be above the global average. The highest emission scenario projects a national increase of 2.5°C by the 2050s and 5.2°C by the 2090s. (WB, 2021)

According to the research from China National Climate Center, by approximately 2025, at least 50% of the summer will bring sustained periods of high temperatures and heat waves. Under the worst-case scenario, the frequency of high temperature and heat wave events in China will be 5 times higher than the current rate by the end of the century (CDMFUND, 2018) .

Figure 2 // **ANNUAL AVERAGE TEMPERATURE ANOMALIES IN CHINA, 1901–2020.**



Source: China Meteorological Climate Change Centre 2021

At the UN General Assembly in September 2020, China pledged to scale up its Intended Nationally Determined Contributions by adopting more vigorous policies and measures. China also aims to have its CO2 emissions **peak before 2030 and achieve carbon neutrality before 2060**. This will drive China's economy and society to achieve profound systemic changes.

Overview and climate in Guangzhou

Guangzhou is the capital of Guangdong Province, China. It is the third largest city in China with an area of 7434km^2. In 2020, Guangzhou reached a GDP of over 2500 billion RMB with a population of over 18 million people.

Guangzhou has a subtropical monsoon climate — hot and rainy with a long summer and a short winter. In the summer, southeast winds are prevalent, while in winter, northerly winds are more common. With high temperature and humidity, and frequently calm wind, only 21.9% of the year is considered "comfortable" by measurement of the *discomfort index,* also known as *Temperature-Humidity Index* (Thom,1959).

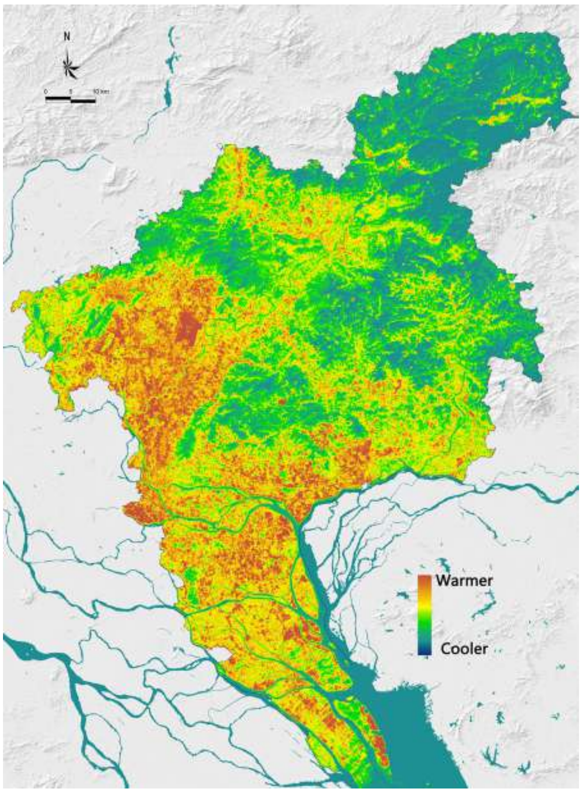
Due to the conversion of natural green space to buildings and roads, a high density of construction, and a significant amount of anthropogenic heat, the central built-up areas of Guangzhou have formed a distinct urban heat island.

This intensifying heat island effect, alongside global warming, has led to significant change in Guangzhou's climate. Since the early 1990s, the annual average temperature has increased by approximately 1.4°. The magnitude of the city's urban heat island has increased by about 1°, contributing to more than 70% of the warming. Additionally, the annual average wind speed in Guangzhou (excluding Conghua district) fell by approximately 30% over the past 20 years.

An urban heat map was produced using surface temperature data from Landsat 8 thermal infrared images. The map demonstrates the gradual expansion of the urban heat island from old town to the north, east, and south surrounding areas, where urbanization and development are accelerating.

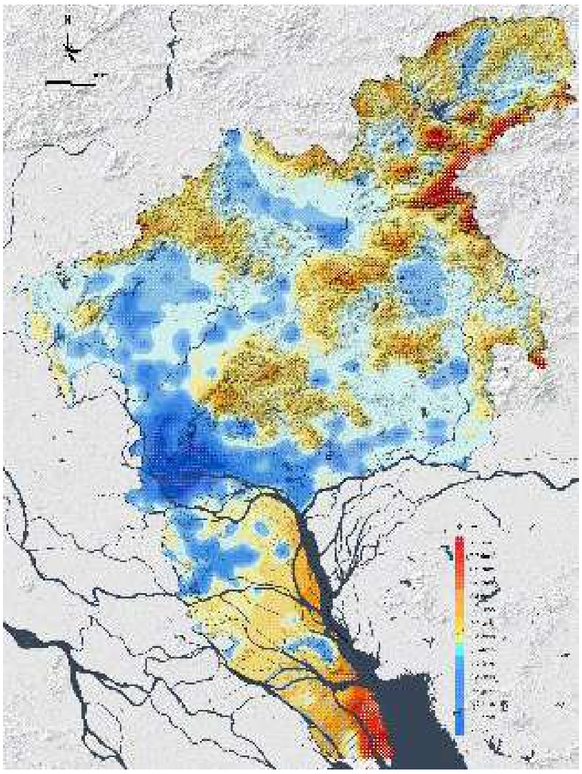
Wind dynamic potential was studied using Weather Research and Forecasting (WRF) model simulation. The model clearly depicts the central built-up area as an effective blocker of wind speed where calm and small winds are prevalent. Winds tend to be stronger in the northern mountainous and southern coastal areas.

Figure 3 // GUANGZHOU THERMAL IMAGERY



Data source: Landsat thermal data, 2021

Figure 4 // DISTRIBUTION OF WIND VELOCITY (WEATHER RESEARCH AND FORECASTING RESULT)



Source: Guangzhou Urban Planning & Design Survey Research Institute

Guangzhou's history

Founded between the Qin and Han dynasties, Guangzhou has seen more than 2,230 years of history. Half of its landscape is covered by green mountains, and all six of its rivers lead to the ocean, providing an advantageous location with abundant natural resources.

Listed as a National Famous Historical and Cultural City, Guangzhou boasts a great number of historical sites and an intangible cultural heritage. The Cantonese opera, Cantonese cuisine, and Guangzhou embroidery enjoy worldwide recognition.

Commerce and trade in Guangzhou have always thrived. It has been hailed as a commercial capital for a millennium. From the prosperous maritime trade during the Tang and Song dynasties, to the Canton System during the Ming and Qing dynasties, Guangzhou has been the longest serving Chinese international trade gateway.

After the reform and opening of China, Guangzhou developed a strong export-oriented economy, taking advantage of its geographic location adjacent to Hong Kong and Macau. From 1978 to present, Guangzhou's population has more than doubled, with GDP increasing by nearly 140 times and urbanization increasing from 45% to 87%.

Traditional wisdom for climate adaptation in urban planning

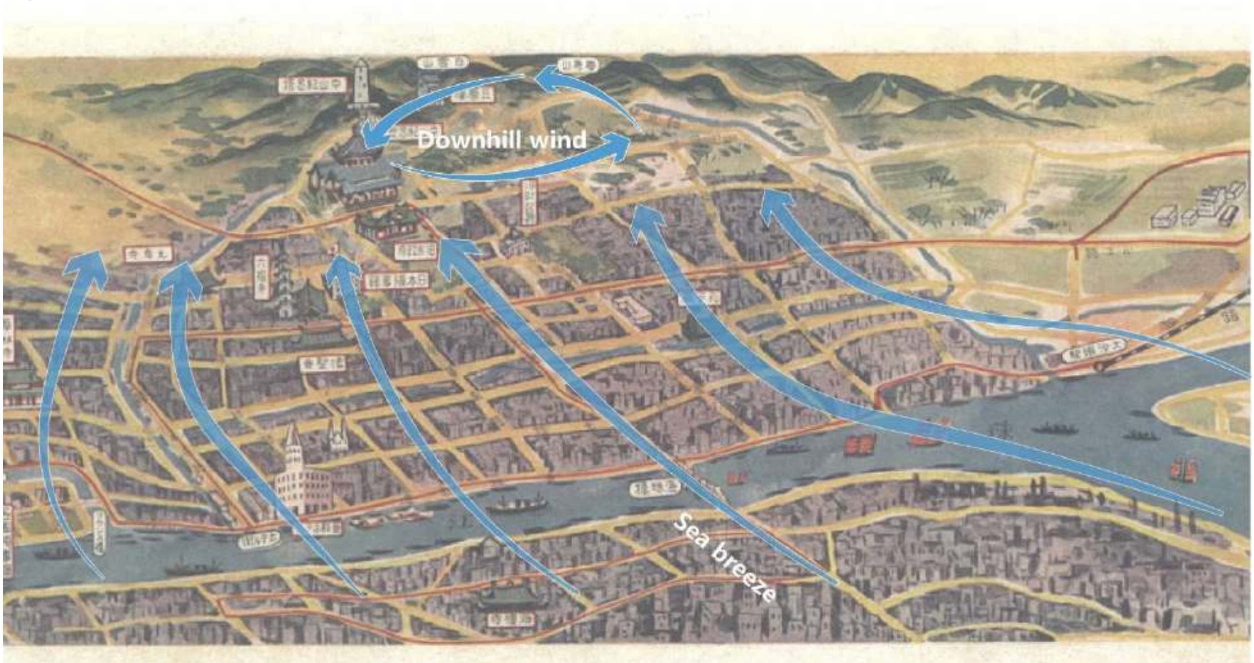
Creating comfortable urban development has always been a challenge in Guangzhou due to its humid and warm climate. The city's location, traditional urban layout, and Lingnan architecture represent the simple but ancestral view on living with nature and adapting to climate.

Located to the south of Yuexiu Mountain off the Pearl River, the terrain of Guangzhou is flat and open with few obstructions. Nanling Mountain lies to the north of Guangzhou, and it wards off cold, northwesterly winds during winter. Coastal oceans to the southeast allow summer monsoons to travel inland unobstructed.

The ancient city was built at the foot of Baiyun Mountain, and this natural protective barrier creates a local circulation between the city and the mountain, cooling Guangzhou with the valley winds.

Builders of the ancient city also constructed the Six-vein Canal to vertically connect with the Pearl River system to channel natural wind. Roads were built following the direction of the prevailing southeast summer wind, allowing sea breeze to flow into the city.

Figure 5 // MAP OF ANCIENT GUANGZHOU



Base map source: Guangzhou Urban Construction Archive

Photo credit: Xiaotie Chen

Living with nature - Traditional Lingnan Architecture

Influenced by Lingnan culture and the hot, humid climate, traditional Lingnan architecture exhibits distinct open layouts, smooth and simple shapes, and flexible and practical details. Their design also shows deep respect for nature. Gardens are integrated with homes, demonstrating a micro-climate design concept that uses natural landscape elements, such as vegetation and water bodies, to improve the building environment.

Figure 6 // ARCADE: CONTINUOUS WALKWAY OUT FROM SUN AND RAIN

Photo credit: Guangzhou Vanke Co., Ltd

Ventilation and insulation are two architectural climate challenges that Guangzhou residents typically must address. To tackle these challenges, the overall layout must be open and complete. During the climate adaptation process, structures with Guangzhou characteristics emerged, including the three-room and two-corridor design, bamboo tube houses, and arcades. These are all examples of passive ventilation cooling structures demonstrating Lingnan characteristics. It is proven to be quite effective to install patios, cool alleys, and void grounds to achieve proper ventilation and cooling, improving the quality of dwellings.

Figure 7 // PATIO: PASSIVE VENTILATION

Photo credit: Guangzhou Urban Planning Bureau, Guangzhou Urban Construction Archives (2012). Craftsmanship with Lingnan Peculiarity.

Guangzhou's urban development strategy

Currently, urban development in Guangzhou is at a critical stage of shifting from high-speed growth to high-quality development. The city has also been presented with a major strategic opportunity — *the Guangdong-Hong*

Kong-Macao Greater Bay Area development. The *Guangzhou 2035 Master Plan* (*plan 2035* for short) is paving the way for quality urban development. It identifies a vision of *a vibrant, global city and a beautiful, livable City of Flowers* by 2035 through six major urban development themes:

- Beautiful land, spatial pattern.
- Prosperous and open international metropolis.
- Charming Lingnan, a city of culture.
- Inclusive and sharing, home to happiness.
- Baiyun Mountain and Pearl River, auspicious city of flowers.
- Pastoral Lingnan, rural revitalization.

According to *plan2035*, Guangzhou will accommodate 22 million people in 2035. To limit the disorderly expansion of cities, the plan will support the maintenance of both an ecological space boundary and an urban development boundary. A system of three-level (district, city and region) ecological corridors has been established to create a spatial pattern where humans and nature co-exist, encompassing more than 5,500 kilometers. Moreover, the plan also uses urban renewal to promote the restructuring and repurposing of urban land space.

Guangzhou's urban cooling strategy

To address the issue of urban heat islands and outdoor thermal comfort, *plan2035* uses an urban climatic planning recommendation map based on thermal load and air dynamic analysis. The zoning units are divided into 4 levels according to their current climate conditions and future heat risks. Relevant development restrictions and urban cooling strategies are determined for each level.

Additionally, based on wind pattern studies, *plan2035* links green belts, water bodies (e.g. rivers and reservoirs), low-rise, low-density areas and artificial paths, including highways and major roads, to form 6 main corridors for wind to blow through the city. These 6 main ventilation corridors include 3 summer wind paths along water systems to allow southeast sea breezes into urban hinterland, 1 summer wind path blowing through the valley, 1 winter air path winding through Liuxi river and 1 winter air path from the eastern mountains.

The city also identified cooling strategies to be incorporated into urban planning. These are categorized into 5 themes (*smart planning, smart surface, smart design, smart facility, and smart energy),* formulating 15 tools and 39 instructive guidelines. *(details in another report "Guidelines on integrating nature based passive cooling options into urban planning and design")*

Sustainable urban cooling pilot and demonstration projects

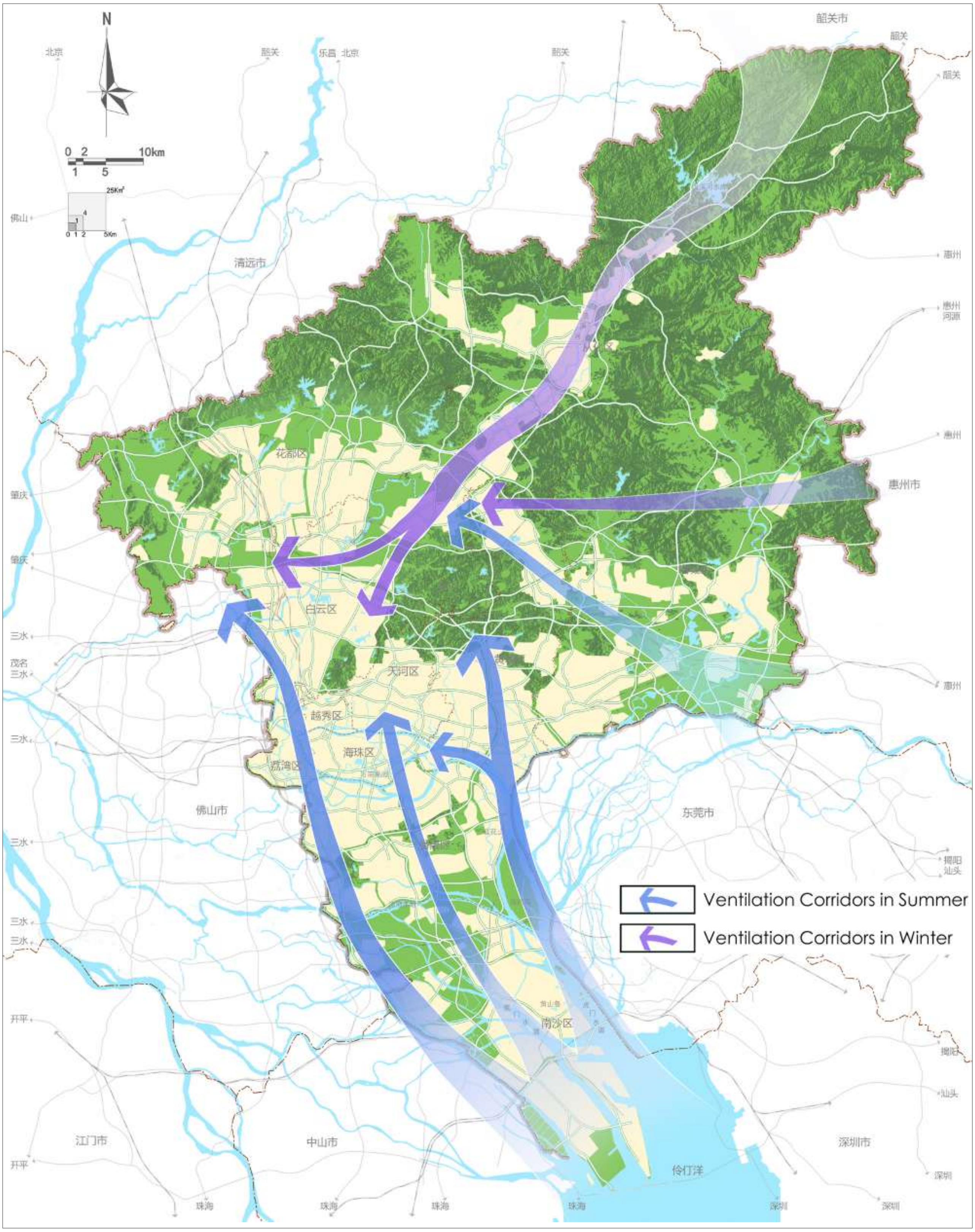
The World Bank launched a sustainable cooling program in 2019. Guangzhou was selected as the pilot city for the *China Sustainable Urban Cooling Project*. The pilot project aims to provide sustainable and affordable cooling solutions for developing countries.

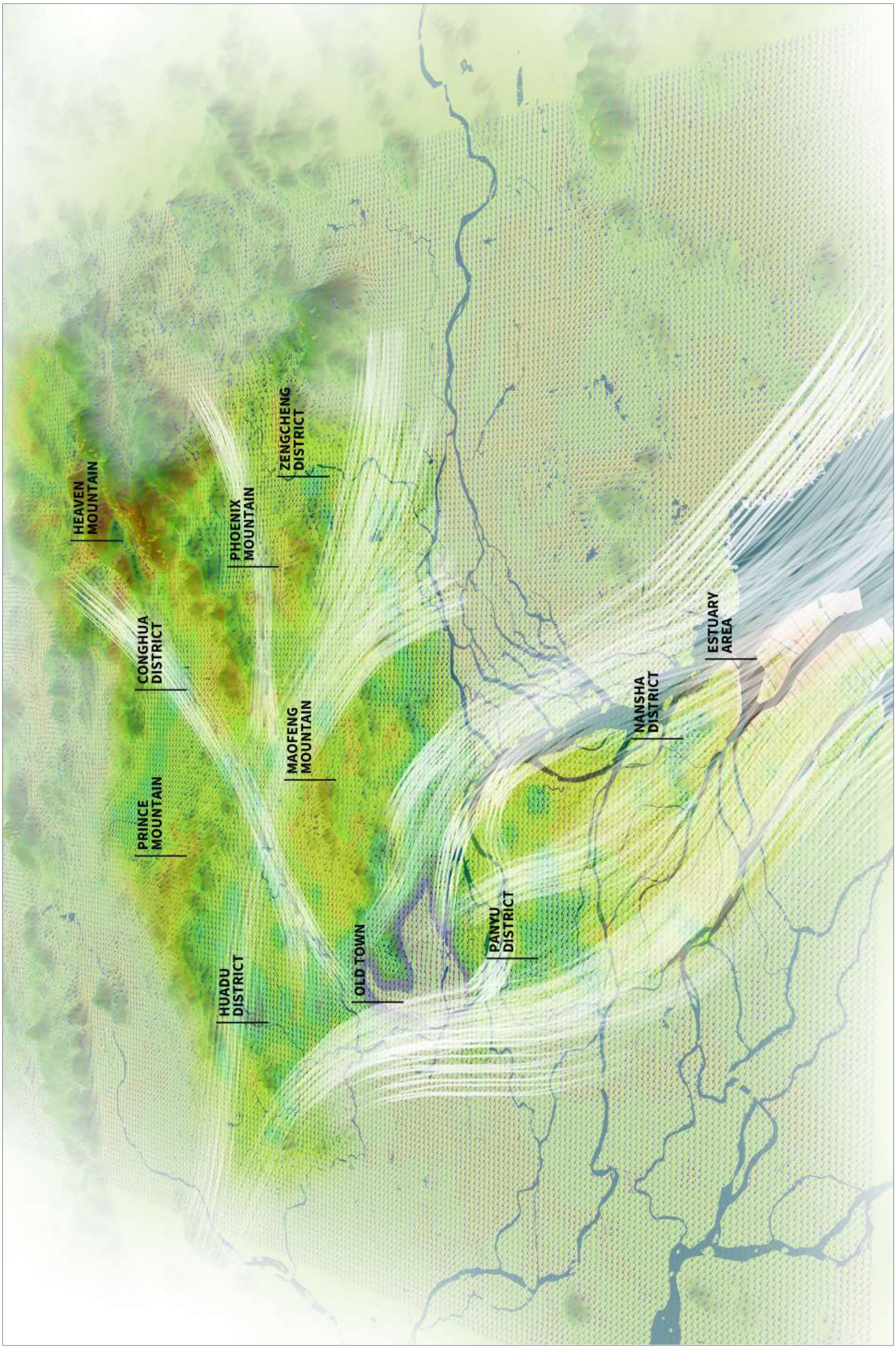
By utilizing the unique and traditional wisdom, Guangzhou piloted nature based and passive urban cooling measures included in the World Bank report – Primer For Cool Cities – Reducing Excessive Urban Heat, with the objective that the measures can be deployed elsewhere in the World Bank projects to help cities respond to climate change.

The program launched 3 demonstration projects where cooling solutions were implemented via collaboration between the local government, developers and a local planning team. The first is the *Yongqingfang Phase II Project*, an old town renovation project; the second is the *China-Singapore Knowledge City Project* to create a new, low-carbon, green, ecological district; the third is the *Haizhu Wetland Project*, to evaluate the cooling effects of green infrastructure. On the basis of the experiences of these pilots, Guangzhou intends to develop an integrated and systematic sustainable cooling framework that improves city's liveability while addressing climate change and participating in international climate actions.

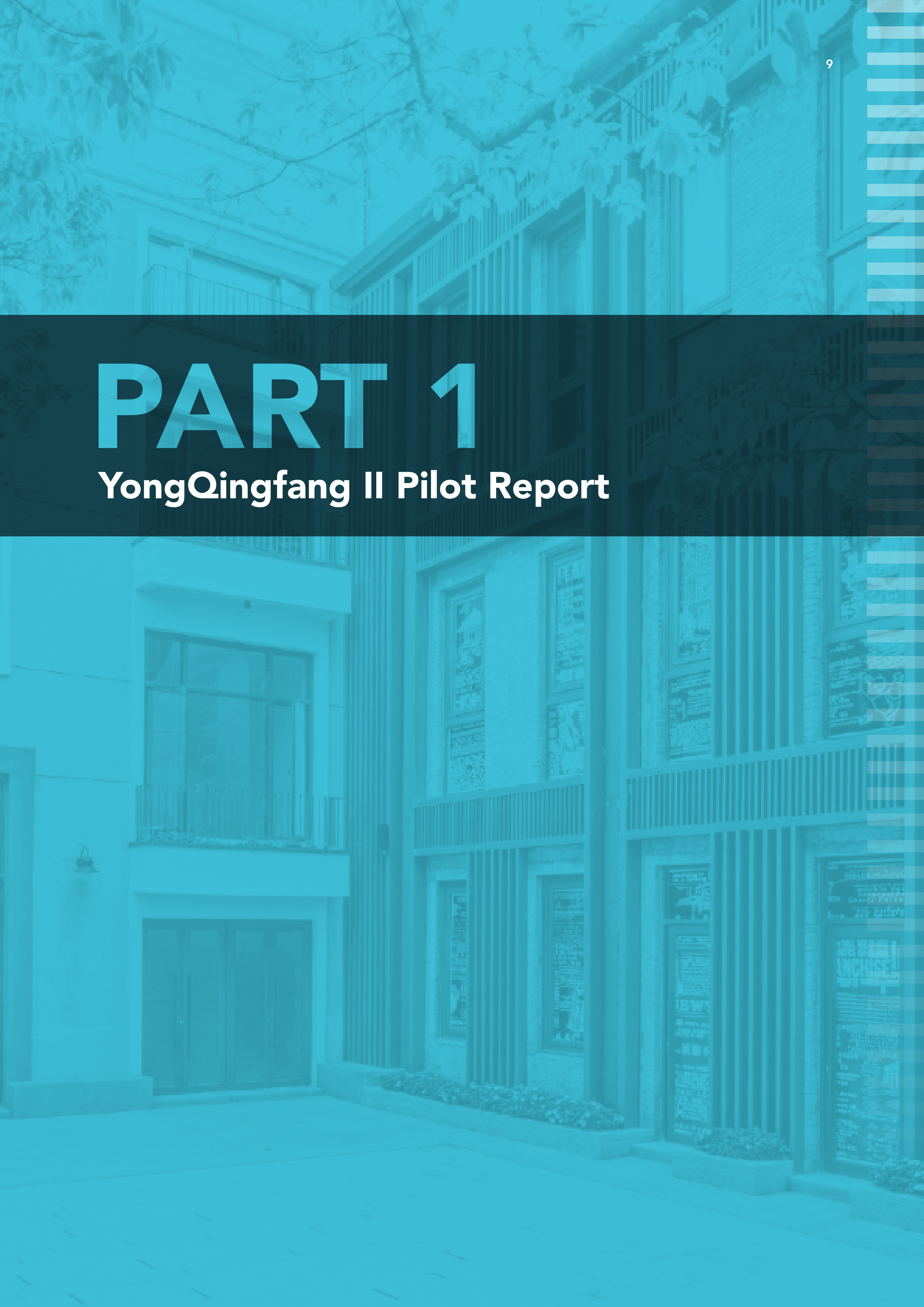
This report articulates the pilot work in the *Yongqingfang Phase II Project* and the*China-Singapore Knowledge City Project*, especially whether and how the various cooling options could be deployed in both the old neighborhood and new area. The experience and perspective gained through these two sites will offer valuable insight into the feasibility of various cooling options and support the integration of nature-based passive urban cooling options with the city's spatial planning process.

Figure 8 // MASTER PLAN OF VENTILATION CORRIDORS





Source: Guangzhou Urban Planning & Design Survey Research Institute



PART 1

YongQingfang II Pilot Report

1. Project overview

Yongqingfang is located in the Xiguan area of Liwan District in the old town of Guangzhou. Xiguan is adjacent to the ancient city of Guangzhou. It is one of the birthplaces of local culture and was an important gateway for foreign trade and cultural exchange during the Ming and Qing dynasties. Yongqingfang boasts abundant historical relics with Lychee Bay running across the site from east to west.

The Yongqingfang project is an urban regeneration project developed by Vanke Real Estate, one of the biggest real estate developers in China. The first phase of Yongqingfang has been completed, and the second phase is under way.

A pilot site and an individual pilot building were selected in Phase II. Different cooling measures are implemented in the real construction process, with a focus on block level and market-oriented mode.

- Pilot site: Jixiang section
- Pilot building: architecture on the east side of Taihualou

Figure 9 // RENDERING OF THE YONGQING FANG DEMONSTRATION PROJECT PLAN

Base map source: Guangzhou Vanke Co., Ltd

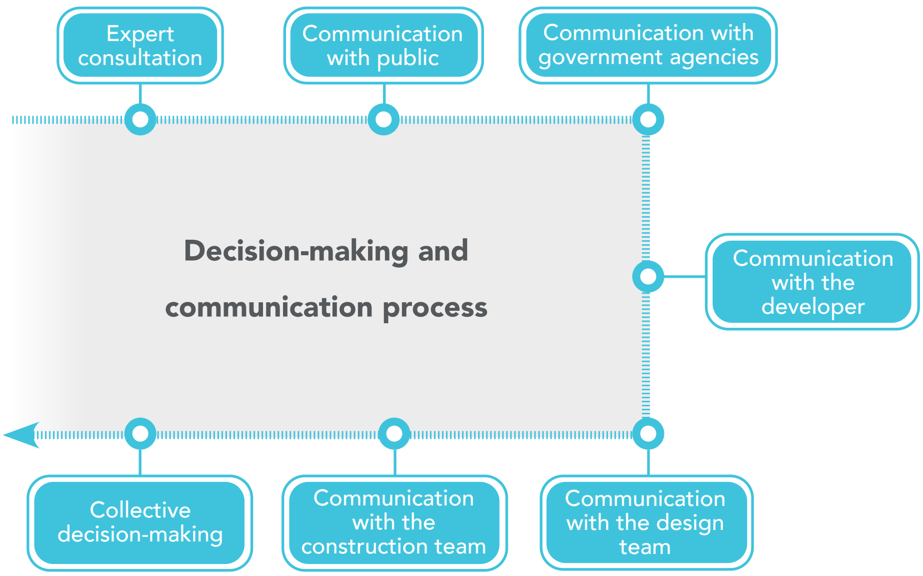
2. Select list of cooling measures

2.1 Organization and decision-making process

A multi-lateral, cooperative organisation constituted by the government, technical teams, special experts, and design teams was set up to promote multi-party participation, address the diverse demands of the public, and achieve joint development and governance in the area.

Working meetings and on-site surveys were held regularly to facilitate the formulation of a cooling proposal. The working concept and construction drawings were first drawn up step-by-step, and then implemented.

After consulting with experts and the government agencies, the technical team agreed on a list of recommended cooling measures. The list was finalized after significant discussion with the developer, the design team, and the construction team to determine the feasibility, benefits, and challenges of implementation.



2.2 Assess cooling options

After repeated discussion, two priorities for urban cooling strategies were determined.

Traditional Lingnan wisdom of ventilation, shading and insulation

First, the traditional Lingnan passive cooling measures to be implemented in Yongqingfang should be identified.

In line with the existing architectural form and style of Yongqingfang, the application of cool alleys and bamboo-tube houses should be a focus, using patios to enhance indoor draft exclusion. Arcades are not suitable for the Jixiang section, which does not border the main street, but can be transformed to overhead public space on the ground.

Second, the use of flexible door and window structures, such as Tanglong doors and Manchu windows, should be promoted and preserved to enhance the indoor ventilation of traditional Lingnan architecture.

Third, double-layered tiles should be utilized for roof insulation. Cavity wall insulation will increase wall thickness and affect the usable area inside the house, which is (only?) recommended to use on a pilot basis, other than at a large scale. Oyster shell walls are not compatible with traditional Lingnan architecture, and it is difficult to obtain the proper materials, making it an unlikely choice.

Modern low-cost technologies in old town

Low-cost cooling measures should be selected as they can be easily promoted for widespread application in old town.

Reflective surfaces. *Reflective materials are more suitable for flat roofs when compared to slope roofs. However, reflective walls and pavements are not recommended because the colors are incompatible with the traditional style.*

Permeable surfaces*. Rooftop greening in restaurants and other functional spaces should be prioritized. Examples include vertical greening on west-facing façades, pocket parks in public spaces, and increased tree canopy and water features. However, permeable paving is incompatible with the historical areas of Yongqingfang where limestone paving and slate paving are common.*

Figure 26 // MODERN LOW-COST TECHNIQUES USED IN YONGQING FANG PILOT.

Source: Guangzhou Urban Planning Bureau, Guangzhou Urban Construction Archives (2012). Craftsmanship with Lingnan Peculiarity.

Box 2 // MULTI-LATERAL ENGAGEMENT AND DECISION-MAKING IN THE JIXIANG SECTION DEMONSTRATION PROJECT

No.	Date	Organisations involved	Work items and agenda
1	2020. 1. 16	GMPNRBI GZPI I Vanke	Study the transformation and progress of Yongqing Fang, understand the subsequent renovation plan of Yongqing Fang and assess the cooperation feasibility in the demonstration project.
2	2020. 3. 3	GMPNRB I GZPI I Vanke	Understand the design proposal and schedule of Yongqing Fang Phase II project; finalize cooperation intent and discuss follow-up cooperation.
3	2020. 4. 3	GMPNRB I GZPI I Vanke	Exchange information on frequently used urban cooling measures and design approaches; put forward key points for the demonstration project.
4	2020. 4. 22	Guest experts I GMPNRB I GZPI	Provide advice on urban cooling for Yongqingfang Phase II project and the building on the eastern side of the Taihualou.
5	2020. 4. 29	GZPI I South China University of Technology	Discuss the design of architecture on the eastern side of the Taihualou in Yongqingfang Phase II project and implement relevant advice.
6	2020. 5. 8	GZPI I Vanke	Discuss specific ideas and arrangements for the implementation of various building cooling measures in the Jixiang section of Yongqing Fang Phase II Project.
7	2020. 5. 16	GZPI I Vanke I Design team I Construction team	Discuss the feasibility and challenges of implementing cooling measures with the design and construction teams.
8	2020. 5. 19-20	GZPI I Vanke	Put forward specific recommendations on the implementation of vertical greening and discuss where and how to implement double-layered surfaces and cavity walls.
9	2020. 5. 26	GMPNRB I GZPI I Vanke	Discuss Vanke's construction drawings for the implementation of cooling measures at the building level and the subsequent working plan for implementing cooling measures in the outdoor landscape.
10	2020. 5. 27	Guest experts I GMPNRB I GZPI	Review construction plans for urban cooling measures.

**GMPNRB: Guangzhou Municipal Planning and Natural Resources Bureau*
GZPI: Guangzhou Urban Planning & Design survey research institute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3. Cooling solutions in Jixiang section

3.1 Site context

Jixiang section is at the end of the'Lychee Bay'river and north of Enning Road with a total area of 1.52ha.

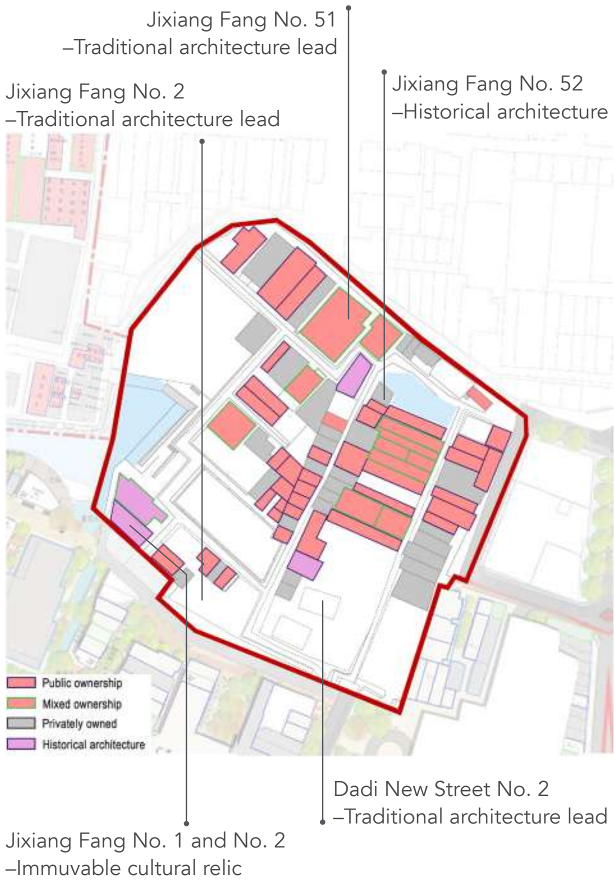
Many buildings in the Jixiang section of Yongqingfang were rebuilt after a historical demolition, but the exact age of the reconstruction is unknown.

There are 84 buildings in the Jixiang section, of which 43 are publicly owned, 11 are under mixed ownership, and 30 are privately owned. Among the buildings under public and mixed ownership, 5 are protected historic buildings.

These buildings are all residential. Most buildings are brick-concrete or brick-wood construction, while a few have a frame structure. Meanwhile, those buildings mostly have 1 to 3 floors, and a few of them are 4 to 6 stories. The buildings have retained historical features such as the Tanglong door, bamboo-tube structures, limestone pavement, and slope rooftops.

As shown in the photos below, most of the original buildings in the south part were demolished many years ago in the renovation of Enning Road and the initiative of 'bring back Lychee Bay', and they no longer exist. In the north part, the original buildings, streets and alleys, texture and style are well preserved, but many other buildings are old and dilapidated as they lack maintenance.

Figure 11 // DISTRIBUTION OF BUILDINGS WITH DIFFERENT OWNERSHIP LOCATED INSIDE THE JIXIANG SECTION



Source: Guangzhou Vanke Co., Ltd

Figure 12 // AERIAL VIEW AND PHOTOS OF THE CURRENT STATUS OF JIXIANG SECTION, YONGQING FANG DEMONSTRATION PROJECT

Source: Guangzhou Vanke Co., Ltd

3.2 Overview of the renewal plan

The design principles: Follow the principle of micro-transformation, retain the traditional layout, preserve the historical style, carry out street regulation and landscape improvement projects.

Style: Retain the original architectural style, which is a combination of flat surfaces and slopes, respond to the surrounding urban environment, and restore the traditional local roofing. Combine flat surfaces with slopes, create a staggered layout, and enable a dynamic façade.

Architecture: Take into consideration the building's ownership, its current status, and the business it will accommodate. Renovate and fix the façade of private houses and continue to use them as residential properties. Repair and renovate houses under mixed-ownership, make use of their flexibility, and change their function to retail. The vacant land will be used for additional construction, and the newly built properties will mainly be used as hotels and retail stores.

Development and construction volume: The gross floor area is about 26 thousand m^2, the building density is about 60%, and the floor area ratio is 1.8.

Figure 13 // ARCHITECTURE TREATMENT MODEL IN JIXIANG SECTION

Source: Guangzhou Vanke Co., Ltd

Figure 14 // LAYOUT OF ARCHITECTURE FUNCTIONS IN JIXIANG SECTION

Source: Guangzhou Vanke Co., Ltd

Figure 15 // GENERAL FLOOR PLAN OF THE YONGQING FANG DEMONSTRATION PROJECT (JIXIANG SECTION)

Source: Guangzhou Vanke Co., Ltd

3.3 Cooling measures recommendation

A list of cooling measures was finally determined at the site level, the building level (including roofs and façades), and the landscape level for the Jixiang section.

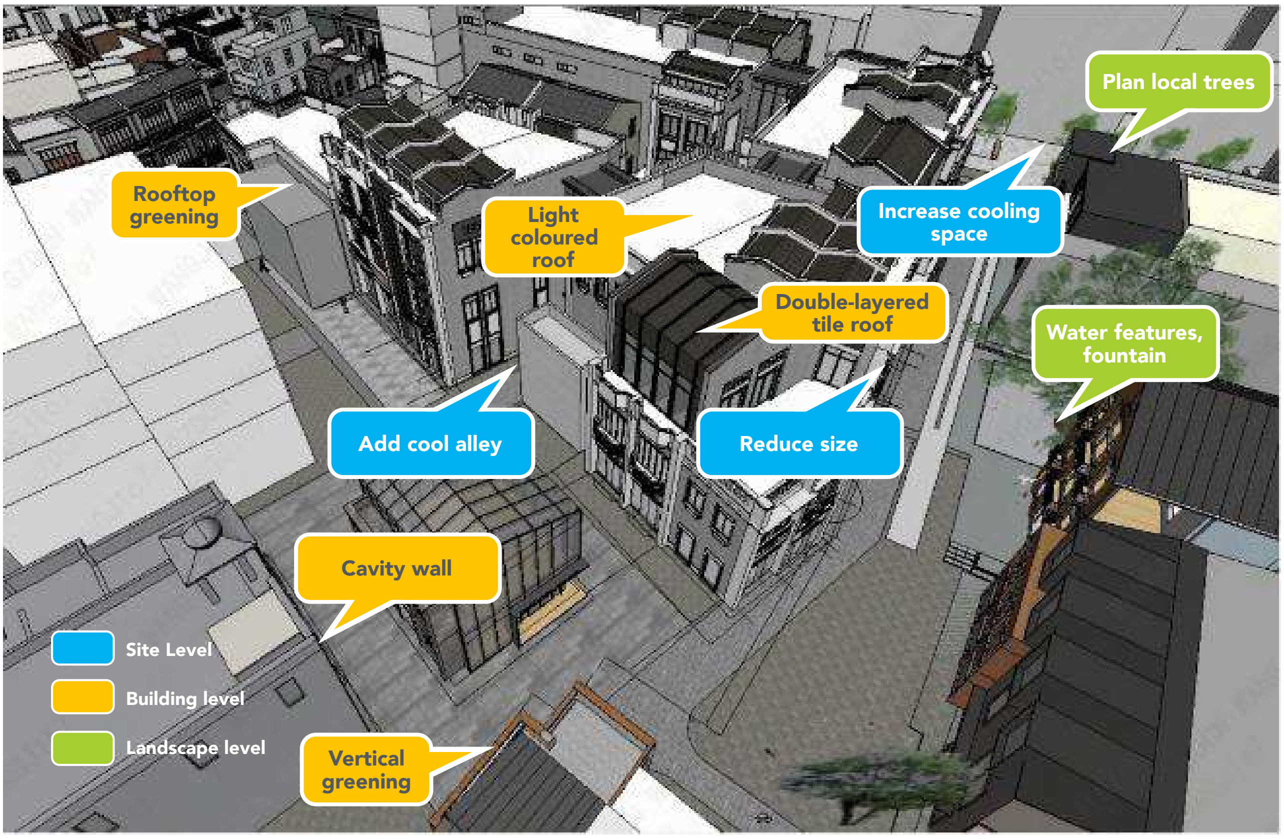
At the site level, break through the original dense and intense texture, introduce a cool alley parallel to the building texture, and widen the alleyway appropriately.

At the building level, take full consideration of architectural shading and insulation measures: glass façades should be integrated with sun-shading window blinds. Double roof, light-colored roof, and rooftop greening can all achieve insulation. Focus on preserving traditional style windows and doors which are good for indoor and outdoor ventilation. For new buildings, all windows and doors installed should be capable of being opened and closed to ensure that every building is properly ventilated.

At the landscape level, focus on increasing water features and trees to lower the temperature through active evaporation and increased shading.

level	recommendations
Site level	• Increase cool alleys and increase cooling spaces • Dissect the size of buildings and use bamboo-tube houses • Widen the streets
Building level	• Consider using tradition double-layered tiles on rooftops • Use light color coatings and rooftop greening • Cavity wall insulation • Create vertical greening in part of the west-facing areas as part of the landscape design
Landscape level	• Plant local trees to increase evapotranspiration cooling and create comfortable shaded area • Install sprinkler facilities and solar-power fans on building façades • Install water features and fountains in public spaces.

Figure 16 // LIST OF SUSTAINABLE COOLING MEASURES AT JIXIANG SECTION



Source: Guangzhou Vanke Co., Ltd

3.4 Site level cooling measures

Most buildings in the northern part of the site are still in use, but a small number have been demolished ,and some vacant lands are left. The main focus in this part is on restoration and renovation.

Not all buildings are reconstructed during the renovation process. Some plots are left as open spaces. For example, the vacated land at the northeast corner is transformed into public green space. This helps create distinct wind inlets and cooling spaces.

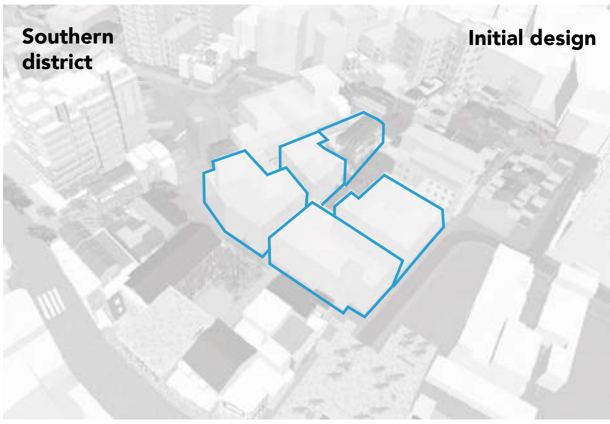
Most of the buildings in the southern part of the site no longer exist. Here, the main focus is on reconstruction to implement cooling measures.

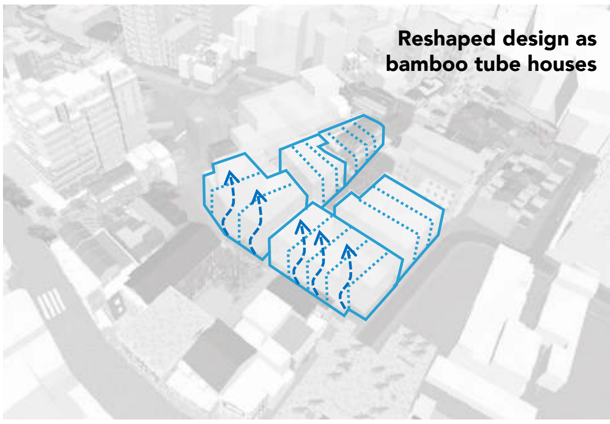
The original large commercial complex is subdivided into smaller clusters with narrow entrances and long depths, similar to traditional bamboo tube houses. Cool alleys and patios will help change wind pressure and improve air flow through the building.

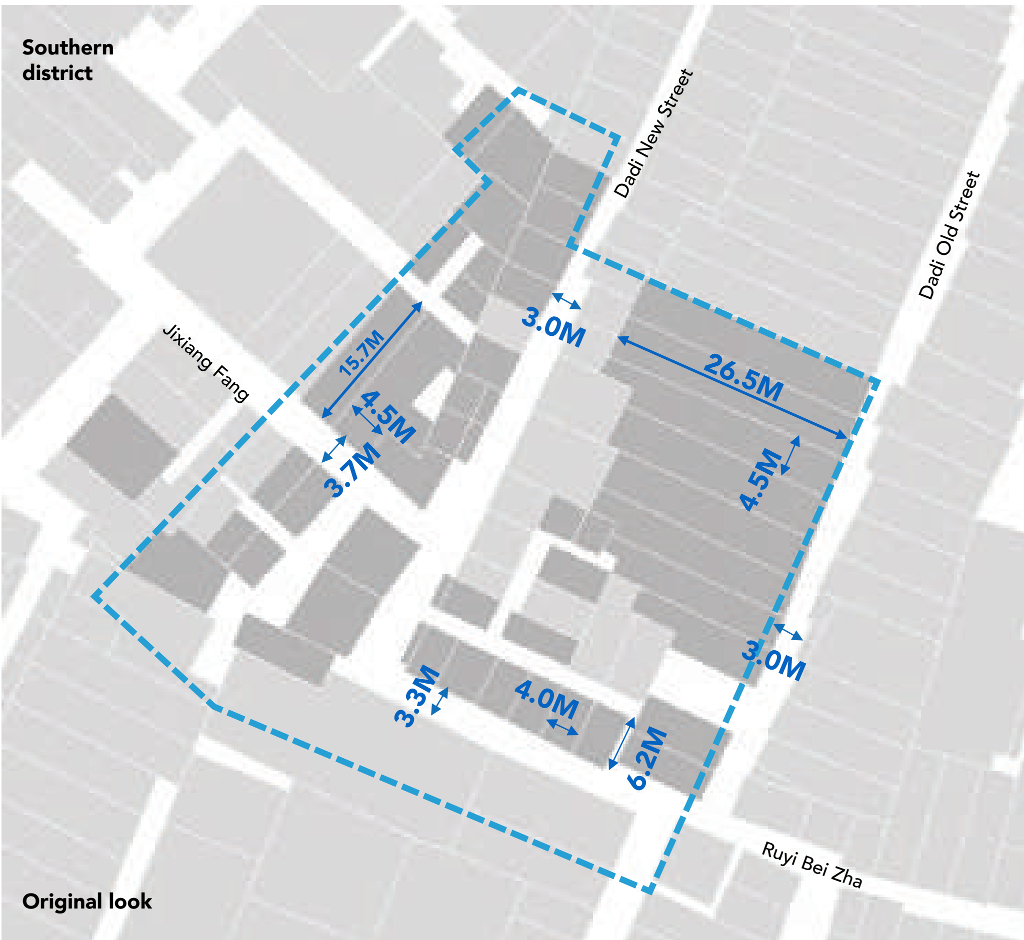
In the southern district, the street layout will be reconstructed using historical information. The ventilation efficiency will be improved through the two following measures:

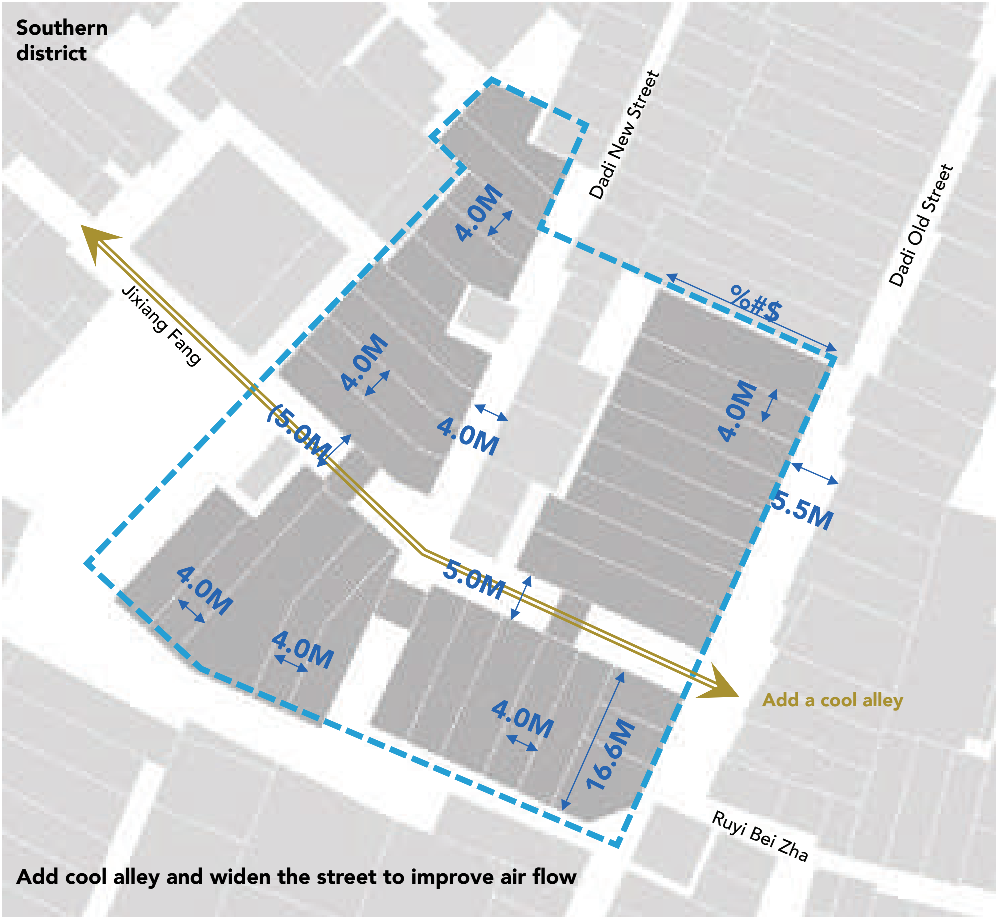
Cluttered topography in this area were cleared out by opening up the culdesac and creating additional cool alleys that run parallel to the buildings.

Before demolition, the street was around 3-meters wide. The original street network of the site will be preserved, and the width of the streets will be extended to around 4-5 meters.









3.5 Building level cooling measures

The following issues are taken into consideration when selecting buildings for implementation of cooling measures.

Ownership: There are a large number of buildings under private ownership or mixed public-private ownership in the Jixiang sections. The developers do not have strong will to invest in private dwellings, and residents do not often make major modifications to their houses. Hence, buildings under public ownership will be the main targets of various cooling solutions, while private buildings will undergo improvements of doors and windows.

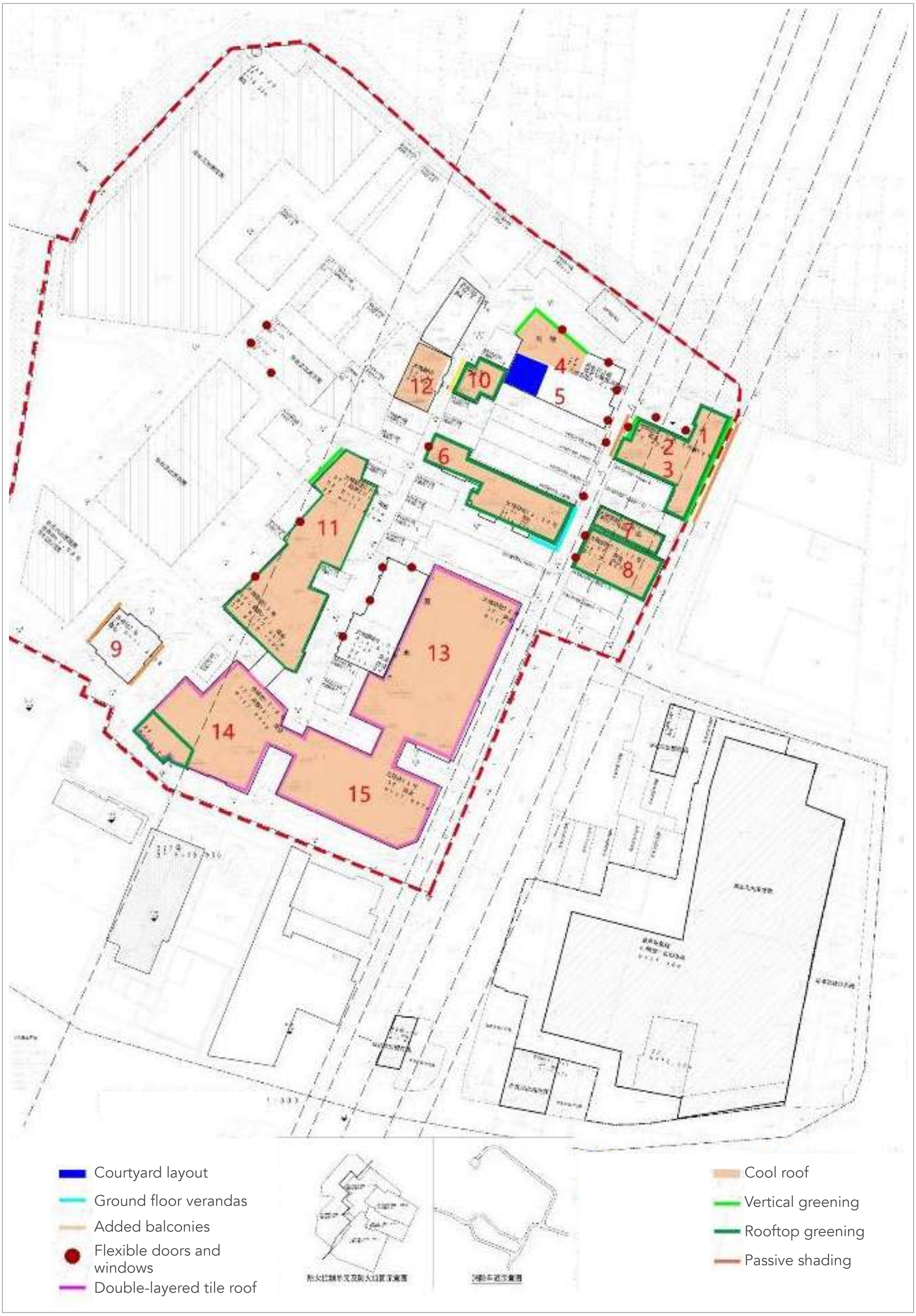
Building characteristics: The cooling solutions should be compatible with the characteristics and style of each buildings. For example, slope roofs and flat roofs should have different cooling strategies.

Climate conditions: In order to maximize the cooling effect and benefit the most people, cooling measures should target buildings with large occupancy and poor thermal comfort.

Comparison and evaluation: A/B test pairs should be chosen to compare the demonstration building to a substantially similar control site.

Cooling measures will be implemented across 15 building sites.

		Measures	Description	Location	Size
Traditional Lingnan regional architectural cooling methods		Courtyard layout	Improved courtyard layout to increase ventilation	4, 5	20 m^2
		Arcades	Usage of arcades or void ground space to offer protection from wind, rain, and excessive sunshine.	6	≈16 m^2
		Balconies	Installation of balconies on the first floor or above to shield rooms from excessive sunlight.	10	≈27 m^2
		Flexible doors and windows	Usage of traditional, flexible windows and doors that improve ventilation	2, 5, 8	—
		Double-layered tile roof	Addition of double-layered tile surfaces.	13, 14, 15	≈350 m^2
Modern low-cost cooling measures		Passive shading	Installation of shading structures on the east, west, and south curtain walls, as well as on rooftop skylights	1, 2, 9	≈320 m^2
		Cool roof	Addition of a reflective coating on roofs	1, 2, 3, 4, 6, 8, 11, 13, 14, 15	≈1080 m^2 (minus the sloped roofs)
		Vertical greenery	Installation of vertical greening that will grow up the walls	1, 2, 4, 11	≈240 m^2
		Green roof	Flexible rooftop greening	1, 2, 3, 6, 7, 8, 10, 11	Total length ≈50 m
			Fixed rooftop greening	14	≈220 m^2


1
2
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Courtyard layout
Ground floor verandas
Added balconies
Flexible doors and windows
Double-layered tile roof
Cool roof
Vertical greening
Rooftop greening
Passive shading

Courtyard layout

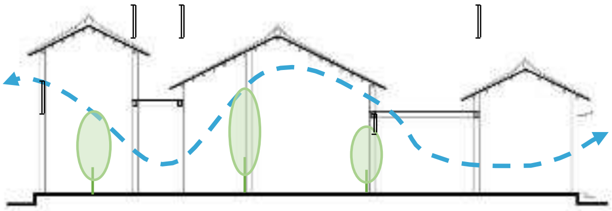
Install a patio inside the building to form a small courtyard, increasing the open interface of the building and improving ventilation.

Arcades

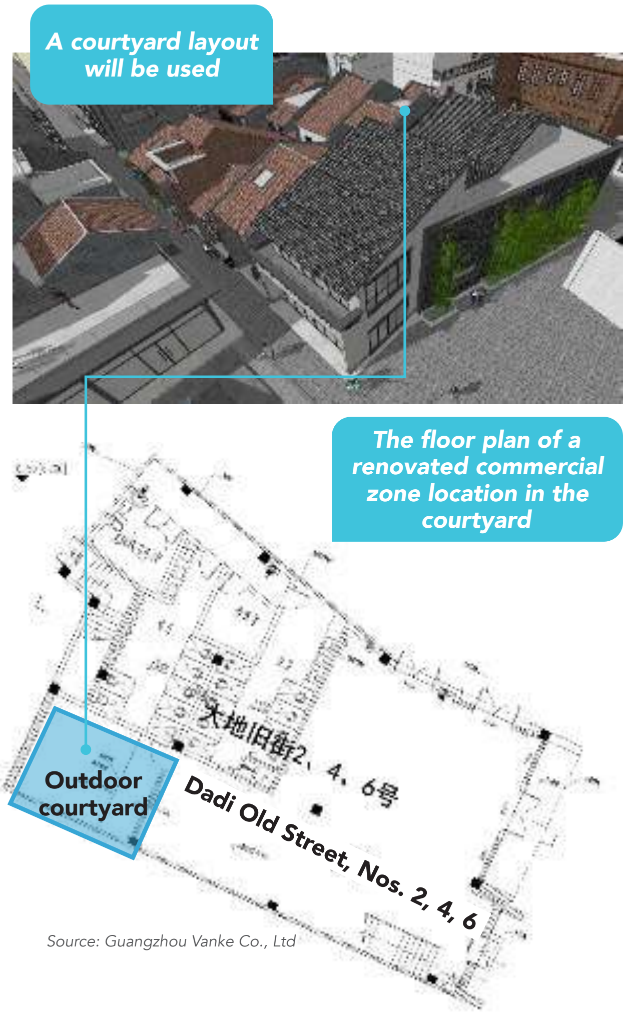
Use arcades or void ground space on the ground floor to provide a comfortable pedestrian space that offers shelter from wind, rain, and sun, allowing pedestrians to adapt to the hot and humid summers of Guangzhou.

Balconies

Install balconies on the first floor and above to create semi-open spaces for people to relax and move about. This also improves façade shading areas and shields rooms from direct sunlight.

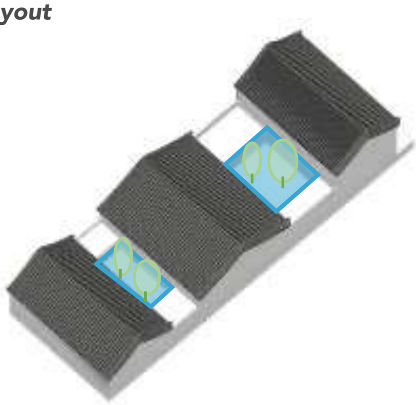


Courtyard layout benefits: good ventilation, sufficient lighting

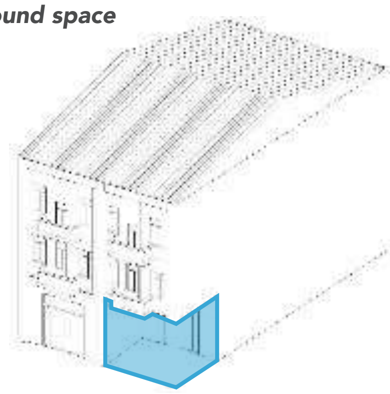


Source: Guangzhou Vanke Co., Ltd

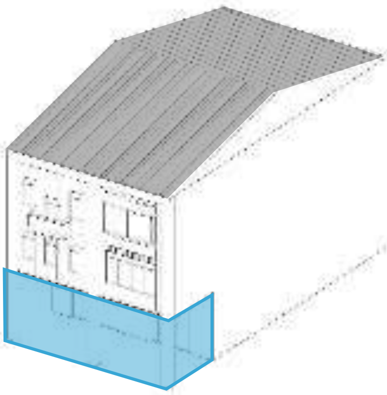
Courtyard layout



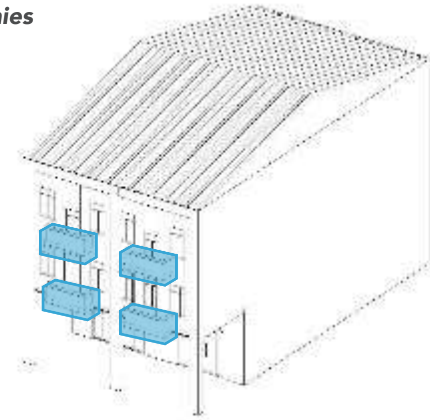
Void ground space



Arcade



Balconies



Flexible doors and windows

Traditional Lingnan dwellings often utilize doors and windows that provide excellent ventilation. The Jixiang section will use a large number of Tanglong doors and lattice structures in both new constructions and renovations.

Tanglong doors: Tanglong doors are made up of three door layers: a screen door, a log door, and a solid wood door. It ensures security and ventilation when the solid wood door is open and the log door is shut. The screen door is only as tall as an adult and is mostly hollowed out, blocking the view without compromising ventilation when shut.

Figure 17 // STRUCTURE OF A TANGLONG DOOR

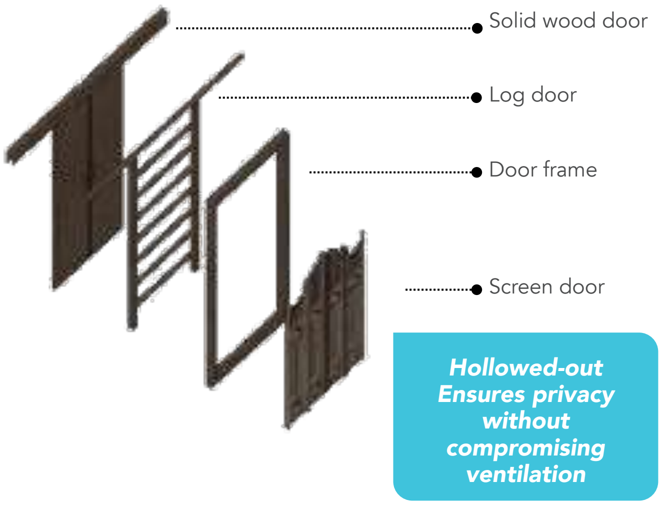
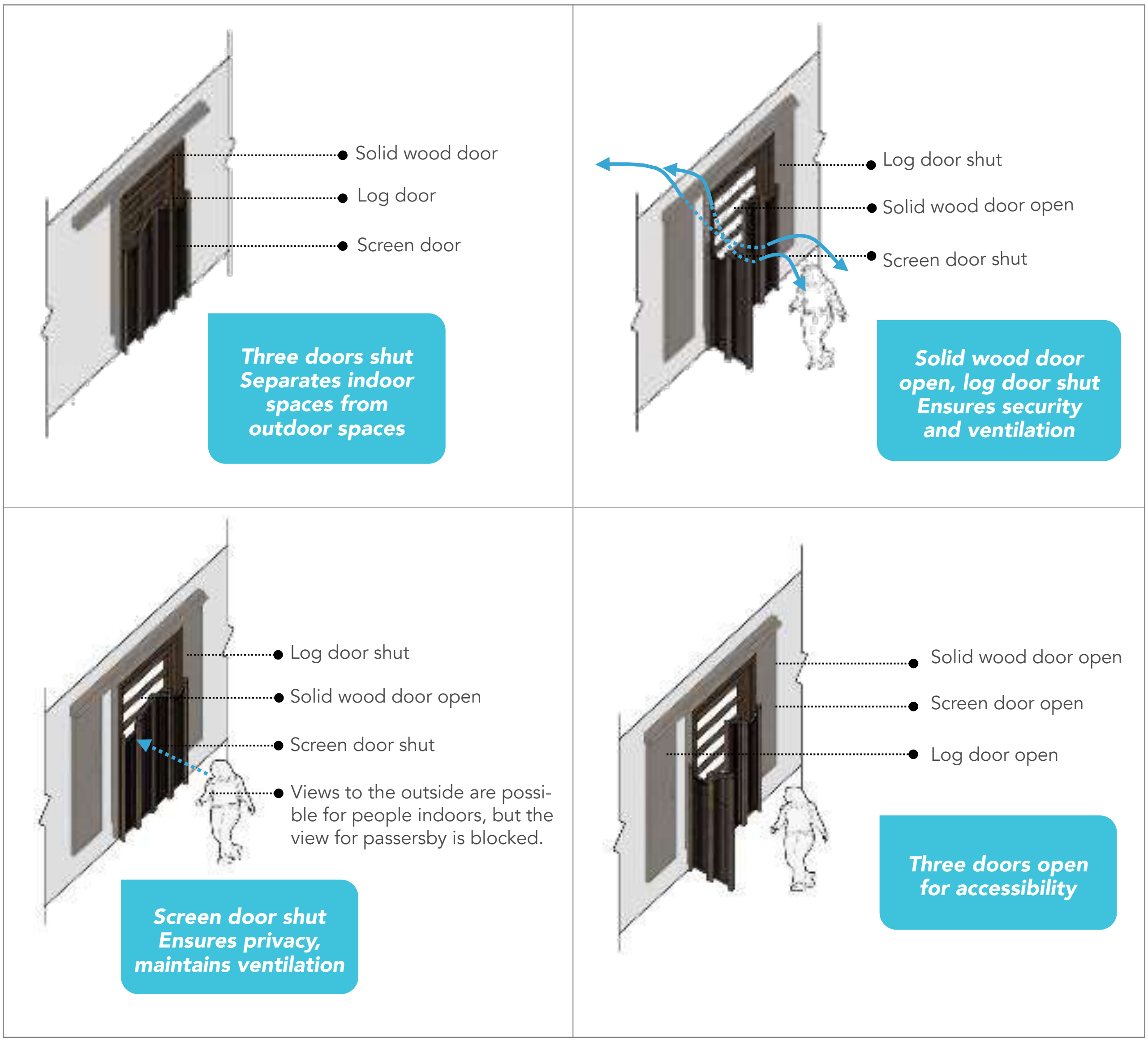


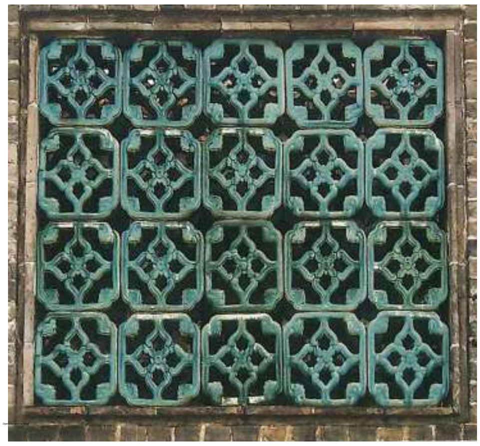
Figure 18 // FOUR USE OPTIONS OF A TANGLONG DOOR



Renewal plan

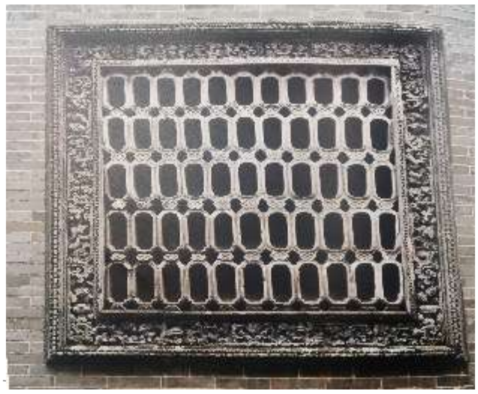
Lattice windows and window blinds: *Lattice windows and window blinds are traditional Lingnan architectural elements which are aesthetically pleasing while offering good ventilation. Two types of lattice windows are commonly used in traditional Lingnan houses and gardens: openable lattice windows integrated with glass and fully hollowed-out lattice windows.*

Adjustable window blinds are also very common in Lingnan traditional architecture, allowing variable levels of shade and ventilation.



Hollowed out lattice windows

Lattice windows with glass



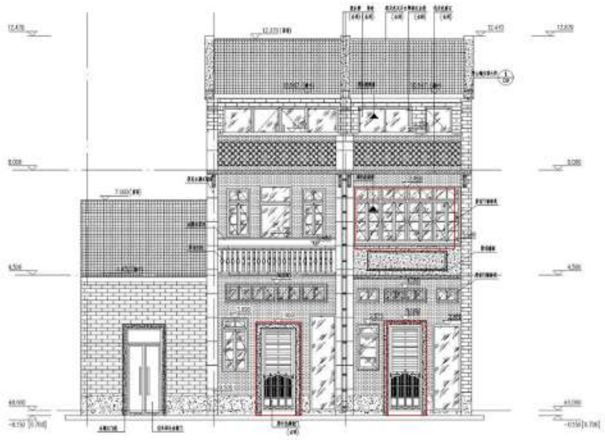
Hollowed out lattice windows

Lattice windows with glass

Source: Guangzhou Urban Planning Bureau, Guangzhou Urban Construction Archives (2012). Craftsmanship with Lingnan Peculiarity.

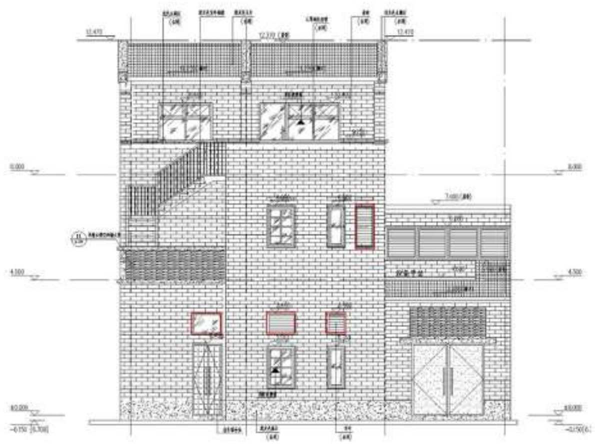
Figure 19 // DADI OLD STREET, NOS. 13, 15, 17 FAÇADES

Tanglong doors are used at the entrances



Source: Guangzhou Vanke Co., Ltd

Latticework is used for the windows.

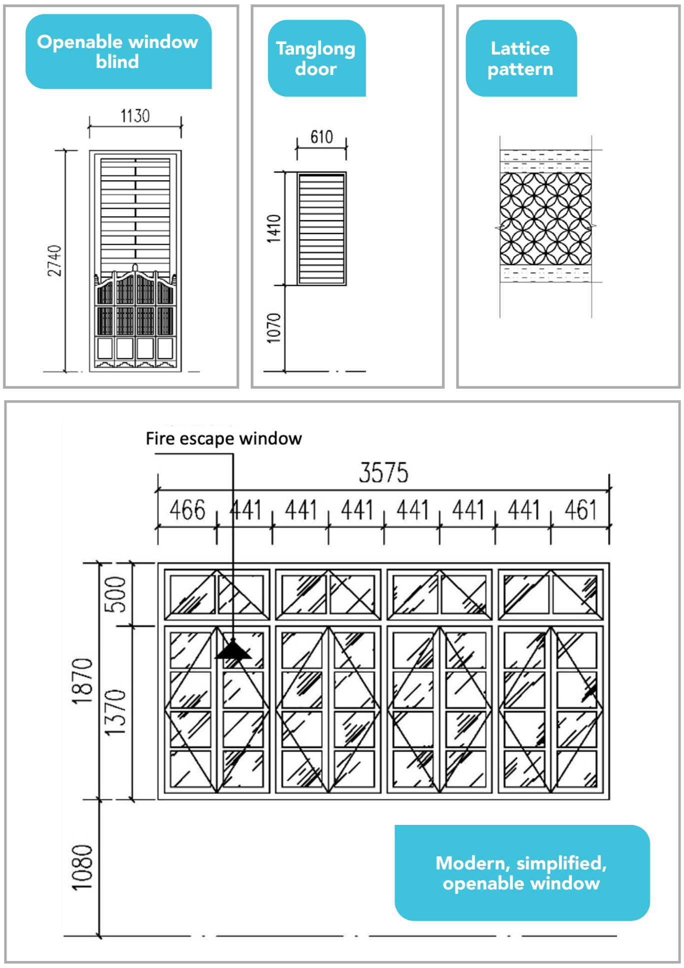


Source: Guangzhou Vanke Co., Ltd

Figure 20 // DADI OLD STREET, NOS. 13, 15, 17 RENDERING

Source: Guangzhou Vanke Co., Ltd

Figure 21 // DOOR AND WINDOW EXAMPLES FOR DADI OLD STREET, NOS. 13, 15, 17



Source: Guangzhou Vanke Co., Ltd

Double-layered tile roofing

Double-layered roofing is commonly used in Lingnan residential buildings to provide better thermal insulation. For example, double-layered, tile roofing, which leaves an air layer between the upper and lower layers of tiles, can effectively improve the insulation coefficient of the roof.

In new commercial buildings in the Jixiang section (Dadi Old Street No. 26, Jixiang Fang No. 13 , and Jixiang Fang No. 12.2), the traditional, double-layered roofing will be converted into a modern construction structure to reduce the heat transfer from the roof to the interior of the dwelling.

Window blinds

For commercial reasons, the initial design of Jixiang Fang No. 2 adopted a more transparent, large, glass façade. Later, after considering the need for cooling, shading, and comfort, window blinds were added.

Light-colored, reflective roofing

Traditional buildings in Guangzhou's urban area use a variety of roofing combinations which can be categorized into sloped roofs, flat-and-sloped roofs, and flat roofs. Traditional sloped roofs typically use dark-colored tiles. After taking into account the cooling efficiency and design requirements of the historic district, a combination of dark-colored, sloped roofs and light-colored, reflective flat roofs was used for buildings in the Jixiang section.

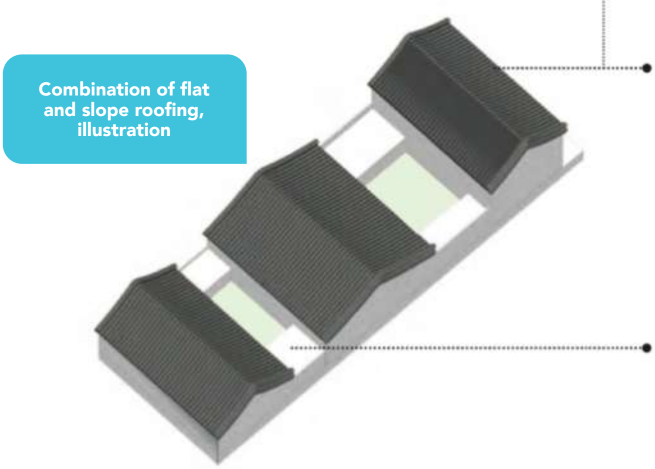
Figure 22 // PLAN COMPARISON OF JIXIANG FANG NO. 2

Source: Guangzhou Vanke Co., Ltd

Initial plan

Source: Guangzhou Vanke Co., Ltd

Improved plan with window blinds



Guangzhou Urban Planning & Design Survey Research Institute, Guangzhou Vanke Co., Ltd

Traditional Lingnan roll roof tiles

Deep-colored, sloped roofing (roll tiles)

Light-colored, reflective roofing

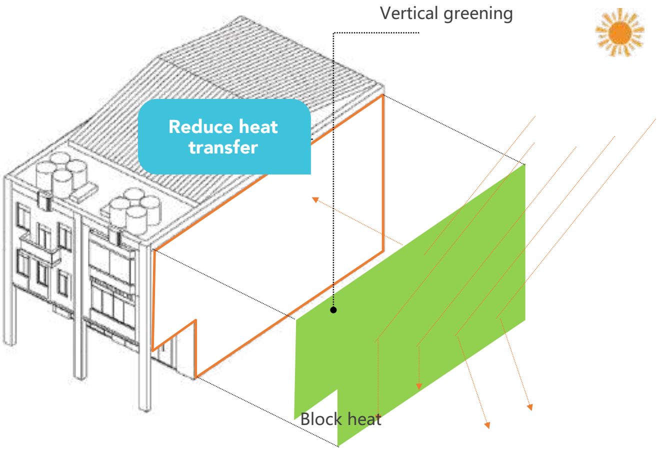
Vertical greening

Vertical greening can be used as an organic alternative to glass and other solid wall surfaces. Vertical greening provides effective insulation, reduces façade temperatures, and filters glare and dust. Additionally, vines are very common in traditional houses and gardens, forming a natural green wall. Hence, vertical greening is a technique that combines function and style and is highly compatible with traditional urban landscapes.

In the original design, the western and northern façades of Nos. 2, 4, 6 Jixiang Fang, Nos. 5, 7 Dadi Old Street, and No. 19 Shiliu Pu had large areas of enclosed walls. This design was optimized by replacing the solid green brick façade with a combination of green bricks and vertical greening to reduce the impact of sunlight coming from the west while adding a bit of style to the architecture.

Vertical greening grown on the ground makes use of the surrounding land. The vines grow along the façades to form natural green walls. There are four advantages to the use of vertical greening:

a. Usage of the ground soil to reduce the thickness of walls, thereby ensuring the maximum indoor functional area.
b. When the building is only 2-3 floors tall, using ground grown, vertical greening is simple, low-cost, and easy to maintain.
c. Vines are fast-growing and highly resilient.
d. The green wall formed by ground-grown, vertical greening has a strong touch of history, tradition, and intimacy, emulating traditional urban landscapes.



Green wall formed by classic bamboo plants

Source: Guangzhou Vanke Co., Ltd

Renovation plan for the west-facing façade of Dadi Old Street, Nos. 2, 4, 6

Rooftop greening

Rooftop greening is an effective and aesthetic way to improve insulation. In the Jixiang Fang Project, flat roofs serve two main functions. They provide a platform for equipment while also serving as an area for business.

The original plan did not have a provision for rooftop greening in the business area, which was relatively plain. After considering the location, a requirement of adding rooftop greening was proposed for some of the buildings to create a better microclimate environment.

Recommended by *"Guangzhou Sponge City Planning and Design Guidelines -- Rainwater System Construction for Low Impact Development"*, both intensive and extensive roof greening are applicable to Jixiang section:

Intensive roof greening : Suitable for new buildings. The substrate depth of intensive roof greening can exceed 600 mm when planting arbors. Small arbors, low shrubs, lawns and groundcover plants can be selected for planting. Intensive roof greening was applied to the first-floor terrace of No. 25 Dadi New Street to create a garden and lounge area.

Extensive rooftop greening: Simple, feasible and convenient, requiring no major changes to the original building structure. Extensive rooftop greening is suitable for renovation and renewal of buildings. The depth of the planting container is generally no more than 150mm. As shown in the figure below, the container modules are assembled on the roof integrating drainage, infiltration, isolation and other functions to complete the overall greening of the roof and meet the requirements of sponge city renewal.

Due to strict building height restrictions to accommodate business activities, most of the new buildings in Jixiang Fang decided to use extensive rooftop greening techniques, such as low-cost, easy-to-replace planter boxes.

Figure 23 // GREEN ROOF WITH PARAPET AND LOUNGE SPACE

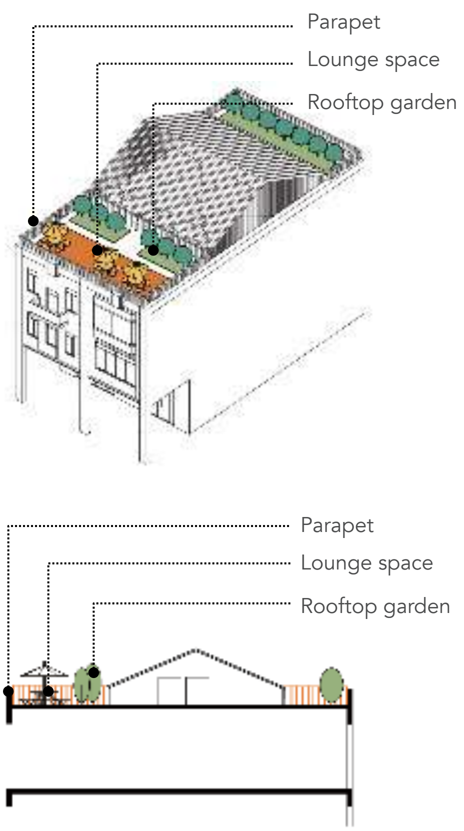
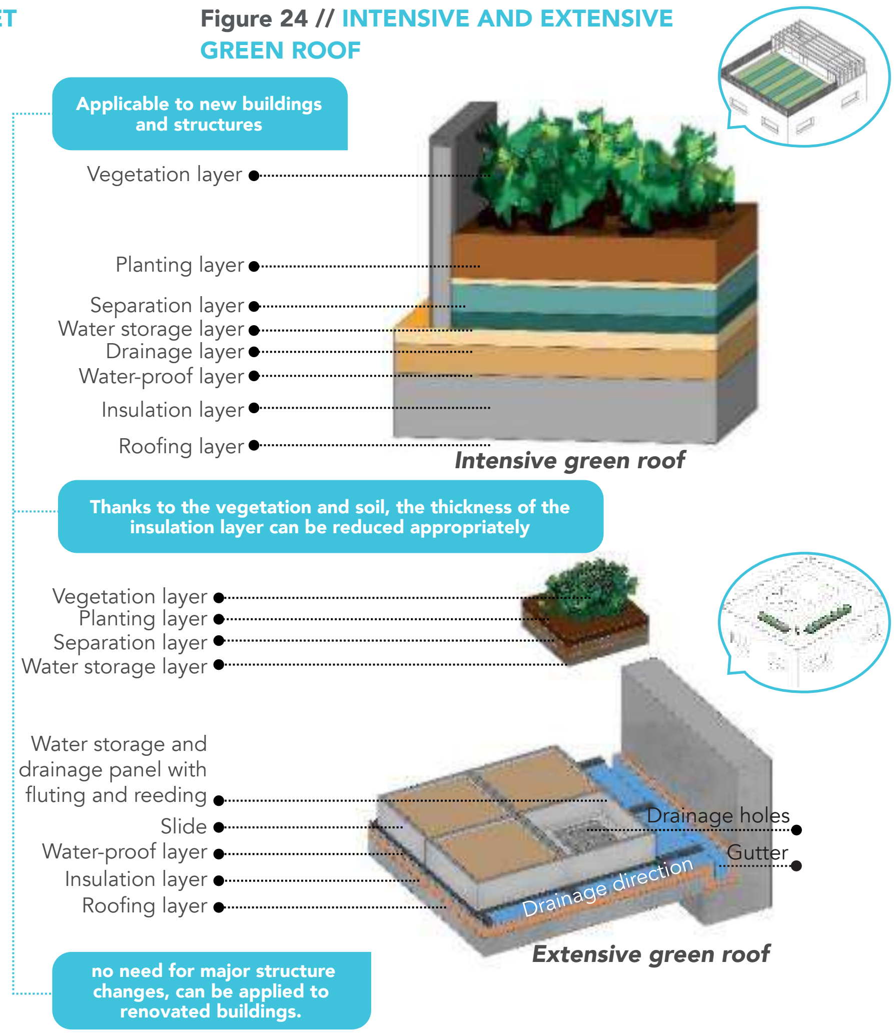


Figure 24 // INTENSIVE AND EXTENSIVE GREEN ROOF



3.6 Landscape level

Based on the surrounding environment of Yongqing Fang, plants, landscape furniture, and the landscape facility complex should be used to increase shelter from the sunlight and rain. At the same time, we recommend combining the use of plants, spraying facilities, water features, and paving materials to create a sustainable water flow system that increases the active evaporative cooling effect.

Plant selection: Guangzhou's native plants and the materials left on the site of Yongqing Fang should influence plant selection. Banyan trees and Boston ivy can be used to form a continuous landscape system.

Landscape furniture: In open spaces, removable landscape furniture is recommended to provide opportunity for rest and recreation. The shading and rain shelter functions of landscape furniture are particularly important.

Spraying facilities: Continue to use the façade spraying facilities and the Yongqing Ring spraying facilities which have already been implemented in Yongqing Fang. Install additional spraying facilities and consider installing solar-powered fans outdoors.

Ground paving: In sections not covered by stone slabs, select the appropriate permeable materials which are in line with the color scheme and style of the neighbourhood. Use permeable paving materials in small open spaces, or consider using the gaps between slabs to store and drain water depending on the topography.

Waterscape facilities: Waterscape facilities can be established on the Enning River to provide a cooling space for public recreation, taking advantage of the evaporative cooling function of bodies of water.

Box 2 // MEMORIES OF BANYAN TREES IN JIXIANG DISTRICT

In the Jixiang district, it is very common to see banyan trees growing up the sides of buildings. Banyan trees are large and lush, exhibiting strong shading and evapotranspiration cooling capabilities. Moreover, banyan trees flourish in warm and humid climates. They can grow quickly, developing many branches.

For a traditional neighbourhood like Yongqing Fang, the banyan tree is the most suitable local cooling tree species. Banyan trees can easily adapt to the environment and have a strong cooling capacity. In addition, banyan trees represent a kind of unique cultural memory of Guangzhou.

Figure 25 // **LANDSCAPE COOLING MEASURES ALREADY IMPLEMENTED IN YONGQINGFANG**

Building façade spray

Banyan tree square


IN THY BEAUTY'S FIELD, THY YOUTH'S PROUD LIVERY SO GAZED ON
WILL BE A TATTER'D WEED OF SMALL
WORTH HELD: THEN BEING ASKED,
WHERE ALL THY BEAUTY LIES, WHERE
ALL THE TREASURE OF THY LUSTY
DAYS, TO SAY, WITHIN THINE OWN
DEEP SUNKEN EYES,

4. Integrated cooling measures in pilot building

4.1 Pilot building context

Location

The pilot building is located to the east of Taihualou, a municipal-level protected heritage site arranged in a classic, garden style layout with strict building height limits.

The building lies on the Lychee Bay River. This river is an important landscape resource for this site, improving the local microclimate.

The building is located in a high-density, traditional neighbourhood with narrow lanes and dense population. With such a compact site, ventilation and lighting should be enhanced through design.

Building information

The total area of this building site is 398 m², and the total floor area is 720 m². The overall building height is 12 meters, though some parts of the building are only 9 meters tall.

The building is owned by the government and will be constructed by Vanke Group with a 20-year lease.

The building will be used for catering, and it will also serve as an important gathering place for residents and visitors alike in the historic district.

4.2 Integrated cooling measures

Three recommendations were made with regard to the design of the pilot architecture.

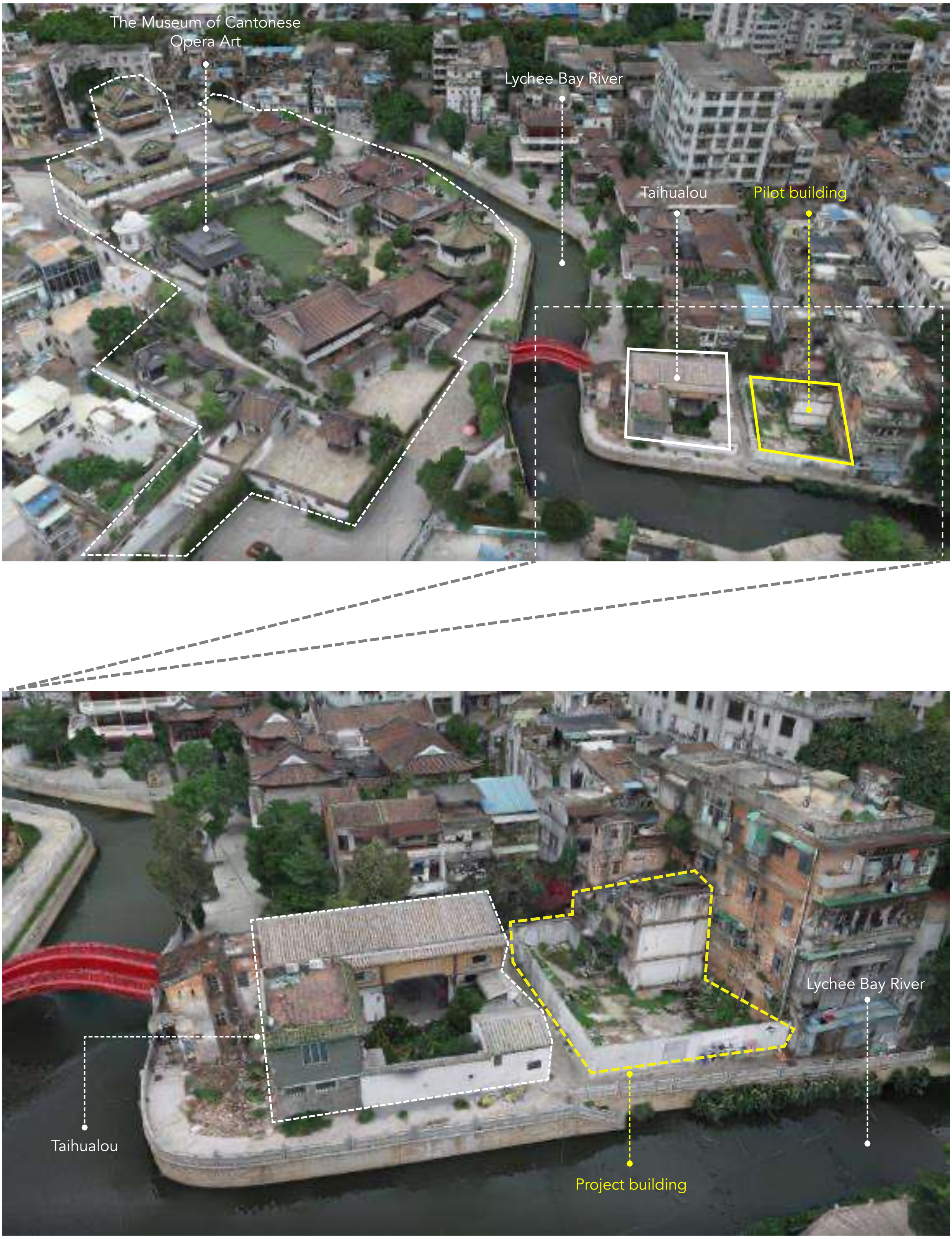
First, there is the issue of excessive use of glass doors and windows. It is recommended to increase the use of traditional Chinese flexible door and window structures and incorporate traditional walls for insulation.

Second, use flexible greening design to bring nature indoors.

Third, it is recommended to incorporate traditional architectural features in the design of eaves by adding some lighter materials or using flexible eaves to enhance the shading effect.

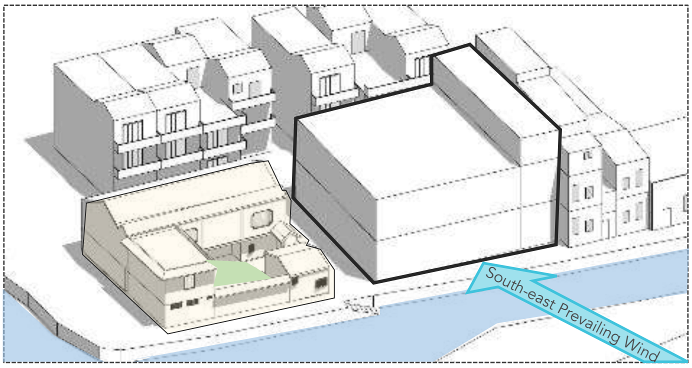
Type	Measure	Application location	Size
Layout	Courtyard layout	Building center, from the 1st floor to roof	Courtyard area≈30 m^2, ≈10% building basal area
	Continuous out-extended balconies	Building north, west and south façade	Periphery≈55m, ≈70% building periphery
Roof	Fixed rooftop greening	Periphery of roof	≈40 m^2, ≈15% building roof area
	Landscape furniture to shield the roof	Building roof	——
	Light-colored roof	Building roof	≈280 m^2, ≈85% building roof area
Façade	100% opened French windows	Building north and south façade	≈350 m^2
	Light-colored reinforced concrete	Building west façade	≈650 m^2,≈ 43% of the western façade area
	Install shading structures	Building north and west façade	≈450 m^2,≈ 26% of the northern and western façade area
	Energy efficient glass	Building north, west and south façade	≈150m^2
Interior	Air-conditioners and fans	All the area	——

Figure 26 // ARIAL VIEW OF THE PILOT BUILDING AND ITS SURROUNDINGS

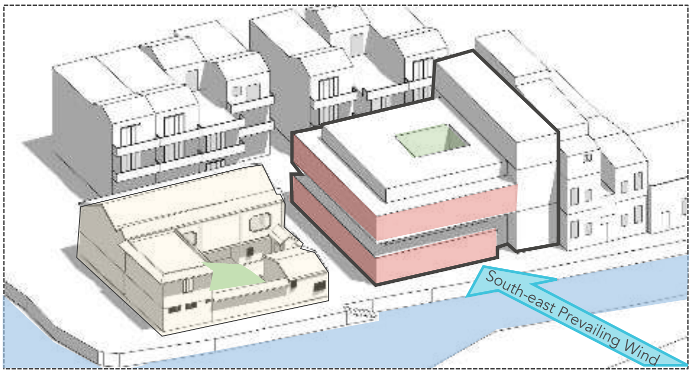


4.3 Building layout ventilation

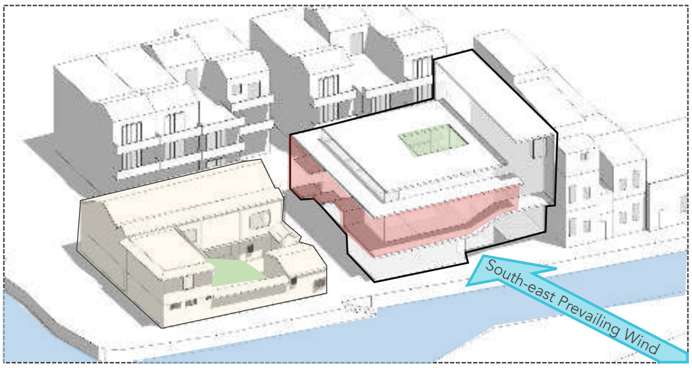
Courtyard layout: Learning from the traditional practice of using patios to improve ventilation, install an open courtyard inside the building to reduce the depth of the interior space and facilitate lighting and ventilation of the interior environment.



Reduce the size: The ground floor and first floor are partially recessed on the western and southern sides to form balconies. This creates a shadow area and a temperature difference within the environment. Moreover, variation in the height of the buildings and the courtyard can facilitate hot pressure ventilation.



Combine solid surfaces with open surfaces: Solid surfaces can be found only on the western side. Open surfaces dominate the spaces that run from the south to the north.



4.4 Building façade design

(1) Design objectives

Avoid creating indoor quasi-calm wind zones: Indoor quasi-calm wind zones refer to areas where the wind speed is less than 0.5m/s, which is an important indicator for indoor natural ventilation.

Formation of through draught: The effectiveness of natural ventilation is related to the ratio of the opening area to floor area as well as their positions. Consideration should be given to the position of the ventilation openings.

(2) Simulation analysis

CFD (Computational Fluid Dynamics) was used to simulate and analyse the indoor natural ventilation of the pilot building. The boundary conditions were set according to the average wind speed and direction of the prevailing winds in the summer and transitional seasons. Natural ventilation simulations were performed for when windows are 25%, 50%, and 100% open, respectively.

(3) Simulation results

All façades should have ventilation openings: The wind openings on the southern, northern, and western sides of the pilot building should be evenly distributed. This can facilitate natural indoor ventilation.

Window opening area should be more than 50% to enable a comfortable indoor wind speed: When the window opening area is 50% and 100%, the average wind speeds in activity areas of pilot building can all reach above 1.0 m/s. Windows can be opened or closed to achieve comfortable conditions when the air-conditioning is off.

Open façades are good for ventilation: The air change rate in the main functional spaces of the pilot building is much higher than 2 times/h, achieving the air change requirement under natural ventilation conditions.

There is no indoor quasi-calm wind zone when the window opening area is 100%: When the window opening area is 50% and 100%, the area of the quasi-calm wind zones in the structure on the pilot building is relatively small, about 12 m^2 and 2 m^2 respectively.

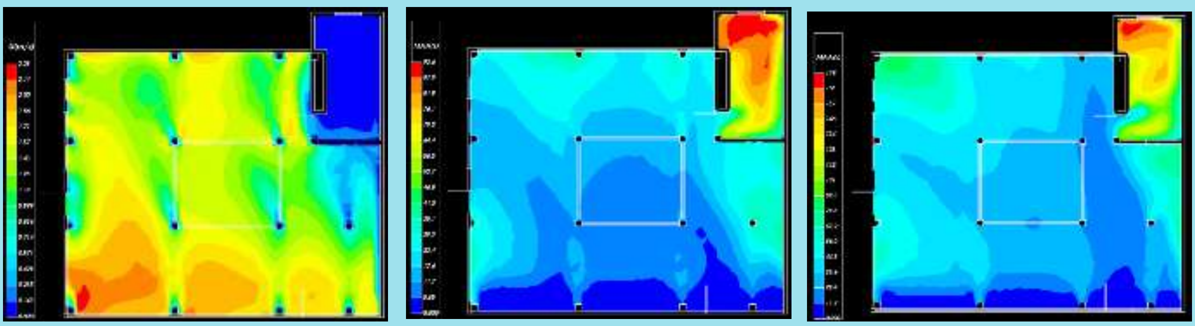
(4) Selecting windows and doors

According to the simulation results, a better indoor wind environment can be achieved when the window opening area is 100%.

In the design process, floor-to-ceiling windows, which can be opened 180°, were selected for the south- and north-facing areas to ensure the proper window opening area and opening height in an effort to maximize ventilation efficiency. The thorough, transparent design in the south-facing area also offered an optimal view.

Fully opened floor-to-ceiling windows

Box 2 // SIMULATION RESULTS OF AIR AGE AT 1.5M ABOVE FLOOR ON THE 2ND FLOOR



100% opened-window 50% opened-window 25% opened-window

4.5 Air-conditioners and fans

a. **Using fans in hot and humid weather can reduce dependence on air conditioning while achieving the same level of comfort.**

Summers in Guangzhou are hot and humid, and active architectural ventilation can effectively reduce indoor humidity and improve comfort. With natural ventilation and the use of electric fans in homes, Guangzhou residents can go without air conditioning for up to six months, significantly reducing building energy consumption.

According to relevant studies, if a fan is switched on in an air-conditioned room, the temperature setting can be set 1 to 2°C higher to achieve the same level of comfort, reducing the number of hours of air-conditioning operation and achieving energy savings.

b. **Compared to using an air conditioning system alone, a linked system of air conditioning and electric fans can reduce air-conditioning cooling load by 31.4%, and energy consumption by 11% throughout the year.**

Multi-connected, air-conditioning systems dominated this design plan. A simulation on the building's annual energy consumption was carried out, ensuring comfort under different working conditions. The catering function of the building, the density of visitors, and other factors were all taken into account.

According to the *Standard for Energy Consumption of Civil Buildings of the People's Republic of China GB/T51161-2016* and the need for indoor thermal environment adjustment, the operational hours of fans were divided into three different working conditions.

Condition 1: In a multi-connected, air-conditioning system, the air-conditioning temperature is set to 26°C with no fan on.

Condition 2: The air-conditioning temperature is set to 27°C with the fan switched on when the natural room temperature is between 26 and 27°C. The air-conditioning cooling load can be reduced by 15.5%.

Condition 3: The air-conditioning temperature is set to 28°C, with the fan switched on when the natural room temperature is between 26 and 28°C. The air-conditioning cooling load can be reduced by 31.4%.

The results show, after using an integrated design of air-conditioning and fans, that the energy consumption can meet Chinese standards. When the temperature for the air-conditioning indoor unit is set to 27°C and 28°C, the corresponding energy saving rates for the two working conditions are 3.0% and 11%, respectively. This indicates that the integrated design of electric fans and multi-connected, air conditioning systems can create significant energy saving benefits for any project.

Table 1 // ANNUAL COOLING LOAD COMPARISON

	Room temperature cap	Annual total cooling load (kW·h)	cooling load area (W/m2)	Reduction rate of the standard setting temperature of air conditioning (%)
Condition 1	26°C	107309.4	55.29	——
Condition 2	27°C	90642.64	46.70	15.5%
Condition 3	28°C	73655.35	37.95	31.4%%

Table 2 // ANNUAL ELECTRICITY CONSUMPTION SIMULATION RESULTS (INCLUDING AIR-CONDITIONING, LIGHTING, AND FANS)

	Room temperature cap	Total energy consumption index (kW·h/m²)	Energy consumption index limit* (kW·h/m²) Shopping mall building (Restaurants)	Energy saving rate (%)
Condition 1	26°C	89.47	85	5.0%
Condition 2	27°C	82.42	85	3.0%
Condition 3	28°C	75.27	85	11%

4.6 Façade Shading and insulation

Add balconies as shading devices

Draw inspiration from the traditional Lingnan architectural design of long, protruding eaves. The pilot building utilizes continuous balconies on the southern, northern, and western façades to increase the shadow area on the building, reducing direct sunlight in the summer.

Shield the sunlight coming from the west

Western sunlight in the summer is one of the main causes of rising indoor temperatures. Recently, a number of classic Lingnan buildings have shown how a special emphasis on using the building façade to provide shading, such as the classic Xia's shading, and the use of horizontal and vertical shading structures, can shield the building from direct sunlight and reduce heat absorption.

The pilot building reduces western sunlight in two ways:

- First, the western façade uses less glass and more light-coloured, clean water concrete with lower heat absorption efficiency.
- Second, 30° vertical shading blinds are installed on the western side to shield sunlight coming from the west in the summer, but allowing sunlight to enter in the winter.

Figure 27 // ILLUSTRATION OF SHADING BLINDS ON THE WESTERN FAÇADE

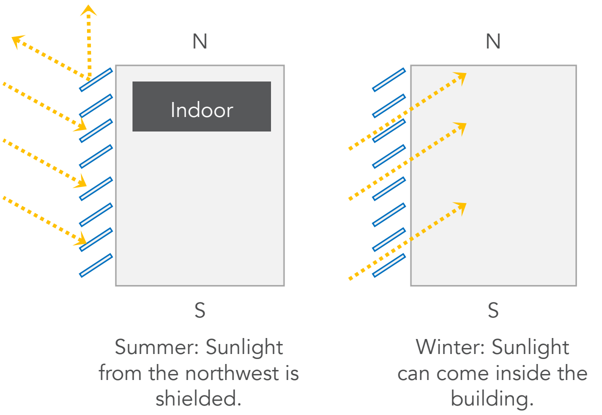
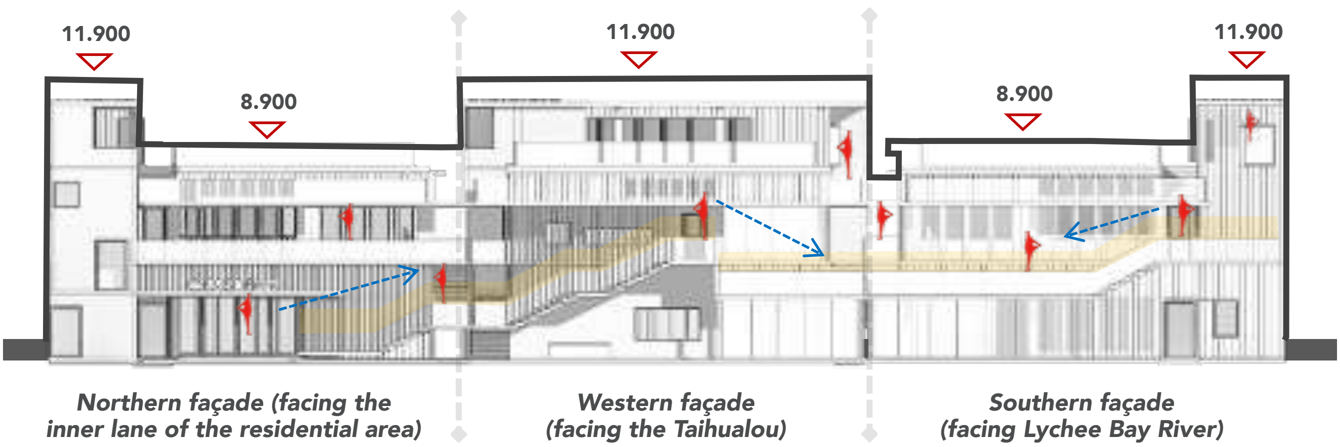


Figure 28 // VERTICAL BLINDS ARE USED ON THE WESTERN FAÇADE

Figure 29 // CONTINUOUS PROTRUDING BALCONIES CONNECTING THE NORTHERN, WESTERN, AND SOUTHERN FAÇADES



Energy efficient glass

The supporting functional rooms (bathrooms, kitchens, etc.) are located on the eastern part of the building, and the façades of these rooms are not suitable for large openable windows and doors. Rather, U-shaped glass elements are used on these small façades due to their energy efficiency, absorbency, and appearance.

Absorbency: Patterned or frosted glass elements were selected. The samples of glass elements were compared with different materials to ensure sufficient lighting while generating diffuse reflections without creating light pollution.

Energy efficiency: Double glazing can be combined with Low-e coating and shading coating to achieve heat insulation and low radiation.

Figure 30 // JOINTS OF DOUBLE-LAYERED U-SHAPED GLASS

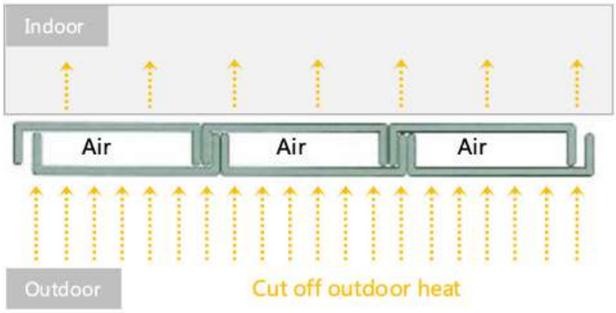


Figure 31 // THERMAL PARAMETERS OF U-SHAPED GLASS WITH DIFFERENG COATINGS

Installation method (from the outside to the inside)	U value (W/m^2K)	g value	Absorvency (%)
Single uncoated	5.7	0.79	86
Double uncoated	2.8	0.68	75
Uncoated+low-e	1.8	0.63	70
Shading+uncoated	2.8	0.49	43
Shading+low-e	1.8	0.45	41
Low-e+low-e	1.1	0.51	45

Figure 32 // INSTALLATION ILLUSTRATION OF DOUBLE-LAYERED GLASS WITH SHADING FILM AND LOW E-FILM

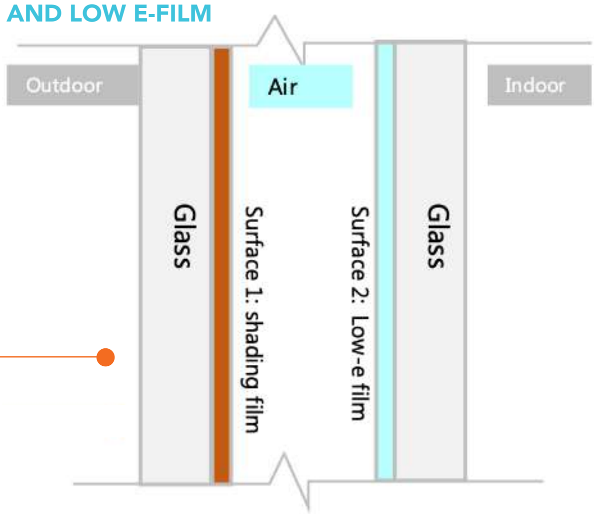


Figure 33 // SAMPLE SELECTION RECORDS OF U-SHAPED GLASS

large pear-pattern wired glass

Sand blasted large pear-pattern glass

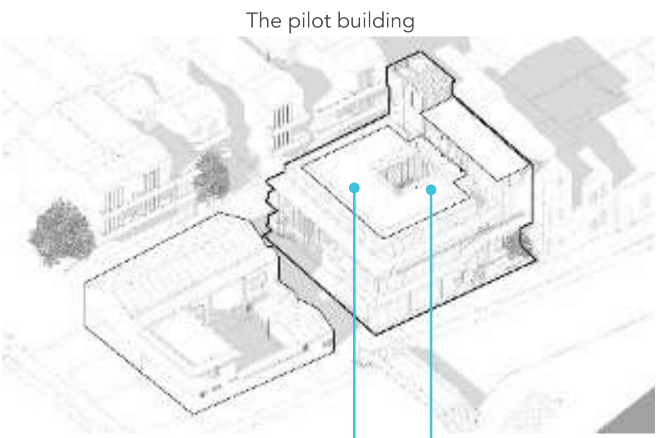
Sand blasted glass sample

4.7 Green roof

Design

Install rooftop gardens that form a functional space for activity with movable green plants, tables, and chairs on the roof to moderately block heat transfer.

Vertical greening will be used on the top of the western and southern façades to block direct sunlight in the summer and prevent heat transfer.



Vertical greening on the top of western and southern façades

Rooftop garden

Selection of plant species

Four suggestions on plant selection were distilled from the analysis of cooling demand.

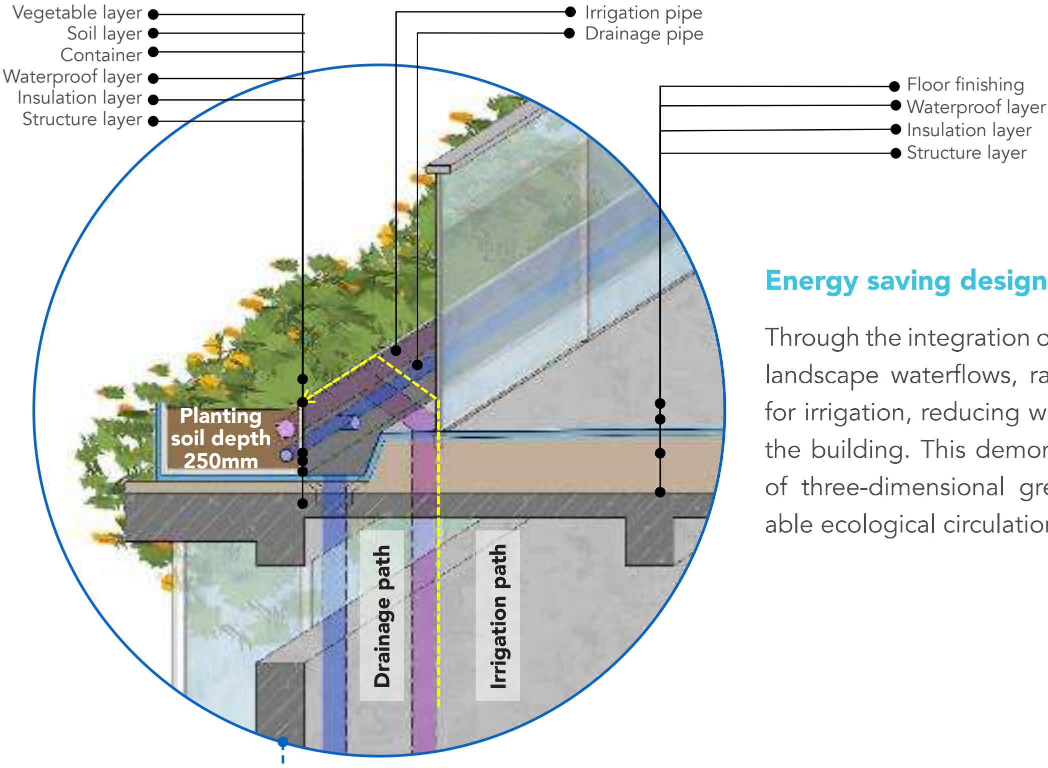
1) Choose climbing plants
Climbing plants not only contribute to rooftop greening but can also produce shadows on the façade, to achieve the overall cooling effect.

2) Choose native plants
Choose native plants with stable growth characteristics, ornamental characteristics and value, strong dust retention and temperature control ability. Avoid invasive species.

3) Choose plants with low maintenance costs
Plants for rooftop greening should have shallow roots and be tolerant of poor soils, disease and insects.

4) Choose plants with seasonal variations
Select plants according to leaf color, flower color and fluorescence to create a beautiful and harmonious rooftop garden that reflects the seasons.

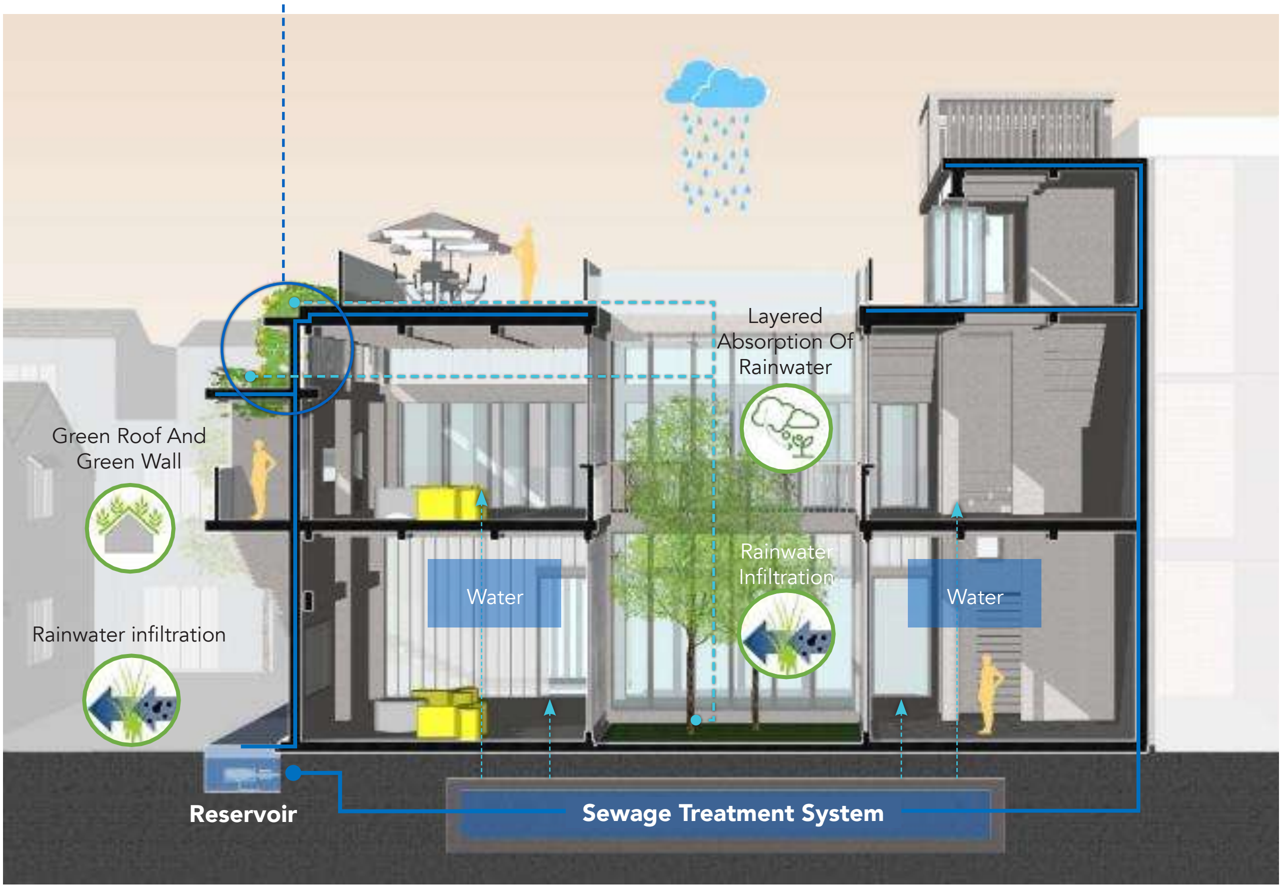
Specific name	Pyrostegia venusta (Ker-Gawl.) Miers	Bougainvillea spectabilis Willd.	Parthenocissus tricuspidata (Siebold & Zucc.) Planch.	Campsis grandiflora (Thunb.) Schum.
Common Names	Flame Vine	Great bougainvillea	Boston ivy	Chinese trumpet-creeper
Type	Woody climbing vine	Woody climbing vine	Woody climbing vine	Woody climbing vine
Flore -scence	Jan. to Mar.	Jun. to Nov.	Jun.	Jun. to Sep.
Origin	South China	South China	South China	South China
Flower color	Salmon	In all colors	Light yellowish-green	Red
Ornamental value	Evergreen plant, lush green leaves with bright orange flowers, forming dense masses, hanging tree heads, like firecrackers	Semi-deciduous plant, keep green in all seasons, flowers are showy as brilliant as samite	Deciduous plant, vine stems along the stone wall can rapidly grow. Its leaves change colors by seasons and the lighting condition in site.	Evergreen plant, with luxuriant branches and leaves. The flowers have bright colors and beauti-ful flower shape
Growth habit	Prefer sunlight and fertile, moist, good drainage sandy soil.	Prefer a warm, humid, sunny environment and is not cold resistant. The best soil is sandy loam with good drainage	Prefer damp environment, but can also bare strong light, cold, drought, barren, with high climate adaptability	Prefer full sunshine, but tolerate semi-shaded. Strong adaptability, cold, drought, barren, pests and diseases resistant. It also has certain resis-tance to moisture, salt and alkali
Image				



Energy saving design

Through the integration of roof, courtyard and landscape waterflows, rainwater is collected for irrigation, reducing water consumption of the building. This demonstrates the concept of three-dimensional greening and sustainable ecological circulation.

Energy saving system in pilot building



Credit: ben-bryant | istock.com

5. Implementation process

5.1 Cost and budget

According to preliminary estimates, urban cooling measures will incur an engineering cost of US$80,000-90,000, while the engineering cost for the entire Jixiang section is around 10 million dollars. There is no significant increase in engineering costs, and the developer will bear all costs.

According to relevant studies, for each US$1.0 invested in urban passive cooling measures, there will be net benefits of US$1.5-15.20 (Estrada, Botzen, and Tol 2017). The residents living in the area and renters of local businesses will benefit from the cooling measures.

5.2 Stakeholders

- **Government:** The city of Guangzhou is committed to green and sustainable urban development. It also facilitates the review and application of leading urban cooling design. However, there is no specific governmental body responsible for policy development, funding, and implementation of urban cooling solutions. Hence, there is a significant lack of practical support for the actual implementation of these measures.
- **Developer:** The developer of Yongqingfang Vanke is committed to becoming a benchmark for real estate companies and has been continuously delivering innovations in its products. The Yongqingfang Project is Vanke's flagship project in Guangzhou's old town redevelopment initiative. In addition to the economic benefits, this project also aims to achieve social impact. While Vanke is motivated to explore the application of sustainable cooling measures, their key aim is to engage and encourage other real estate companies and developers to follow suit. A potential question is how to incentivize the developers to install cooling measures.
- **Residents:** Residents of Yongqingfang are not overly concerned about micro-climate environmental issues, but they are supportive of the city's cooling measures and hopeful that their implementation will drive up housing prices. Residents are mostly concerned about noise control and air pollution, such as dust caused by construction.
- **Renters:** Renters often removed windows and doors and altered facades without permission when decorating the shop. This hindered the implementation of cooling measures. It is recommended that rent reductions may be given to businesses based on the implementation of cooling measures.

Category	Measures	Size	Cost
Greening	Fixed rooftop greening	≈220m²	Increased cost ≈50,000 dollars
	Ground-grown vertical greening along walls	≈240m²	
	Movable rooftop greening	Total length ≈50m	
Architecture	Rooftop reflective coating	≈790m²	Increased cost ≈35,000 dollars
	Double-layered tile roofs	≈350m²	
	Install shading structures on the curtain walls of the east, west, and south sides as well as on the rooftop skylight.	≈320m²	
	Install flexible windows and doors such as Tanglong doors and lattice windows.	≈20	

A pocket square in YongQingfang

6. Conclusions and recommendations

6.1 Conclusions

In this pilot project, the cooling measures assessed are applicable to historic and traditional buildings and are consistent with the area's historic style. The cooling approaches deployed are proven to be practical and replicable.

Two major directions of urban cooling strategies were developed. The first was to explore and inherit traditional Lingnan architecture and its application of ventilation, shading, and heat insulation measures, adapting them for contemporary building. The second was to identify sustainable, low-cost, cooling techniques that could be adapted to the local environment, utilizing Guangzhou expertise.

The use of green building simulation technology was explored to provide scientific evidence for small architectural design projects within high-density, historic, urban areas. With the overall wind environment of high-density, historic areas in mind, indoor, natural ventilation simulation analysis and building energy consumption simulation analysis were used to facilitate a coordinated design. Building forms, layouts, and façades were adjusted according to analysis results to optimize the physical environment of the building.

6.2 Recommendations

Not all cooling measures are suitable for all uses. When screening the urban cooling actions, there should always be a strategy of determining the city's unique and local solutions.

Throughout history, cities have adapted to their unique local climate, so it is feasible to explore the passive climate adaption techniques in traditional styles and architecture. These techniques, like the arcades and patios in Guangzhou, are typically low-cost and showcase the city's characteristics. They can be inherited as the city's traditional cooling identity.

Annex: A summary of cooling measures used at the building level in the Jixiang section of Yongqing Fang Phase II Project:

				Original building information						Renovated building information						
No.	Building No.	Property ownership	Construction method	Height (m)	No. of floors (floors)	Floor area (m^2)	Form of roof	Type of structure	Function	Height (m)	No. of floors (floors)	Floor area (m^2)	Form of roof	Type of structure	Function	Building cooling measures
1	Dadi Old Street, No. 5	Public	Newly built	Originally unused space						7.145	1	375.83	Flat and sloped roof	Steel bar and concrete	Commercial	• Ground-grown, vertical greening on the east façade • Shading structures should be added to the glass curtain walls on the east and west façades as well as on the rooftop skylight. • Movable rooftop greening can be included on the terrace of the first floor; at least 20% of the rooftop accessible to people should be covered in green plants. • Flat roofs not covered by green plants should use light-colored reflective coating (including rooftops accessible to people and terraces used for the placement of equipment. • Add double-layered tile roofing and reduce the heat transferred to the inside from the roof. • Install flexible windows and doors such as Tanglong doors and lattice windows at Dadi Old Street, No. 7 to improve ventilation and lighting.
2	Dadi Old Street, No. 7	Public	Renovated	8.715	2	135.703	Sloped roof	Brick and concrete	Residential	8.85	2					
3	Shiliu Fu, No. 19	Public	Renovated	8.715	2	225.3	Sloped roof	Brick and concrete	Residential	9.445	2					

No.	Building No.	Property ownership	Construction method	Original building information: Height (m)	No. of floors (floors)	Floor area (m²)	Form of roof	Type of structure	Function	Renovated building information: Height (m)	No. of floors (floors)	Floor area (m²)	Form of roof	Type of structure	Function	Building cooling measures
4	Dadi Old Street, Nos. 2, 4	Public	Newly built	Originally unused space						10.56	2	502.25	Flat and sloped roof	Steel bar and concrete	Commercial + public toilet + micro fire station	• Design the west and north façades using vertical greening. • Shading structures should be added to glass curtain walls on the east and west façades as well as on the rooftop skylight. • Flat roofs, not covered by green plants, should utilize light-colored, reflective coating (including rooftops accessible to people and terraces used for the placement of equipment. • For courtyard layouts, increase the area of open spaces and improve building ventilation. • Install flexible windows and doors such as Tanglong doors and lattice windows to improve ventilation and lighting.
5	Dadi Old Street, No. 6	Public	Renovated	8.135	2	174.62	Sloped roof	Brick and concrete	Residential	10.032			Sloped roof			
6	Dadi Old Street, Nos. 16, 20	Public	Demolished and re-constructed	10.385	4	520.29	Flat roof	Steel bar and concrete	Vacant	13.306	4	508.27	Sloped roof	Steel bar and concrete	Commercial + office	• Movable rooftop greening can be included on the terrace of the first floor. • Flat roofs not covered by green plants should use light-colored, reflective coating (including rooftops accessible to people and terraces used for the placement of equipment. • Leave stilts on the ground floor to offer shelter from the wind, rain, and sunlight and provide a comfortable space for pedestrians.

No.	Building No.	Property ownership	Construction method	Original building information: Height (m)	No. of floors (floors)	Floor area (m²)	Form of roof	Type of structure	Function	Renovated building information: Height (m)	No. of floors (floors)	Floor area (m²)	Form of roof	Type of structure	Function	Building cooling measures
7	Dadi Old Street, No. 13	Public	Newly built	Originally unused space						7						• Movable rooftop greening can be included on the terrace of the second floor, and green areas should take up at least 80% of the space. • Flat roofs not covered by green plants should use light-colored, reflective coating (including rooftops accessible to people and terraces used for the placement of equipment. • Install flexible windows and doors such as Tanglong doors and lattice windows at Dadi Old Street, No. 15, 17 to improve ventilation and lighting.
8	Dadi Old Street, No. 15	Public	Demolished and re-constructed	11.54	3 Part of Building 2	177.68	Flat and sloped roof	Brick and concrete	Vacant	12.2	3 Part of Building 2	396.1	Flat and sloped roof	Steel bar and concrete	Commercial + office	
	Dadi Old Street, No. 17	Public	Demolished and re-constructed	11.315	3 Part of Building 2	176.97	Flat and sloped roof	Brick and concrete	Vacant							
9	Jixiang Fang, No. 2	Public	Renovated	8.77	2	144	Flat and sloped roof	Brick and concrete	Residential	17.769	2	1860.3	Sloped roof	Steel bar and concrete	Commercial	• Shading structures should be added to the glass curtain walls on the east and west façades as well as on the rooftop skylight.
10	Dadi New Street, No. 22	Public	Renovated	14.26	3	151.56	Flat roof	Brick and concrete	Residential	13.66	3	119.53	Flat roof	Steel bar and concrete	Commercial	• Movable rooftop greening can be included on the terrace of the first floor, and green areas should take up at least 80% of the spaces. • Flat roofs not covered by green plants should use light-colored, reflective coating (including rooftops accessible to people and terraces used for the placement of equipment. • Install balconies to increase the shading area of the building façade, reduce the amount of sunlight directly coming into the rooms.

No.	Building No.	Property ownership	Construction method	Original building information: Height (m)	No. of floors (floors)	Floor area (m²)	Form of roof	Type of structure	Function	Renovated building information: Height (m)	No. of floors (floors)	Floor area (m²)	Form of roof	Type of structure	Function	Building cooling measures
11	Dadi New Street, No. 25	Public	Newly built	Originally unused space						17.846	3, part of the build-ing 2	1202.86	Flat and sloped roof	Steel bar and concrete	Commercial	• Add ground-grown, vertical greening on the west façade. • Fixed rooftop greening can be included on the terrace of the first floor, and green areas should take up at least 80% of the spaces. • Flat roofs not covered by green plants should use light-colored, reflective coating (including rooftops accessible to people and terraces used for the place-ment of equipment. • Add double-layered tile roofing, and reduce the heat transferred to the interior from the roof.
12	Dadi New Street, Nos. 35, 37, 39	Public	Demolished and re-con-structed	Originally unused space						12.6	3	127.41	Flat and sloped roof	Steel bar and concrete	Commercial	Add ground-grown, vertical green-ing on the west façade. Flat roofs not covered by green plants should use light-colored, reflective coating (including rooftops accessible to people and terraces used for the placement of equipment. Add double-layered, tile roofing, and reduce the heat transferred to the interior from the roof.
13	Dadi Old Street, No. 26	Public	Newly built	Originally unused space 17.997						8.77	2	137.3	Sloped roof	Steel bar and concrete	Commercial	Movable rooftop greening can be included on the terrace of the first floor. Add reflective coating on the sloped roofs of newly built com-mercial buildings. Use double-layered tiles on part of the sloped roof. Install flexible windows and doors such as Tanglong doors and lattice windows to improve ventilation and lighting.
14	Jixiang Fang, No. 12-2	Public	Newly built	3, part of Building 2 1188 Flat and sloped roof Steel bar and concrete 17.997 3						Com-mercial						
15	Jixiang Fang, No. 13	Public	Newly built	1183.8 Flat and sloped roof Steel bar and concrete						Com-mercial						

PART 2

China-Singapore Guangzhou Knowledge City Pilot Project

1. Project overview

China-Singapore Knowledge City is a new town consisting of outer suburbs, located in Jiulong Town, Huangpu District, in the eastern part of Guangzhou.

The planned area is 178 km^2, of which 90 km^2 will be developed. It is a national-level, bilateral, cooperative project between the governments of China and Singapore.

Benchmarked against international best practices, China-Singapore Knowledge City has incorporated good experiences into its design with a focus on sustainability. The Knowledge City is one of excellent examples of green development in the country .

The Jiulong Lake district is the pilot area for the cooling project.

Figure 34 // LOCATION OF CHINA-SINGAPORE KNOWLEDGE CITY AND JIULONG LAKE AREA

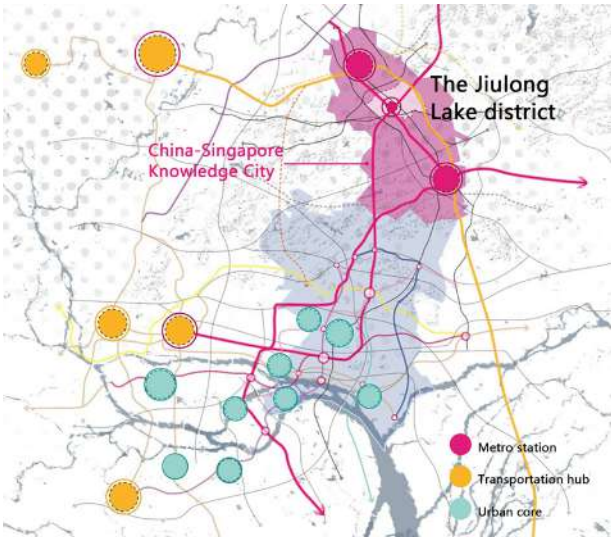


Figure 35 // RENDERING OF THE JIULONG LAKE DISTRICT PLAN

Source: China-Singapore Knowledge City development and construction office

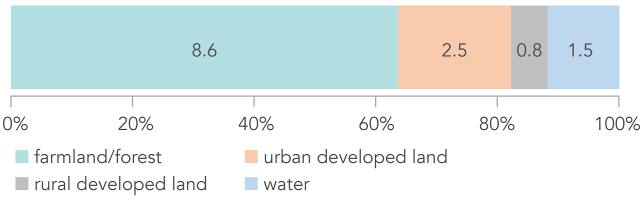
The Jiulong Lake district is situated in the heart of China-Singapore Knowledge City. It has an area of 12.6 km^2 and a population of approximately 34,000. In the future, it will accommodate 140,000 people and become the hub of Knowledge City and the headquarters for the core economy, providing information services, premium services, commercial and business services, and integrated support services.

The area surrounding Jiulong Lake is primarily undeveloped. Water resources, farmlands, and forests account for 82.9% of the total land area. Construction will occur on rural, residential, and industrial lands, primarily located on both sides of Open Avenue. The main body of Jiulong Lake has already been completed, and it now forms a sizeable lake spanning roughly 70 hectares.

This is a new development project utilizing a site-level, government-led process. The site is currently in the planning stage, so cooling solutions will need to be included in the urban plan, and later, the land sale contracts. Ultimately, this project will provide a useful template for other new developments in the future.

An aerial view of the China-Singapore Knowledge City Jiulong Lake area

Figure 36 // TOPOGRAPHICAL AREAS IN THE JIULONG LAKE SECTION OF CHINA-SINGAPORE KNOWLEDGE CITY



Box 3 // HIGH STANDARD OF GREEN DEVELOPMENT IN CHINA-SINGAPORE KNOWLEDGE CITY

China-Singapore Knowledge City is committed to creating a high quality, urban-ecological environment with 100% green buildings while incorporating the idea of a sponge city. In August 2020, it was awarded a three-star, green, ecological urban design certificate by the Chinese government.

More than 85% of newly constructed green buildings have been rated two-star green buildings or above, and the proportion of three-star green buildings will eventually reach 40%. To raise the star rating requirements for energy-intensive public buildings, no less than 90% of buildings should be green buildings with a high star rating.

Source: China-Singapore Knowledge City development and construction office

Photos of the China-Singapore Knowledge City development

2. Select list of cooling measures

Consulting and decision-making processes similar to the Yongqingfang project were used in the Knowledge City project. Local experts from South China University of Technology and international experts from the Natural Capital Project joined this project to support modeling and assessment of cooling strategies.

5 types of cooling measures (*district cooling, cool coatings, water sensitive actions, 3D greening and climate responsive design)* were assessed by the expert teams, local teams (Guangzhou Urban Planning & Design Survey Research Institute and South China University of Technology) and China-Singapore Guangzhou Knowledge City Development and Construction Office ofice. Three priorities were determined when screening the measures:

1. Find synergies with the ongoing Sponge City actions, maximizing the effect of evaporation cooling and stormwater management.
2. Pursue cooperation with the Singapore government, introduce experiences from Singapore such as 3D greening, void deck, district cooling.
3. Emphasize solutions in the planning process like climate responsive design to promote wind flow and minimize solar radiation in urban texture, which is not feasible in a developed area but very important in a newly developing area.

Expert team	Local team	CSGKC office
District cooing	• Recommended • This effective technology has already been utilized in Zhujiang New Town and college city.	• A tentative decision has been made to use direct central cooling in the International Convention Centre. • Application of this technology in the Knowledge Green Valley area depends on whether investment capital will come into this area.
Solar reflective coatings	• Recommended • Surface and façade reflective coatings should be used on residential buildings. • High-albedo pavement is relatively new with limited material availability in domestic market, it is not currently recommended for use at a scale.	• Apart from using cool roofs, solar PV is another viable option. The widespread application of solar PV shall be determined by the correlation between the cost of solar PV design, equipment, and labor verses the potential return on investment (savings)
Water sensitive actions	• Highly recommended • A combination of the ongoing Sponge City with Cooling actions. • To reduce road surface temperatures, permeable road surfaces and roadside mister systems are prior choices.	• Presently, pebbles have been considered for use in paved surfaces to increase rainwater drainage and lower temperatures. • Roadside misters better use grey water and rainwater, that means new plumbing must be constructed and laid, which will increase investment costs.
3D greening	• Highly recommended • To insure a successful outcome, it is also recommended to launch relevant incentive policies for vertical greening. • Self-maintenance	• It is difficult to require private owners to carry out maintenance of 3D greening after the completion and acceptance of the project, resulting in some investment waste. • The residences are very concerned about the leakage damage result from green roof, it might be problematic to use this technology in residential buildings. • It is necessary to experiment with 3D greening species which are suitable to be grown in Guangzhou.
Climate responsive design	• Highly recommended • Especially important to a new city • Void ground and covered walkways are very important	• Choose a typical site in Jiulong lake district to do demonstration design as a good example for other areas to follow. • Transfer the principles to general guidelines in order to apply in other areas.

Box 4 // MULTILATERAL PARTICIPATION AND JOINT DECISION-MAKING IN THE CHINA-SINGAPORE KNOWLEDGE CITY DEMONSTRATION PROJECT





No.	Date	Organisations involved	Work items and agenda
1	2020.1.17	GMPNRB I GZPI I CSGKC office	Engage the China-Singapore Knowledge City Development Office regarding the location of the demonstration project.
2	2020.4.17	GMPNRB I GZPI I CSGKC office I Design agencies	Exchange views on specific issues: eco-friendly design approach, current status, range of the demonstration project, vertical greening of Knowledge City, development of a sponge city.
3	2020.4.22	Guest experts I GMPNRB I GZPI	Provide consulting advice on the cooling of the area surrounding Jiulong Lake and Knowledge Green Valley.
4	2020.5.11	GZPI I South China University of Technology	CFD simulation launch of the China-Singapore Knowledge City Green Valley project.
5	2020.5.27	NatCAP team I GMPNRB I GZPI	Launch the inVEST urban cooling model calculation.
6	2020.6.24	GZPII South China University of Technology	Discuss the feasibility of each cooling measure.
7	2020.7.22	GMPNRB I GZPI I CSGKC office I Design agencies	Consult with the Development Office and design agencies regarding specific urban design solutions, improve the drafting and shading design of Knowledge Green Valley.
8	2020.7.30	NatCAP team I GMPNRB I GZPI	Discuss the work approach for the inVEST urban cooling model calculation.
9	2020.8.12	NatCAP team I GMPNRB I GZPI	Initial discussion on the calculation range, situation setting, and data allocation of the inVEST urban cooling model.
10	2020.9.9	Guest experts I GMPNRB I GZPI I CSGKC office	Review the cooling plan for the area surrounding Jiulong Lake and Knowledge Green Valley area.

**GMPNRB:* Guangzhou Municipal Planning and Natural Resources Bureau; GZPI: Guangzhou Urban Planning & Design survey research institute; CSGKC: China-Singapore Guangzhou Knowledge City

3.Sustainable cooling solutions

3.1 Key measures and requirements

From the 5 types of cooling measures assessed, the following list of requirements was formed, which will be included in the planning conditions during land sale process.

District cooling

Set up an energy station, use district cooling systems to reuse waste heat for cooling purposes.

Solar reflective coatings

Use solar reflective roofs as an alternative for non-green roofs. Greening areas and areas with a solar radiation reflective coefficient of no less than 0.4 should make up 75% of the total rooftop area.

Water sensitive actions

Promote the widespread use of permeable surfaces; use semi-natural/natural systems to increase water infiltration and storage. No less than 70% of the outdoor parking lot, pedestrian street, bicycle path and external courtyard of new developments should be permeable paving.

3D greening

Promote 3D greening, especially green roofs, green walls and sky gardens. The green buildings in Jiulong lake district should implement 3D greening.

Climate responsive design

The urban layout and architectural design should be in line with wind direction and light paths. Select the green knowledge valley to set an example.

3.2 Implementation

To promote the implementation of the cooling solutions, both mandatory activities and voluntary incentives are recommended to engage the private sectors and encourage the public.

Mandatory Activities

Ventilation must be addressed in the process of urban designs to comply with ventilation control requirements.

Developing projects located in strategic areas, projects with big construction volume, or projects with significant changes in building intensity should assess the wind ventilation impact that may result from the implementation in the submitted proposals.

For long-length buildings, super high-rise buildings and other construction projects that may have a significant impact on the urban wind environment, experts should pay special attention to urban design research and demonstrations of climate and ventilation during review.

Incentives

- **Arcade and void deck:** Encourage elevated design of the ground floor of buildings. The public open space of void decks and the covered walkways formed by arcades along the road are excluded from the floor area ratio (FAR) if they satisfy the specific requirements.
- **3D greenery:** Vertical greening, rooftop greening, and public overhead platform greening are recommended. The greening areas of public overhead platforms will be included in the green area ratio,

and the discounted coefficient will be determined by soil depth.

- **Covered linkages:** Build covered linkages between metro stations, bus stations, and routes to residential communities. Include shading corridors in the standards for public service infrastructure construction in Knowledge City. Outdoor covered linkages will not be included in the calculation of floor area ratio or building density.

3.3 InVEST modeling of cooling effect

InVEST modeling was introduced in the planning stage to assess the potential outcomes and benefits of the cooling activities.

Two land use statutory plans were evaluated, and the results show a considerable increase in cooling capacity and improvement in micro-climate conditions with the urban cooling solutions plan. Details can be found in the annex "*Cooling benefit calculation based on the InVEST model*".

Figure 37 // ELEVATED GROUND FLOOR: EXCLUDE FROM FLOOR AREA RATIO (FAR) IF SPECIFIC REQUIREMENTS ARE SATISFIED.

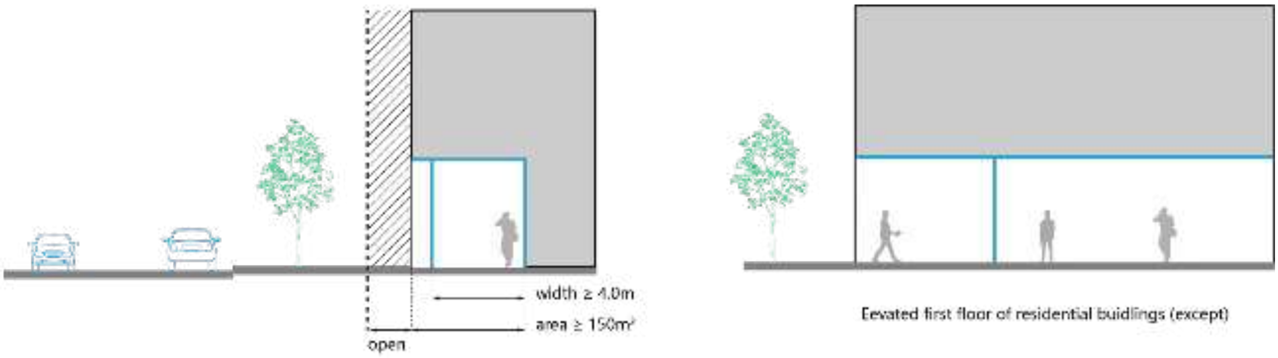
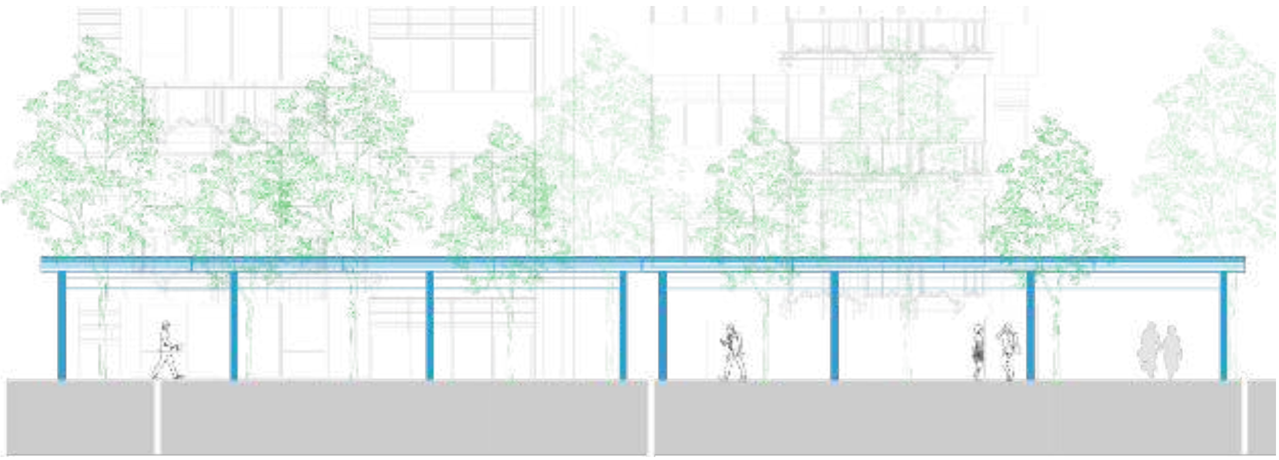


Figure 38 // 3D GREENING: INCLUDED IN THE GREEN AREA RATIO

Figure 39 // COVERED LINKAGES: EXCLUDED FROM BUILDING INTENSITY



4. Sustainable cooling demonstration design

To establish a paradigm for the future developers, the Knowledge Green Valley along the lake was selected for demonstration of cooling urban design. This will provide a good reference for the rest of the Jiulong lake district in the future as development continues.

4.1 Pilot Site Location

The Knowledge Green Valley sits at the heart of the area surrounding Jiulong Lake and the western part of the key area. It spans approximately 20 hectares, and it is located to the north of the International Convention Centre. Green Valley is a key part of Knowledge City's central axis. It is poised to become a dynamic, innovative neighborhood with a mixture of scientific research offices and apartments for industry talent. This scenic area is dotted with small hills and covered in secondary forest.

4.2 Wind conditions

Background wind information obtained from the Knowledge City weather station indicates that, in the summer, prevailing winds are mainly south, south-south-west and south-east winds. Future land changes will increase the areas of southeast-facing Jiulong Lake and southeast-facing waterways. Southeast-northwest circulation may be enhanced in some parts of the Green Valley. Therefore, the urban design of Knowledge Green Valley should focus on the diversion of southeast and south winds.

4.3 Cooling sources

Laohulong Reservoir in the northwest part of the site and Jiulong Lake in the southwest part are both large water bodies, which should be considered as critical cooling sources in the planning and design process. The site primarily consists of hills covered in secondary forests, so low impact development and microtopography design need more attention.

Figure 40 // ORIGINAL PLAN: WINDS AT LOW AND HIGH LEVELS ARE BLOCKED

4.4 Suggestions on Original plan

(1) Main ventilation corridors

Laohulong Reservoir, located in the northern part of the main ventilation corridor, is planned to be removed. This will significantly reduce the cooling source within the site, and the effects of the main ventilation corridor will not be maximized. It is recommended to keep the reservoir.

The green, open spaces within the project site are not connected to the main ventilation corridor and are located downwind, preventing the corridor from maxi

mizing the cooling effect. The green space should be moved to the main ventilation corridor, which should also be widened.

(2) Building layout

The interfaces along the river are currently not permeable, and breezes along the river cannot enter into the building cluster. It is recommended to leave the riverside interfaces permeable and divert river breezes into the block.

There is no opening in the southeastern and southern directions of the building complex, and wind cannot enter the blocks. The arrangement of the buildings should be adjusted to leave openings in the southeastern and southern directions.

There are no built structures in the western part of the green space, so effective shading is missing. The green space should be moved to the main ventilation corridor.

(3) Building Height

There is little to no variation in building height, which is adverse for site ventilation. The height of buildings should be gradually increased as they move further away from the riverbank or lakeside.

Buildings in the western part of the site are not elevated to provide shading for the site. Hence, taller buildings should be placed in the western part of the site.

(4) Building morphology

There are too many building podiums. These buildings will significantly impede air flow and affect ventilation at the pedestrian level. Building gaps/separations and void decks are recommended to reduce ground coverage.

Buildings have not been designed to increase permeability or reduce building frontage. Hence, structures featuring hollowing, smooth, curved forms should be increased.

Figure 41 // ORIGINAL PLAN: WINDS AT LOW AND HIGH LEVELS ARE BLOCKED

Source: China-Singapore Guangzhou Knowledge City Development and Construction Office

4.5 Optimized plan

Maximize site ventilation

- a ventilation corridor system of one main corridor and five secondary corridors is created;
- open spaces and green spaces are interconnected to form a network to direct winds.
- A stepped building height profile is adopted. The building heights gradually increase as they move away from the river and lake to increase ventilation capacity.
- The orientation of waterfront buildings, as well as hollow-up and streamlined building forms, are well-arranged to channel the river breeze.

Building blockage is reduced by subdividing the podium structure, using voids and setbacks. Layout of the buildings are aligned with topography to form a local micro-circulation.

Minimize solar radiation

- Taller buildings are located in the western part of the site to create effective shading.
- The height distribution of buildings is optimized to increase shading for open spaces in the center.

Use water and greenery cooling

- Keep the existing Laohulong Reservoir, and plan to build a linear park to form a landscape ventilation

Source: China-Singapore Guangzhou Knowledge City Development and Construction Office

corridor together with Jiulong Lake, which will stand parallel to the prevailing winds.

- Place more vegetation in the green spaces and parks, and control vegetation density.
- Lower air and ground temperatures through shading and evaporation.

Provide sun and rain protection

- Build a continuous, covered corridor system that stays free from the impact of wind and rain
- Control interface continuity. Continuity should be no less than 70% on both sides of major roads and no less than 50% alongside the main corridor.
- Elevated ground designs are encouraged, along with a combination of covered corridors, arcades, and overhanging eaves.

Maximize site ventilation

- From the experience of Singapore's LUSH program, the combined total of regular greening and vertical greening is increased to 100%.
- Buildings are crafted with a diversity of 3D greenery measures, including sky gardens, vertical greening, and green roofs, creating a three-dimensional urban forest.
- Hollow buildings and high-rise green spaces are utilized to allow breezes to infiltrate while providing community areas.

Design with topology

- Hilly microtopography and low-lying areas are combined to form rain gardens and wetland parks; a tidal landscape of green areas and water is fostered.
- Urban space is combined with natural elements such as ponds, low hills, and vegetation to form knowledge units. The overall layout follows the contours of the hilly topography, and public spaces are planned based on the topography.
- The architectural design takes the connection with hills into full account. The use of stilts, three-dimensional setbacks, and other techniques are integrated with nature.
- Both elevated floors and staggered floors are used, and vertical greening helps to integrate with micro-hills, thus forming a complete, connected, three-dimensional greening system.

Source: China-Singapore Guangzhou Knowledge City Development and Construction Office

- The use of a microtopography design protects the original ecology, utilizes slope to form local breeze circulation, implements low-lying areas to form rain gardens, and creates vertical green spaces.

4.6 Ventilation performance evaluation

Use CFD (Computational Fluid Dynamics) to perform evaluations on the wind environment around buildings.

Boundary conditions

Use average wind speed statistics collected by weather stations covering China-Singapore Knowledge City from 2017 to 2019, consider the site environment, and determine and simulate the working conditions of easterly and southeasterly winds.

Wind direction	wind speed	height
south	1.88	10 meters
southeast	1.18	10 meters

Computational domain

The vertical height between the top of building(s) and the upper boundary of the computational domain should be more than 5 times the height of the highest building. The distance between the edge of the building(s) and the horizontal boundary of the computational domain should be more than 2 times the site width .

Simulation result

The wind velocity maps were developed from the simulation results. Wind velocity ratio is the ratio of wind velocity at one specific point to the boundary wind velocity, which is an important criteria to evaluate the ventilation performance.

According to the results, the wind environment of the new plan is better than that of the original plan. The Knowledge Green Valley shows better ventilation efficiency in southeast prevailing wind than in south wind.

With the southeast prevailing wind, the ventilation efficiency of the main ventilation corridors, building clusters, and river interfaces have been improved under the new plan.

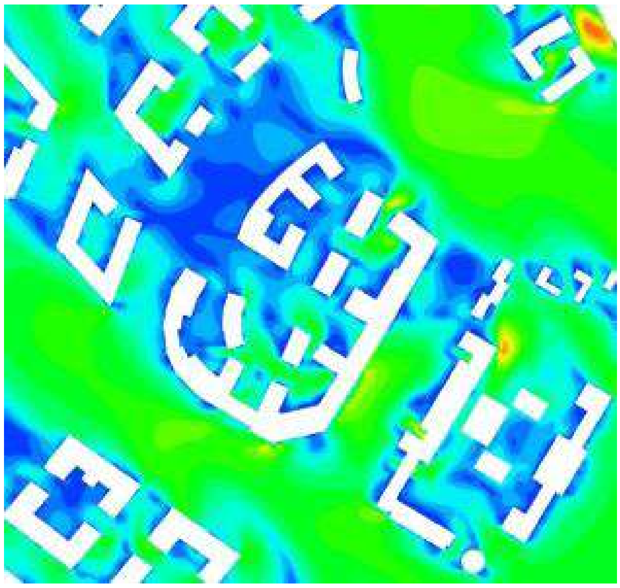
With the south prevailing wind, the ventilation efficiency of the southeast cluster and the eastern section of the ventilation corridor has also been improved significantly. However, there are more windless shadows in the buildings behind.

Original plan

Buildings in the back were hugely affected by wind shadow, and wind speed inside the building cluster was relatively slow. The cooling effect of the main ventilation corridor was limited, and the ventilation potential of the interfaces by the riverside was limited.

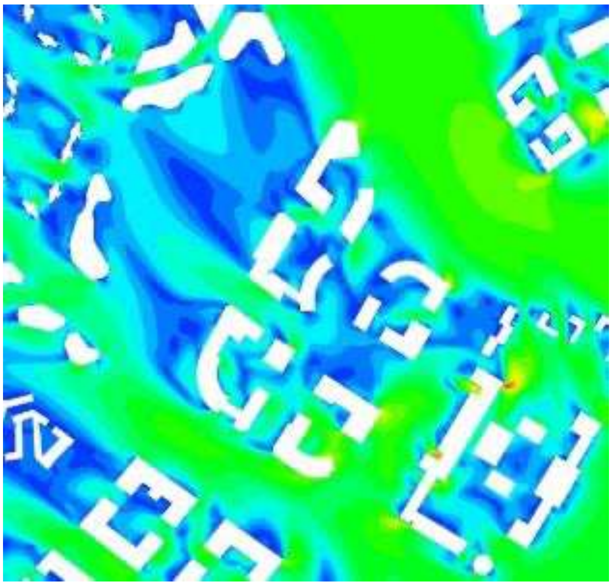
Optimized plan

The ventilation environment has been improved significantly, especially in the back of the site, the rear of the ventilation corridor, and interfaces by the riverside. Moreover, wind shadow in the back of the blocks has been removed.



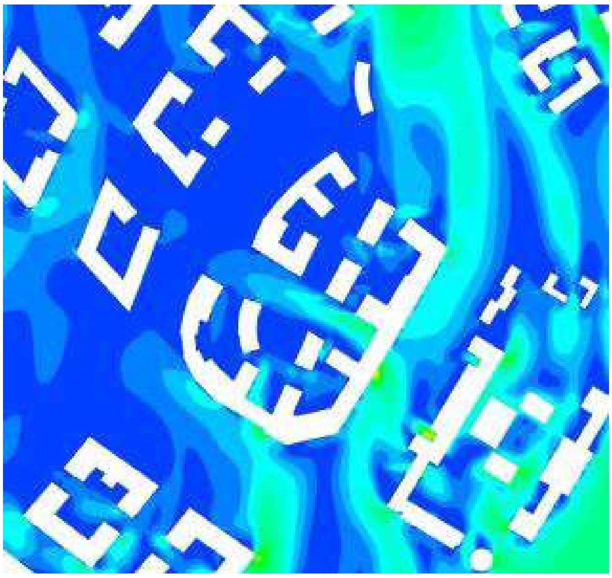
Original plan (southeast prevailing wind)

The overall wind velocity ratio is 0.33, the average wind speed is 0.39m/s, and small parts of the northern side are windless areas.



Optimized plan (southeast prevailing wind)

The overall wind velocity ratio is 0.38 and the average wind speed is 0.45m/s. Compared with the original plan, ventilation capacity improved by 30%.



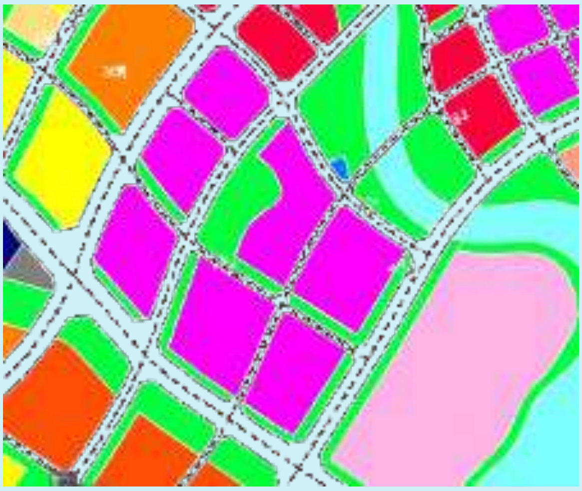
Original plan (south prevailing wind)

The overall wind velocity ratio is 0.18, the average wind speed is 0.34m/s, the overall wind velocity is relatively small. Wind to the north part is obstructed by high buildings, and there is large windless area.

Optimized plan (south prevailing wind)

The overall wind velocity ratio is 0.22, the average wind speed is 0.41m/s. The air flowing performance is improved compared to the original plan. The wind ventilation in upfront areas has improved, but the backwards is still windless.

BOX 5 // REGULATORY PLAN OF KNOWLEDGE GREEN VALLEY



Source: China-Singapore Guangzhou Knowledge City Development and Construction Office

Table 3 // PLOT INDICATORS

Plot No.	Type	Area	FAR	Floor area	Building density	Green area ratio	Building height
AG22	commercial	26439m^2	3	79317m^2	40	30	60
AG28	residential	20012m^2	2.5	50030m^2	28	35	60
AG29	residential	26563m^2	2.5	66407.5m^2	28	35	60
AG23	commercial	25492m^2	3	76476m^2	40	30	60
AG26	commercial	24196m^2	3	72588m^2	40	30	60

4.7 Implementation of the urban design

Under the current planning system, urban design is not a part of statutory planning, but rather a technical approach which can be used to support the regulatory plan and facilitate the identification of relevant planning requirements and indicators in regulatory plan.

Therefore, while sustainable cooling has been incorporated into urban design, there are some challenges involved with its implementation.

Regulatory plan

Some improvements in the cooling design have been incorporated into the regulatory plan. The Laohulong reservoir is protected as water and green plot, and the park is adjusted to the main corridor. Meanwhile, the plot size has been cut down to limit large building volumes.

Urban design guidelines

To put the design details into action, current measures primarily include the following:

- Strategic areas shall be sold with an urban design plan, and developers must follow a predetermined urban design plan during the construction process.
- The urban design plan shall be converted to design guidelines. The guidelines will be divided into unit guidelines and plot guidelines with different coverage and specific enforcement requirements. These guidelines will become part of the plot management plans and will be included in the land transfer contract when proposing precise planning requirements.
- A district chief designer will be introduced to provide professional consulting, a technical review, and quality check services throughout the implementation process.

Sustainable cooling measures in the urban design plan were translated into visual language, provisions, and requirements on building height limits, dynamic interface, building form and style, architectural setback corridors, etc. Sustainable cooling requirements will be effectively passed on to the parties responsible for construction at the urban planning and urban design level.

Building height

- The height of buildings located within the central area of the view corridor should be no taller than 60 m.
- The reservoir bordering the northwestern side and the water corridor on the northeastern side should form a spatial landscape where the front is low and the back is tall.
- The buildings inside the vertical protection line should showcase the vertical landscape of the site, and buildings should be adapted to changes in the hilly topography.
- In the residential plot, there should be no more than 3 towers with the same height.
- The height gap between the tallest tower and the shortest tower should be at least 10 m.

Architectural interface control

- Plots AG22, AG28, AG29 are located off Knowledge Ninth Road. Plots AG22 and AG23 are located off Innovation Avenue. Plots AG26 and AG23 are located off the green area to the south. 70% of each of these plots should have a continuous street-wall interface.
- Plots AG26 and AG29 are located off Open Fourth Road, and they should have 50% of a continuous street-wall interface.
- The interfaces should be equipped with covered corridors. There should be more stilts connected to residential buildings, lobbies, service annex buildings, canopies, and shading structures.
- Plots AG26 and AG28 are located off the green area to the west. They should have 70% of a continuous veranda interface. The veranda interface should combine public service facilities, shops, and stilts to enable open, public access. The net width of the verandas should be no less than 3 metres, and the net height should be no less than 4.5 metres.
- The entrance, layout, and number of the first-floor corridors should be constructed according to plan.

Greening buildings

- Sky gardens are recommended. Greening is recommended for the rooftops of terraced buildings to create a vertical, multi-layered forest effect. The vegetative cover of terraced building rooftops should be no less than 30%, and these green spaces should be accessible and available to residents.

- The outdoor units of air conditioners on annex buildings and towers should be covered with green plants, landscape racks, or racks.
- The standard façade design of residential towers inside residential plots AG28 and AG29 should utilize balconies, shading panels, and façade materials to enhance the design variation horizontally. Sky gardens should be designed in combination with shelter floors.

Architectural interface control

- The architectural layout of annex buildings and high-rise towers should meet the setback requirements illustrated in the plan.
- A proper setback is required so that buildings can make room for public green areas and open spaces. The width of buildings should also be strictly controlled.

Source: China-Singapore Guangzhou Knowledge City Development and Construction Office

5. Conclusions and recommendations

5.1 Conclusions

This project explored the guidance and control mechanisms of sustainable cooling measures from planning to implementation. China-Singapore Knowledge City was selected to produce a full-process cooling design in a newly developing district. Guided by an ecological framework and the development model of a compact, efficient, new town, the planning and management of integrated, systematic urban cooling measures in newly constructed projects throughout the process of urban development were explored. Cooling measures were converted into general requirements for sustainable cooling and were included in the controlled, detailed planning of the Jiulong Lake district. Such measures also became part of the urban design plan along with planning and design conditions. All were subject to full-process control, from planning to construction.

This project implemented an urban design approach based on sustainable cooling. Knowledge Green Valley, a typical medium intensity development cluster, was chosen for demonstration of urban design. Actual plans were used to explore the specific approach to implementing the general requirements of sustainable cooling, which ensured the consistency of urban cooling measures in regulatory planning and urban design. Sustainable cooling design methods which ensure maximum ventilation and shading were tested and used. These included building height profiles, architectural interfaces, forms and facilities of buildings, ventilation corridors, and open spaces, etc. These methods set a good example for other areas with a hot and humid climate in cooling-oriented urban design while ensuring good ventilation, good shading, and an overall cooling effect in built-up areas.

This project explored incentive policies to promote the implementation of urban cooling strategies. The following incentive policies have been put forward: FAR exemption and subsidies for 3D greenery, FAR exemption of void decks, and continuous walkways of arcades. Indicator control methods such as interface continuity, green roof ratio, and building porosity were introduced, and air ventilation assessment was suggested in the construction project review stage. The aforementioned measures, a combination of both compulsory and incentive policies, can drive sustainable cooling all the way from planning to construction.

Various scales of cooling effect evaluation models were used. For the first time, the InVEST Urban Cooling model was used in the planning phase to perform cooling effect modeling on different land use plans. Technologies, such as CFD simulation, were used to compare differences in ventilation and shading of different land use plans, to back planning decision-making, and to support the use of weather analysis simulation technology in the planning management process.

5.2 Recommendations

A combination of mandatory measures and incentives are crucial for implementation. Few cities have the resources to finance the costs of cooling initiatives. Mandatory requirements, incentives and partnerships with the private sector are necessary to share not only the costs but also the risks and technical capacities. To finance urban cooling projects, it is recommended to deploy a combination of internal and external funding sources, policy and regulatory tools, incentives and strategic partnerships with the private sector.

For new developments, priority should be given to long-term, large-scale measures in design process. Unlike renewal projects in which minor changes can be made to the urban fabrics, the new developing projects have more opportunities to use a variety of cooling methods. The passive designs and climate-responsive designs, like the wind paths in the Green Knowledge Valley, are highly recommended in such projects because the long-term cooling benefits would be embedded in the urban texture and consistent over time.

ANNEX. Cooling benefit calculation based on the InVEST model

Introduction

The cooling effect of two different plans were compared and analyzed, enhancing the impact of urban cooling in planning decision-making and design.

Two Land Use Plans

The two plans were used as simulation settings for the InVEST Urban Cooling model.

Maximizing "green and blue"spaces and connecting to wind flows

The green space system in the east part is reorganized to integrate the green space into a continuous winding network. Large green belts along the three rivers converging towards Jiulong lake connect hilly ponds and Phoenix Mountain, forming a finger-shaped green network. As a result, the proportion of ecological land increased by 2%. Various water sources, green areas, and topography were used to cool down urban fabric, improving both habitat for biodiversity and recreational space.

Managing development intensity

The plan appropriately controls development and construction density by retaining existing ecological lands, such as hilly ponds, and decreasing development intensity in ecologically sensitive neighbourhoods, reserving space for old village renovation.

Simulation setting

The InVEST urban cooling model is an ecological benefit calculation model based on land use and cover. However, in the regulatory plan of Jiulong Lake district inside China-Singapore Knowledge City, land categorization is based on Urban Land Use Standards. These standards categorize land into residential, commercial, business, public service, primary and middle school, public infrastructure, green areas and squares, and roads, etc. To further highlight the differences in the cooling benefits of plots with different developmental intensity, residential land, commercial and business land, and public service land have been newly categorized according to FAR (Floor Area Ratio).

In the end, land use and cover has been divided into the 15 categories.

Box 5 // INVEST URBAN COOLING MODEL CALCULATION PRINCIPLE

The model calculates the cooling performance of each plot according to three parameters: shading, evaporation, and albedo. The value of each parameter (between 0 and 1) is set according to the land use and actual site conditions. The cooling performance formula is set according to simulations of real case scenarios and research results taken from relevant literature.

$$CCi = 0.6 \cdot shade + 0.2 \cdot albedo + 0.2 \cdot ETI$$

Shading of green plants takes the biggest weight in cooling performance, as their cooling effect is the strongest. The weight of albedo and evaporation is 0.2 respectively; both of which have cooling effect. Based on local cooling performance, the model can be used to make further predictions on how the local magnitude of UHI effect influences the cooling temperature in the area.

Table 4 // LAND USE/COVERAGE CATEGORIES AND CODES

code	Description	code	Description
1	Public service (l) $FAR < 2$	9	Residential (h) $FAR \geq 4$
2	Public service (m) $FAR \geq 3$	10	Station\parking lot
3	School	11	Utility
4	Historic	12	Mixed forest
5	Business & commercial (l) $FAR < 4$	13	Water
6	Business & commercial (m) $4 \leq FAR < 8$	14	Park
7	Business & commercial (h) $FAR \geq 8$	15	Road\street
8	Residential (m) $FAR < 4$		

Original plan for the area surrounding Jiulong Lake

New plan for the area surrounding Jiulong Lake

Original plan for Knowledge Green Valley

New plan for Knowledge Green Valley

Parameters

Reference Evapotranspiration was taken from NASA's global open-source data with a resolution of 500 × 500 m.

The baseline air temperature was set at 28.6°C, and a weather model produced forecasts using real data collected by the China-Singapore Knowledge City Jiufo No.2 Middle School weather station between July and August to determine the base temperature without urbanization.

The magnitude of the UHI effect was set at 1.1°C, according to the statistics from Guangzhou Municipal Weather Station, and the average magnitude of the UHI effect in Guangzhou between July and August was 1.1°C.

The average relative humidity was set at 83%, which was based on the average value of the relative humidity detected by the China-Singapore Knowledge City Jiufo No.2 Middle School weather station between July and August.

Green area maximum cooling distance was set at 500 m based on previous studies of urban heat islands. (Schatz & Kucharik, 2014)

Air temperature blending distance was set at 500 m based on previous studies of urban heat islands (see footnote).

Areas of interest: the entire area Jiulong Lake district; the 2X buffer of Knowledge Green Valley.

Parameters of biophysical properties

Shade: Typical plots in Guangzhou were selected for remote sensing impact interpretation to determine the tree canopy ratio in public green areas, protective green areas, and different types of attached green areas. The green area ratio of different types of land were determined based on the index values set in the Guangzhou Urban and Rural Planning Technical Provisions and the controlled plan. A comprehensive green area ratio and tree canopy ratio were used to set the shade parameter of the base plan. In the advanced plan, the recommendation was to consider using 3D greening on public land, residential land, middle school and primary school land, and business and commercial land to properly improve the shade parameter.

Evapotranspiration coefficient (Kc): According to research conducted by a team led by Richard G. Allen of Utah State University, the evapotranspiration effect of green plants is influenced by regional climate, properties of the plant, and management of environment (Allen, Pereira, Raes, & Smith, 1998). A variety of factors affect the coefficient, including sunshine duration, humidity, wind speed, choice of tree species, height of trees, size of tree crowns, and irrigation. While climate conditions are the same across both plans, green area coverage is increased in the advanced plan. In terms of tree species, trees with larger canopies are preferred - especially in green belts along streets, to increase the evapotranspiration to some extent. Additionally, the wind speed is also relevant, and the reasonable layout of the Green Velley area improves the local ventilation.

Albedo: Albedo of urban surfaces is closely related to the material in use. Deilami pointed out in his research that using highly reflective paving would only lead to a 5 °C increase relative to outdoor temperatures. However, materials with low albedo may drive building temperatures up to 40 °C (Deilami, Kamruzzaman, & Liu, 2018) . Moreover, according to statistics from the United States Environmental Protection Agency and Low Carbon Living CRC (Australia) , rooftops built with cold materials and façades built with highly reflective (albedo >65%) and highly radiant (radiance >0.85) materials can help buildings reduce 74% of solar irradiation. The albedo of the advanced plan was set based on the feasibility and strategy of using cold materials in different types of buildings with a focus to increase the albedo of public land, business land, primary school and middle school land, roads, parking lots, and stations.

Building density: A standard value based on the average floor area ratio of each plot was used.

Green area: The value for farmland and forests, bodies of water, and parks was 1; the rest were 0.

Table 5 // OVERVIEW OF THE SHADE PARAMETER CALCULATION

LULC_type	Aerial imagery	GR	Tree Canopy Ratio	Original plan	New plan
Public service (l)		0.4	0.8	0.32	0.4
Public service (m)		0.35	0.8	0.315	0.4
School		0.35	0.6	0.21	0.5
Business & Commercial (l)		0.25	0.5	0.125	0.25
Business & Commercial (m)		0.2	0.5	0.1	0.2
Business & Commercial (h)		0.2	0.5	0.1	0.2
Residential (m)		0.35	0.8	0.28	0.4
Residential (h)		0.30	0.8	0.24	0.4
Utility		0.3	0.5	0.15	0.2
Park		1	0.9	0.9	0.9
Road\street		0.15	1	0.15	0.15

Table 6 // PARAMETERS OF BIOPHYSICAL PROPERTIES IN THE BASE MODEL AND OPTIMIZED MODEL

	Shade		Kc		Albedo		Green area		Building intensity	
LULC_type	Original plan	new plan	Original plan	new plan	Original plan	new plan	Original plan	new plan	Original plan	new plan
Public service (l)	0.32	0.4	0.76	0.93	0.19	0.7	0	0	0.15	0.15
Public service (m)	0.315	0.4	0.55	0.65	0.19	0.65	0	0	0.25	0.25
School	0.21	0.5	0.93	0.93	0.19	0.65	0	0	0.1	0.1
Historic	0.5	0.5	0.93	0.93	0.2	0.2	0	0	0.05	0.05
Business & commercial (l)	0.125	0.25	0.76	0.76	0.19	0.65	0	0	0.45	0.45
Business & commercial (m)	0.1	0.2	0.55	0.65	0.18	0.55	0	0	0.75	0.75
Business & commercial (h)	0.1	0.2	0.37	0.37	0.18	0.2	0	0	0.95	0.95
Residential (m)	0.28	0.4	0.55	0.55	0.19	0.2	0	0	0.25	0.25
Residential (h)	0.24	0.4	0.37	0.37	0.18	0.2	0	0	0.45	0.45
Station\park-ing lot	0.1	0.1	0.35	0.35	0.2	0.65	0	0	0.1	0.1
Utility	0.15	0.2	0.3	0.3	0.18	0.2	0	0	0.1	0.1
Mixed forest	0.9	0.9	1	1	0.15	0.15	1	1	0	0
Water	0.9	0.9	1	1	0.06	0.06	1	1	0	0
Park	0.9	0.9	1	1	0.2	0.2	1	1	0.01	0.01
Road\street	0.15	0.15	0	0	0.2	0.65	0	0	0	0

Calculation result

A weighted factor was used in this calculation. Calculation results mainly included three components: cooling index, average cooling capacity, and average temperature forecast. The average temperature consisted of average temperature forecasts for both before and after air blending. The average cooling capacity also covered the park cooling capacity.

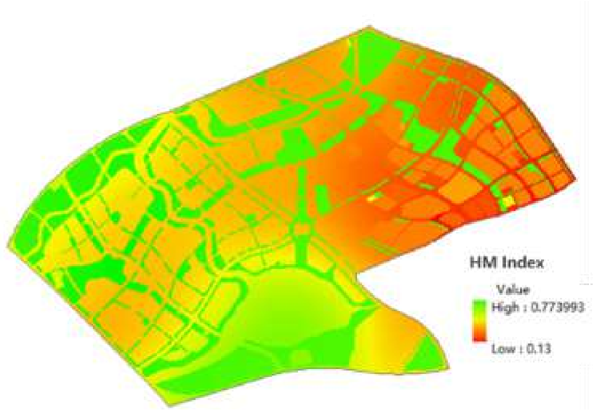
When using the base data of the preliminary plan, the cooling capacity of the Jiulong Lake district stood between 0.13 and 0.78, while the average cooling capacity was 0.43, and the forecast average temperature was 29.2 °C. The cooling capacity of Knowledge Green Valley stood between 0.23 and 0.77, while the average cooling capacity was 0.33, and the forecast average temperature was 29.2 °C.

Calculation results based on the new plan indicated that the cooling index of the Jiulong Lake district stood between 0.19 and 0.74, while the average cooling capacity was 0.46, and the average temperature forecast was 29.1 °C. The cooling capacity of Knowledge Green Valley stood between 0.25 and 0.77, while the average cooling capacity was 0.33, and the forecast average temperature was 29.2 °C.

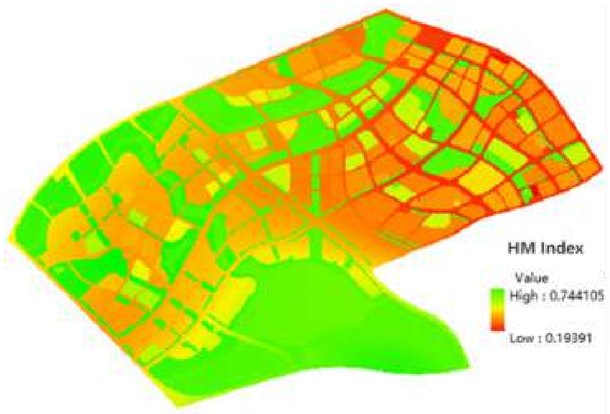
Overall, the cooling effect of the advanced plan is better than the preliminary plan. When the magnitude of the UHI effect is 1.1 °C, the average cooling capacity (0.46) of the area surrounding Jiulong Lake in the new plan increased by 7% compared with the original plan (0.43), and the temperature decreased by 0.1 °C. The average cooling capacity (0.48) of Knowledge Green Valley in the new plan increased by 50% compared with the original plan (0.33), and the temperature decreased by 0.1 °C.

Table 7 // OVERVIEW OF CALCULATION RESULTS

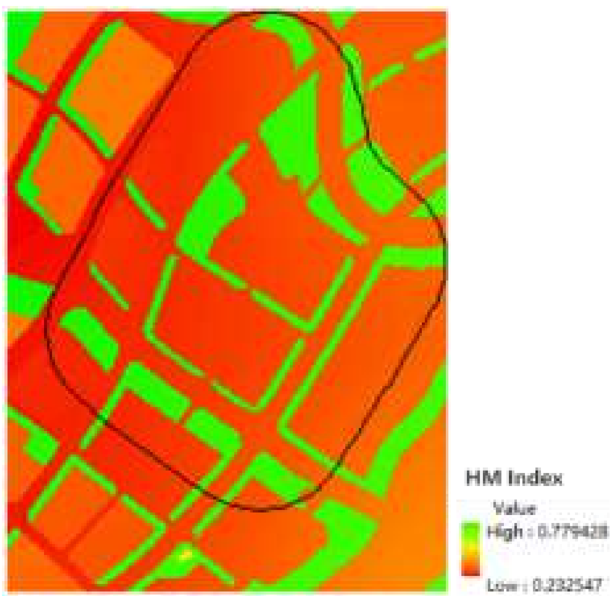
		Original plan		New plan	
Jiulong Lake District		Knowledge Green Valley	Jiulong Lake District	Knowledge Green Valley	
Weighted Factors	Cooling index	0.13 - 0.78	0.23 - 0.77	0.19 - 0.74	0.25 - 0.77
	Average cooling capacity	0.43	0.33	0.46	0.48
	Average temperature forecast	29.2 °C	29.2 °C	29.1 °C	29.1 °C
	Average temperature forecast spatial distribution (T-air)	29.0 - 29.3 °C	29.2 - 29.3 °C	29.0 - 29.3 °C	29.1 - 29.2 °C
	Park cooling capacity spatial distribution	0.12 - 0.73	0.26 - 0.37	0.12 - 0.73	0.26 - 0.36



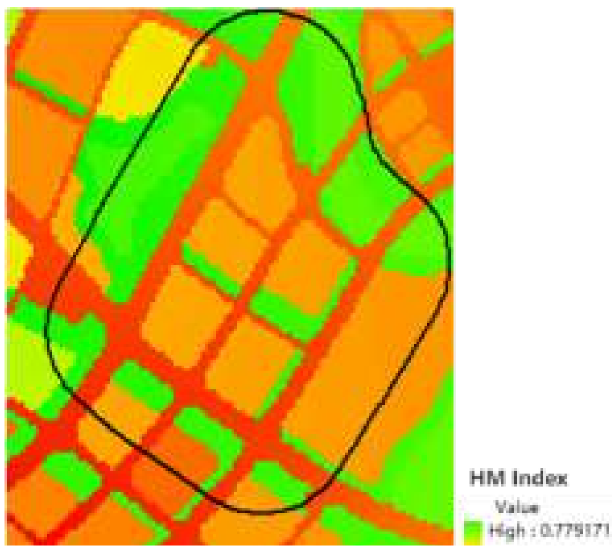
Calculation results of original plan JiuLong Lake district



Calculation results of new plan JiuLong Lake district



Calculation results of original plan Knowledge Green Valley



Calculation results of new plan Knowledge Green Valley

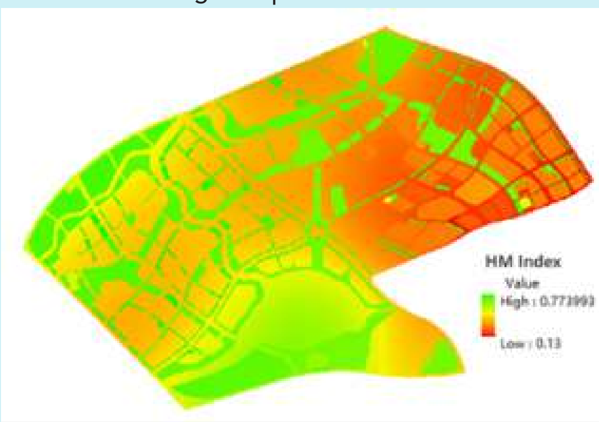
BOX 6 // MODEL SENSITIVITY TEST OF *WATER BODY* PARAMETER

Differences in parameters and variations in base data will have different levels of impact on calculation results. There will be some uncertainty when setting water body parameters since it is difficult to predict the cooling performance of bodies of water. The REALCOOL project team, comprised of scholars including Jacobs and Klok, studied (Jacobs, Klok, Bruse, et al. 2020) the typical thermal effect of a water body environment inside the cities of the Netherlands. The research found that although a body of water itself may not bring about an obvious cooling benefit, when combined with natural landscape design, it is still possible to create a cooler urban environment with bodies of water. Therefore, the setting of water body parameters should go through further sensitivity testing based on actual site conditions.

To determine water body parameters, a controlled variable method was used to test the impact on the resultant value when the green area parameter was set as 0 and 1, respectively.

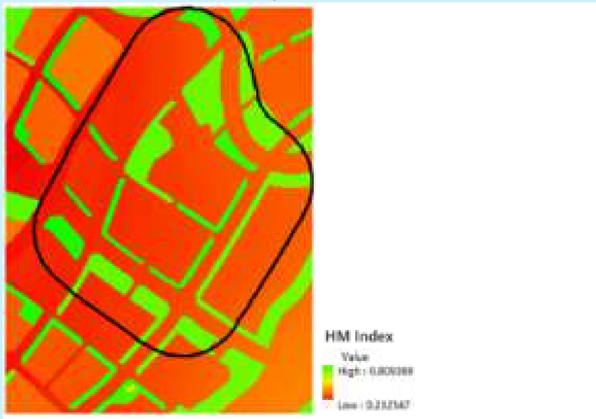
When green area = 1

Average cooling capacity: 0.43
Average temperature: 29.29 °C



Jiulong Lake district

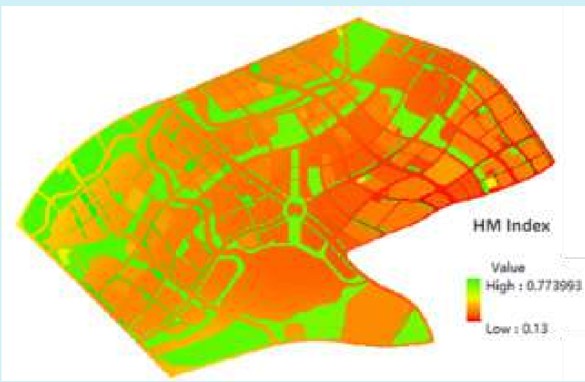
Average cooling capacity: 0.33
Average temperature: 29.28 °C



Knowledge Green Valley

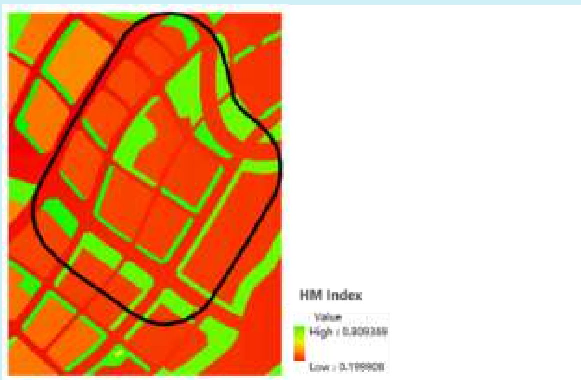
When green area = 0

Average cooling capacity: 0.43
Average temperature: 29.29 °C



Jiulong Lake district

Average cooling capacity: 0.33
Average temperature: 29.31 °C



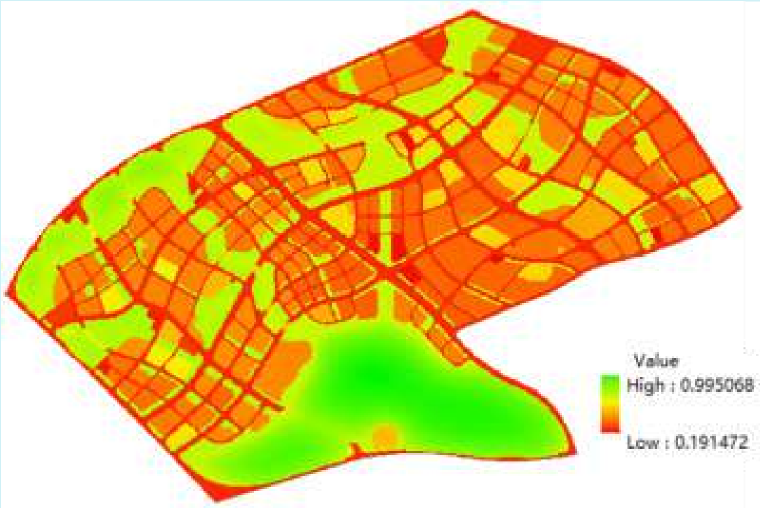
Knowledge Green Valley

Comparison of the two sets of results suggested that differences in water body parameters will cause a 0.03 - 0.07 °C variation in average temperature forecasts, having no obvious impact on cooling performance. Based on current conditions of the Knowledge City, the fabric structure surrounding the Jiulong Lake is open and wide. Trees around the lake increased shading for the site while also making it possible to achieve natural ventilation. Based on testing results and site conditions, the “green area” parameter of water body was set as 1.

BOX 7 // MODEL SENSITIVITY TEST OF PARAMETER GREEN AREA COOLING DISTANCE

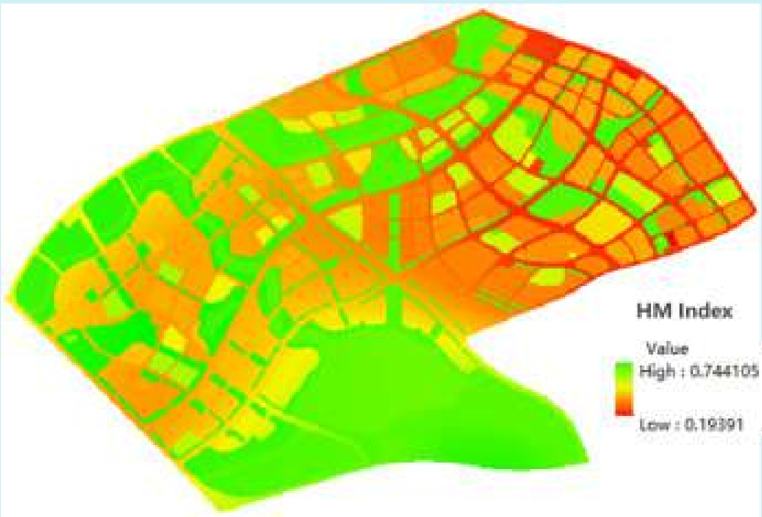
The green area cooling distance parameter refers to the parameter-setting template provided by the Natural Capital Project team. According to measurement experience and research, a value of 500m is applicable to large cities in the United States and Europe. However, its application at the scale of China-Singapore Knowledge City has yet to be tested. According to the research findings of Zardo , in general, the cooling impact distance of a tree is five times the height of the tree, and this should be adjusted according to local conditions. However, in the absence of relevant local data, it can be assumed that the cooling impact distance of a green area is 100 m. In this report, sensitivity tests were carried out on green areas with a cooling impact distance of 500 m or 100 m and the results are as follows:

When green area cooling impact distance was 100m



Average cooling capacity: 0.46
Average temperature: 29.2 °C

When green area cooling impact distance was 500 m



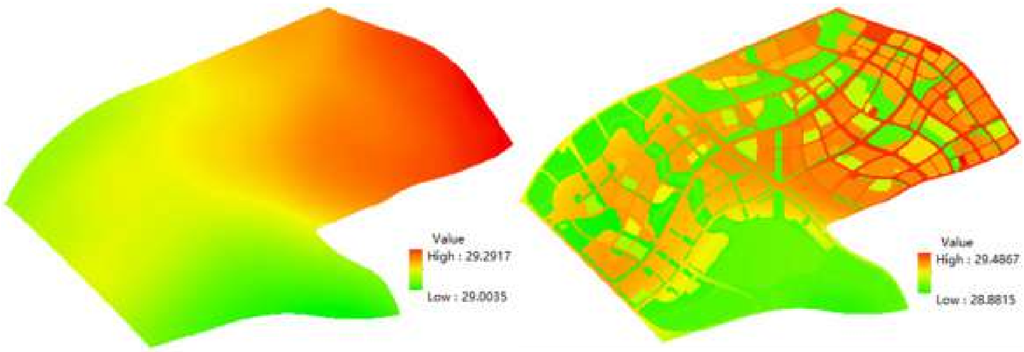
Average cooling capacity: 0.46
Average temperature: 29.1 °C

According to the sensitivity test results, reducing a green area's cooling coverage will have an impact on the cooling performance of the district. However, the gap is marginal. Based on the rationale and calculation formula of the model, the green area maximum cooling distance has limited influence on the cooling capacity of the city; instead, it only affects the air temperature of the target area. The cooling capacity will improve with the increase of the green space cooling coverage. According to previous research, a 500 meter green cooling coverage area can be applied to most cities in the world. Therefore, in this test, 500 m was used as the green area cooling distance parameter.

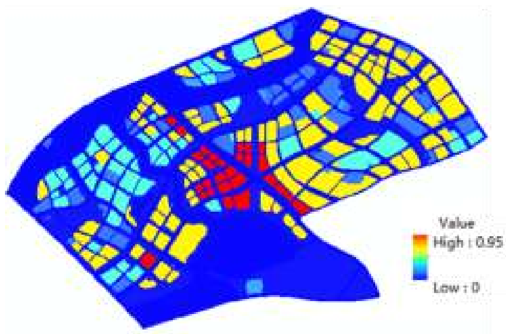
Analysis and discussion

When comparing the calculation results of both plans for China-Singapore Knowledge City, the cooling effect of the new plan proved to be significantly better than that of the original plan. If construction materials and paving are improved, and green area ratio is guaranteed, the average cooling capacity of the area surrounding Jiulong Lake should be 0.46 with an average temperature forecast of 29.1 °C. The average cooling capacity of Knowledge Green Valley should be 0.48, and its average temperature forecast should be 29.1 °C. Compared with the preliminary plan, two different districts in the advanced plan should be able to achieve an extra cooling effect of 0.1 °C. The average cooling capacity should also be improved. When compared with the maximum cooling effect simulation results (area surrounding Jiulong Lake: 28.85 °C; Knowledge Green Valley: 28.87 °C), the new plan still showcased a great cooling effect as it achieved 30% of the maximum cooling effect.

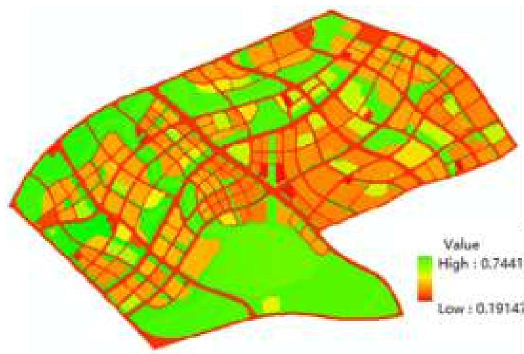
The continuous forest and the Jiulong lake front are the main cooling sources for the Jiulong Lake district. The average temperature of the southwestern part of the Jiulong Lake district is lower than that of the northeastern part. In the southwestern part, the green area ratio is relatively higher, whereas high density buildings are mainly found in the northeastern part. If we look at the park cooling capacity, a large area of the continuous park spaces has a great cooling effect, while small green belts scattered around buildings have much less of an effect.



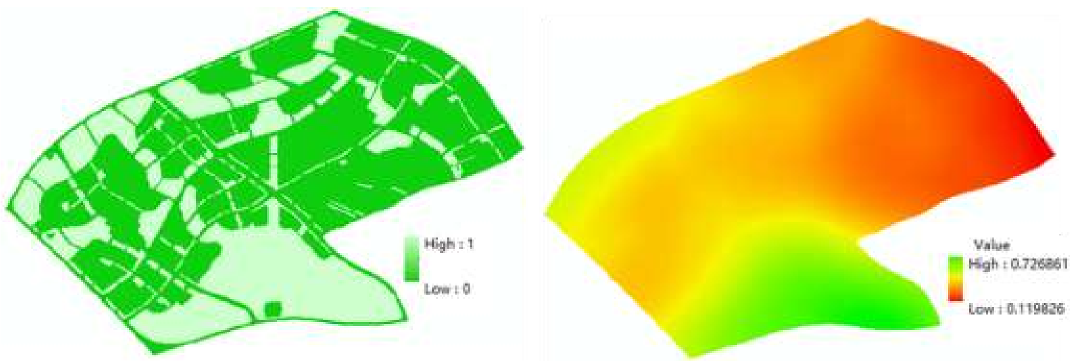
Average temperature forecast spatial distribution (T-air)



Building density distribution

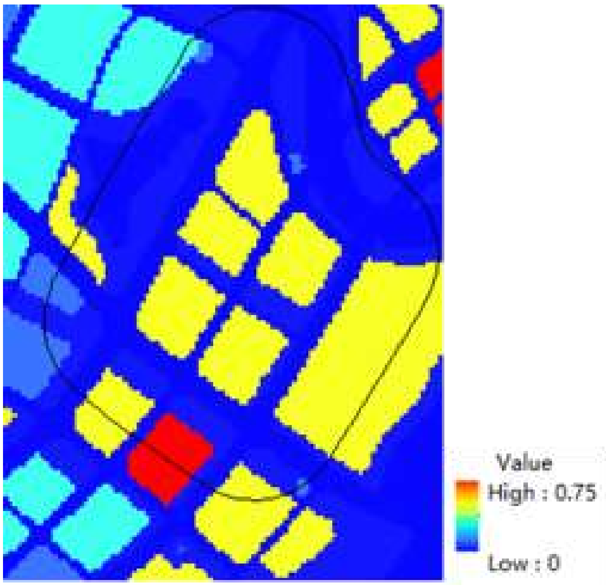


Average cooling capacity spatial distribution

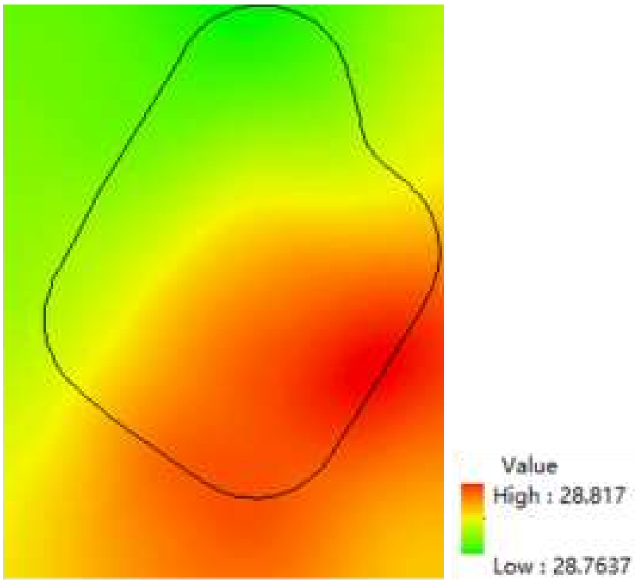


Park cooling capacity distribution

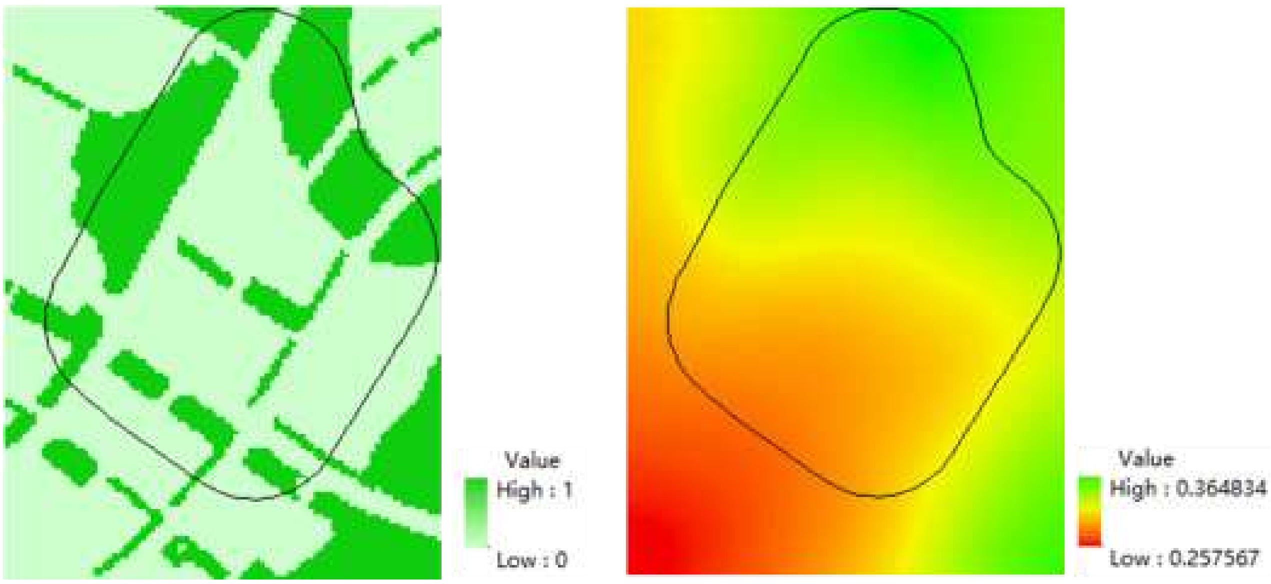
Heat released from buildings is the main source of heat in Knowledge Green Valley. The average temperature in the northern part of Knowledge Green Valley is lower than that in the southern part. The average cooling capacity of Knowledge Green Valley is basically consistent with the distribution of parks. Therefore, the main reason for the variation in temperatures is the large area of continuous green spaces in the west. **The Laohulong Reservoir that was preserved in the advanced plan also contributes to the outcome, and the green belt along the river plays an important role as well.** They, together, lead to a great cooling effect, whereas the floor area ratio and building density in the south are relatively high.



Building density distribution



Average temperature forecast spatial distribution (T air)

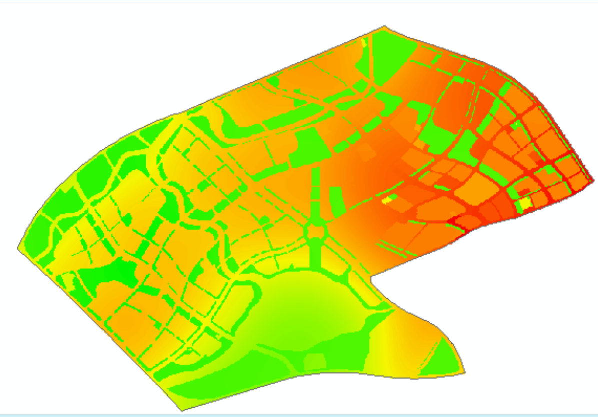


Park cooling capacity distribution

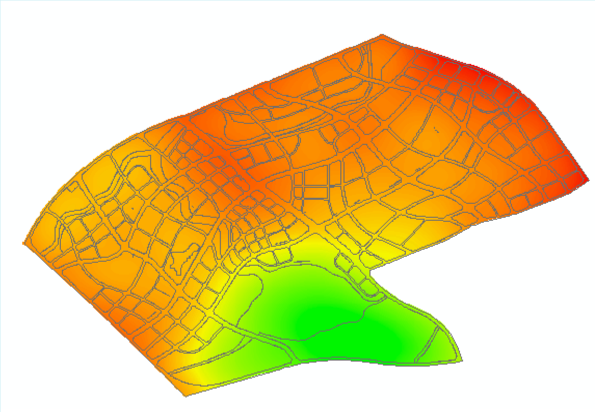
BOX 8 // MAXIMUM COOLING EFFECT SIMULATION

A maximum cooling effect simulation using the InVEST model was performed on the Jiulong Lake district to enhance the legitimacy and objectivity of site cooling effect analysis evaluation. When all the plots in the Jiulong Lake district were set as green spaces, the simulation results indicated that the maximum cooling capacity of the area surrounding Jiulong Lake would be 0.52, and the minimum average temperature forecast would be 28.85 °C. The maximum cooling capacity of Knowledge Green Valley also turned out to be 0.52 and the maximum average temperature forecast was 28.87 °C. The maximum cooling effect simulation of the site offers a valuable reference for the model calculation results.

Base scenario

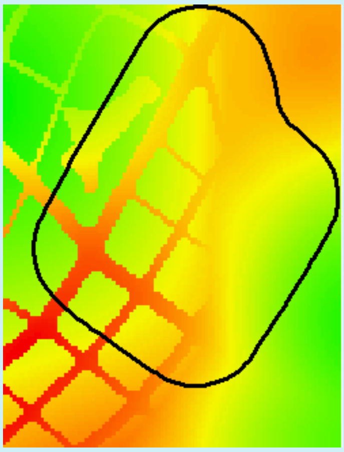


Average cooling capacity: 0.43
Average temperature forecast: 29.21 °C



Average cooling capacity: 0.52
Average temperature forecast: 28.85 °C

Average cooling capacity: 0.33
Average temperature forecast: 29.27 °C



Average cooling capacity: 0.52
Average temperature forecast: 28.87 °C

Strengths and weaknesses

InVEST provides an easy, feasible modeling tool that can be utilized by planners for widespread use. This calculation tried to use the InVEST Urban Cooling model in a plan scheme, rather than a current situation for the first time. It effectively simulated the urban green spaces'impact on urban temperatures. The local cooling capacity index was calculated, measuring the albedo of construction and paving materials. This offered a theoretical basis for decision-making, planning and design. It served as a valuable reference. At the same time, compared with other modeling tools such as ENVI-met and CFD, the InVEST Urban Cooling model was easy to use and could be adopted by more urban planners, designers and architects.

Limitations of using the InVEST model in regulatory plans. According to the calculation principle of the InVEST model, calculation of the cooling effect is primarily based on the type of land cover and land use. However, the regulatory plan is mainly used as a transition in the urban planning system. It allows for the accurate planning of land use types and development intensities from the perspectives of an urban industrial structure, land use, spatial distribution of population, and urban environmental protection. However, it does not map the specific patterns of land cover within given land use areas (e.g. an entire parcel designated as a 'school area', which would be composed of buildings, grass, trees, and sports fields, is considered a single 'land use' in regulatory planning). Thus, the decision-making demands in regulatory plan make it difficult to accurately calculate the explicit cooling effect of land cover. Another issue involves the scale effect. This model was not sensitive towards the scale of the measured area. It was unable to factor in a medium- and small-scale heat exchange and balance. For example, the effect of wind cannot be reflected in this model calculation.

Setting parameters requires further scientific support. In this model, the setting of parameters that affect urban cooling primarily depends on practical experiences and literature review. Therefore, there are some limitations in setting parameters. The indistinct parameter selection leads to uncertainties during the model calculation. In the calculation process, experience-based sensitivity tests should be performed repeatedly to check the legitimacy of the parameters. Similarly, when assigning parameter values, it is sometimes difficult to determine the appropriate values. For example, the maximum air mixing temperature and the cooling capacity of large parks, etc. presented issues.

Difficult to perform value measurement. In this model, it was difficult to measure the energy consumption of cooling in some areas. A special parameter was needed to determine energy-savings and associated costs, resulting in a one kilowatt reduction of the energy saved in each building's energy use calculation. This is a parameter rarely used in practice, and it is difficult to obtain relevant statistics. The data sources are usually very hard to trace.

Model application recommendations and improvement

This model offers important statistical support to the future development of the China-Singapore Knowledge City demonstration project. With regard to the application of modeling results in future urban planning and decision-making process, the following recommendations have been proposed.

Increase the compatibility for medium- and small-scale areas. This model is more suitable for large-scale urban simulations and calculations. It is recommended to optimize the model's compatibility for medium- and small-scale areas' thermal environment.

Provide parameter setting instructions. Performing calculations for medium- and small-scale areas should be more feasible, so that the results can be used to create a comfortable thermal environment. Human thermal environment perception should also be factored in to improve the results. Recommendations should be made for different categories and areas in the modelling parameter setting guidelines to meet the demand of different users and improve model convenience. This would increase the potential for widespread application of the model.

Improve value measurement methods. Simplify the parameter setting in energy consumption measurement, set the existing parameter as average energy consumption, and enhance the accessibility of base data and the legitimacy of the model.

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