Piloting Nature-based Solutions for Urban Cooling

OVERVIEW

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The Overview draws on the following technical reports:

- **Piloting urban cooling solutions for urban regeneration and new town development in Guangzhou** supported by Guangzhou Municipal Planning and Natural Resources Bureau, Guangzhou Urban Planning & Design Survey Research Institute, Guangzhou Urban Planning Association
- **Guidelines on Integrating Nature-Based Cooling Options into Urban Planning and Design** supported by Guangzhou Municipal Planning and Natural Resources Bureau, Guangzhou Urban Planning & Design Survey Research Institute, Guangzhou Urban Planning Association
- **Economic Evaluation of Key Ecosystem Services by Urban Natural Asset** by Natural Capital Project Team, including Chris Nootenboom, Eric Lonsdorf, Roy Remme, Rob Griffin, Baolong Han, Tong Wu, and Anne Guerry

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Executive Summary

Reducing excess urban heat and protecting populations from extreme temperatures is one of the 21st century's key resilience and sustainability challenges. As the planet warms, cities are increasingly finding that they need new ways to keep urban temperatures down to protect their residents.

Urban cooling options have primarily focused on space cooling through air conditioning.Nature-based solutions and leveraging urban design to cool cities have yet to be fully deployed and understood, especially by policymakers and urban planners. These solutions include both natural and man-made green and water features as well as urban planning that minimizes and dissipates heat retention with wind flows; they also include modifications to the solar reflectivity of urban roofs, walls, and roads to lower the amount of solar energy absorbed by urban surfaces.

The World Bank in collaboration with Guangzhou Municipal Planning and Natural Resources Bureau and Guangzhou Urban Planning & Design Survey Research Institute, conducted three pilot activities at different sites to test nature-based solutions and urban design as part of urban cooling options:

- An old town regeneration of Yongqing Fang in the city core
- A new town development to create a green, low-carbon, ecological district in China-Singapore Guangzhou Knowledge City
- An evaluation of the cooling effects and economic value of a local natural asset, Haizhu National Wetland Wetland Park

Figure 1 // THREE PROJECT SITES – YONGQING FANG, ECOLOGICAL DISTRICT IN CHINA-SINGAPORE GUANGZHOU KNOWLEDGE CITY AND HAIZHU NATIONAL WETLAND PARK

Source: Guangzhou Municipal Planning and Natural Resources Bureau, Guangzhou Haizhu District Wetland Protection and Management Office, China-Singapore Guangzhou Knowledge City Development and Construction Office.

These pilots in Guangzhou helped build the capacity of urban planners and policymakers in identifying cooling solutions and strengthen the engagement with the public and private sector stakeholders. The results of the pilot activities offer critical lessons on approaching cooling at scale and developing a framework for evaluating cooling options for city and municipal leaders, urban planners, and developers.

The key cooling solutions and recommendations are summarized as follows:

Technical solutions

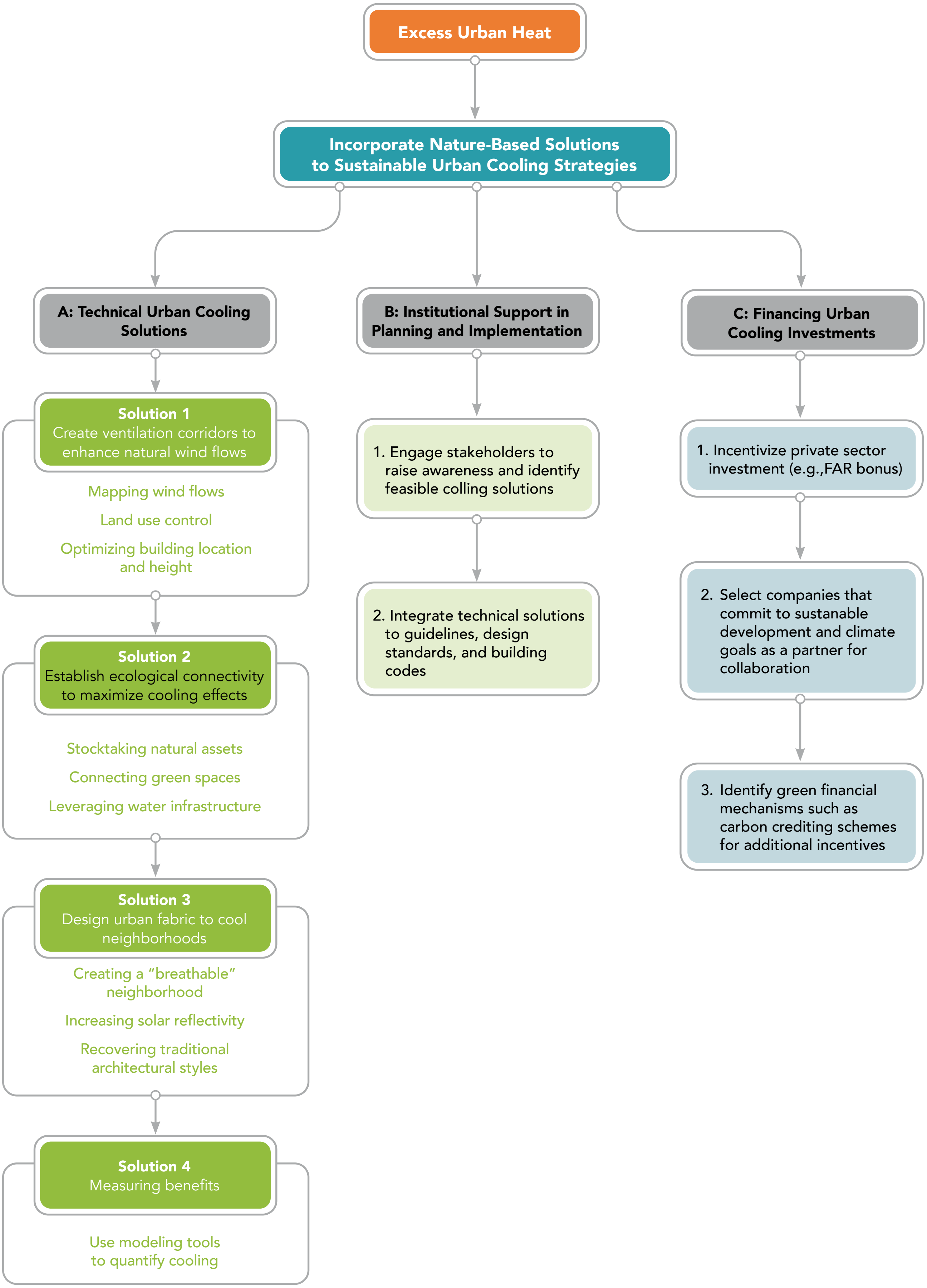
- Many active and passive urban cooling solutions are currently available to cities. They can be grouped into **three main categories**:
  - Enhancing and channeling wind flows
  - Leveraging green and blue spaces for increased cooling effects
  - Designing urban fabric to cool neighborhoods
- When selecting urban cooling actions, a city should identify its **historical local solutions**. Cities have adapted to their unique local climate throughout history, so it is feasible to explore nature-based climate adaptation techniques that draw on traditional styles and architecture. These techniques are typically low in cost and showcase the city's characteristics.
- Using **modeling tools** in the planning phase helps to assess the cooling effects of different land use plans and supports an evidence-based approach to decision-making. For example:
  - Simulating wind flows around buildings allows comparison of differences in ventilation and shading of different designs.
  - Developing a heat map to identify vulnerable areas and populations is an important early step for selecting appropriate and equitable solutions.
  - Scenario analysis to quantify the cooling effects of green and blue spaces helps planners optimize the urban design to maximize cooling.

Implementation framework

- **A combination of regulatory measures and incentives is crucial for implementing sustainable cooling solutions**. For example, sustainable cooling measures need to be translated into mandatory requirements and design codes for buildings and urban spaces; this translation must entail explicit guidelines with unit- and plot-specific measures. These guidelines will become part of the plot management plans included in the contract with the plot developer to ensure implementation.
- Many cities do not have the resources to finance the cost of cooling initiatives. **Providing incentives and partnerships with the private sector is necessary to share the costs and the risks and to provide the needed technical capacity**. Incentives for developers may include floor area ratio (FAR) bonuses and subsidies for expanding green areas.
- **Engaging multiple stakeholders**, including the public, enables a human-focused, collaborative approach that reflects the local conditions and characteristics as much as possible. This in turn helps leverage existing local efforts and data and improves the chance of adopting policies that perform well under local conditions, resources, and constraints.

The policy and implementation framework is shown in figure 2.

Figure 2 // NBS COOLING POLICY AND IMPLEMENTATION FRAMEWORK



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Introduction

Increased Heat in Cities

Heat waves are one of the deadliest weather-related disasters in Europe; 140,000 deaths associated with 83 heat waves have been recorded since the beginning of this century (UNEP 2020). In 2020 alone, extreme temperature disasters resulted in 6,388 recorded deaths (CRED and UNDRR 2020).

While climate change is increasing temperatures globally, cities are at particularly high risk from excess heat. Cities are growing rapidly in areas and populations. For the first time in history, more than half the world's population lives in cities, with 90 percent of urban growth occurring in the developing world. By 2050, two out of every three people will live in an urbanized area. Assuming current trends continue, the urban areas will increase in size by 80 percent between 2018 and 2030 (Mahendra and Seto 2019).

Poor urban design and poor choice of materials create an environment where urban air temperatures are consistently higher than in nearby rural areas. This phenomenon is called the urban heat island (UHI) effect, and it has led urban temperatures to rise at twice the average global warming rate.

The world's largest cities are forecast to see additional warming of over 2°C by 2050. Medium-size cities will experience nearly 1°C of additional warming. One study of 1,692 cities found that 20 percent would experience temperature increases of 4°C by 2050 and 7°C by 2100 (ESMAP 2020a).

Severe UHI Effects in Chinese Cities

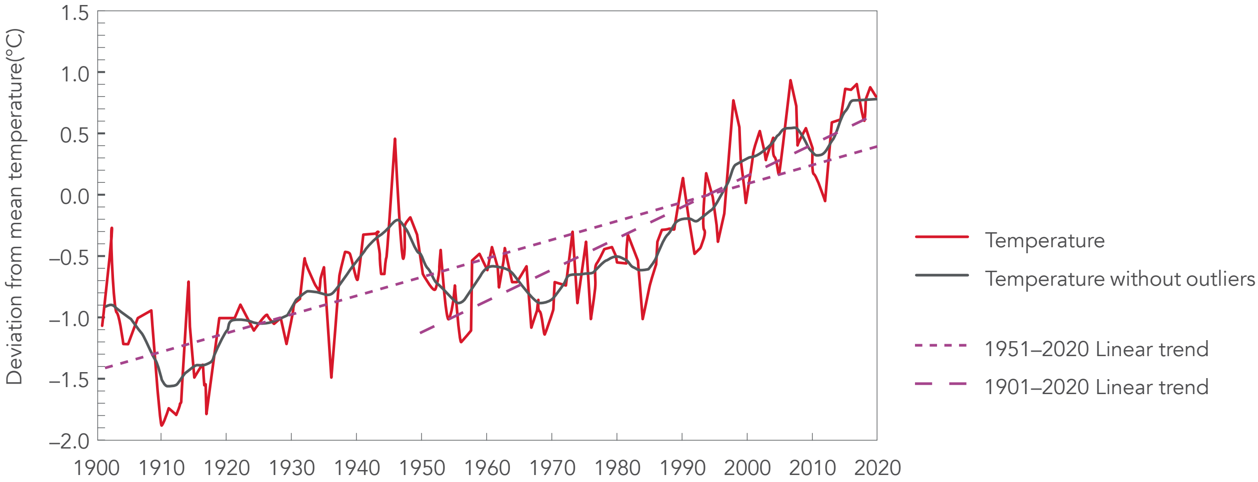
Nearly half of the global urban expansion is forecast to occur in Asia, with China and India accounting for 55 percent of the regional total. Climate change will impact China in the future. The rate of temperature increase in China has been significantly higher than the global average. Between 1951 and 2020, the average temperature in China rose 0.26°C every 10 years (China Meteorological Climate Change Centre 2021). According to research from the China National Climate Center, by approximately 2025, at least 50 percent of the summer will be characterized by sustained periods of high temperatures and heat waves. Under a worst-case scenario, the frequency of high-temperature events and heat waves in China will be five times higher than the current rate by the end of the century.[1]

Significant UHI impacts have already been felt in major metropolitan areas in China. For example, heat islands impacted 80 percent of six urban districts in Beijing in 2017 (Wand and Yuan 2019), and the presence of the UHI effect can be attributed to the accelerated transition from suburban land to urban land (Qiao et al. 2014). During the period 2003–2016, over 80 percent of 302 Chinese cities experienced increased UHI effects (Yang , Huang, and Tang 2019). The challenge is even direr as China is amid a period of rapid urbanization. By 2025, the urbanization rate will increase from 60.6 percent to 65 percent, meaning that 57 million people will enter the city from rural villages and towns in the five years leading up to 2025.[2] An additional 255 million people are expected to move to Chinese

[1] The probability of extreme heat events in summer will increase significantly in China in the future, according to the National Climate Center of the China Meteorological Administration (China Clean Development Mechanism Fund 2018).

[2] Proposals for Formulating the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035.

Figure 3 // **ANNUAL AVERAGE TEMPERATURE ANOMALIES IN CHINA, 1901–2020.**



Source: China Meteorological Climate Change Centre 2021

cities by 2050 (UNDESA 2018). Urban land area in China is expected to increase sharply until 2040 (Chen et al. 2020) and will encroach on cropland, which will worsen the UHI effect.

Chinese cities have started to notice the importance of addressing UHIs. Several initiatives undertaken in the past decade—such as sponge city developments (focused on ensuring rainwater is absorbed and avoiding runoff), parks, and green buildings—can be seen as contributions to urban cooling. The challenge is that these initiatives have been designed as sectoral and independent interventions, not as part of a comprehensive approach that integrates cooling options in the urban planning process.

Cities have many mutually beneficial options to promote cooler environments. A holistic systemwide approach is needed for addressing urban cooling, one that manages both the supply side, by increasing efficiency in cooling buildings, and the demand side, by reducing the cooling need (UNEP 2021); see box 1.

Urban cooling options have primarily focused on space cooling through air conditioning. Nature-based solutions to cool cities have yet to be fully deployed and understood, especially by policy makers and urban planners.[3]

Nature-based solutions complement rather than replace a traditional technology approach and deliver large cooling benefits to cities. Research shows that green and blue urban infrastructure (e.g., green spaces, water bodies), urban design, reflective roofs, and pavements can deliver 12 times their cost in net benefits and cool cities by 0.5°C (Estrada, Botzen, and Tol 2017). Cooling of that magnitude is equivalent to negating over a third of the total global warming over the last century (Schickman 2017). Urban nature-based cooling solutions could also increase urban resilience and play an important role in helping cities reach carbon neutrality.[4]

China has initiated urban regeneration projects to improve the livability of old urban cores and build new towns to accommodate the rapidly growing urban population. These projects offer good opportunities to integrate cooling measures into the planning process for urban development in order to prepare for a warmer future.

3 Nature-based solutions are an integrated urban development strategy that aims to improve the quality of green areas and to restore natural habitats and ecological corridors. They contribute to social and recreational purposes and help mitigate the impacts of climate change and UHIs.

4 Carbon neutrality targets have been set by New York (2050), Stockholm (2040), Berlin (2050), London (2050), and Copenhagen (2025), for instance.

Box 1 // ACTIVE COOLING SOLUTIONS

The strategies to mitigate excessive urban heat and provide thermal comfort fall into two groups: passive and active cooling. Active cooling, which is discussed here, refers to the use of mechanical means to promote cooling, such as electric fans and air-conditioning systems. Air conditioners are the dominant technology for space cooling to reduce indoor air temperatures (as well as humidity levels). It is expected that cooling-related demands, and consequently use of air conditioners, will in the future expand significantly in many developing countries.[a]

However, traditional air conditioners always consume a large amount of energy and generate more anthropogenic heat, which in turn exacerbates the UHI effect and contributes to global warming, creating a vicious cycle. Without action to address energy efficiency, energy demand for global space cooling will more than triple between 2016 and 2050, consuming as much electricity as all of China and India today (ESMAP 03/20). At the same time, access to cooling has not been equal or inclusive; the growth in space cooling demand excludes the 1.1 billion people who will likely never have physical or economic access to mechanical cooling (Sustainable Energy for All 2018).

While active cooling solutions are needed, cities need to shift to energy-efficient cooling technologies and climate-friendly centralized cooling applications such as district cooling, and to nature-based cooling solutions, which can improve outdoor climate comfort and thus reduce active cooling consumption. More information is available in ESMAP's (2020b) "Primer for Space Cooling" and the UNEP (2021) report "Beating the Heat: A Sustainable Cooling Handbook for Cities."

a. IEA (2018) estimates that half of the projected growth in energy use for space cooling by 2050 comes from emerging economies, including India, China, and Indonesia. China and India account for more than half of the global expansion in the number and capacity of residential air conditioners.

Box 2 // NATURE-BASED SOLUTIONS FOR CITIES AND PASSIVE COOLING FOR BUILDINGS

Nature-based solutions for cooling cities refer to a broad range of solutions at the city and urban fabric level that reduce urban air temperatures. By designing systems of well-articulated green and water spaces, channeling wind flows, and greening building facades and roofs, cities can help reduce urban temperatures. Moreover, by promoting passive building design (e.g., integrating natural breeze, and solar orientation) and using light-colored reflective material, cities can modernize traditional construction. Many passive cooling techniques are inspired by historical building design practices. For example, light-colored roofs and walls were used by the ancient Egyptians and Sumerians to keep homes cool. Additionally, water features and building design to encourage airflow are hallmarks of traditional architecture across the Middle East and North Africa (Schickman 2020).

Both nature-based solutions and passive design are energy efficiency investments that can reduce cooling energy demand up to 20 percent on average. They can also reduce indoor air temperatures by an average of 3–5°C (Schickman 2020). Implementing nature-based solutions and passive building design are key strategies to combat climate change. These solutions are slowing greenhouse gas (GHG) emissions, helping cities adapt to climate impacts, addressing biodiversity loss, and protecting human health.

City-level plans to deploy nature-based solutions are emerging across the world. Melbourne, Australia, for example, is planning to increase its urban forests to improve air quality, provide more shade, and reduce the need for mechanical cooling, and Milan, Italy aims to plant 3 million new trees by 2030 to reduce urban temperatures by 2°C. (ESMAP 03/20)

Global Context for Cooling Cities with Nature-Based Solutions

Cities around the world—for example, Brisbane and Singapore—have implemented nature-based solutions and passive design for cooling cities. Brisbane's Buildings that Breathe guide, a part of the Brisbane City Plan 2014, aims to provide an inspirational design benchmark for practitioners, developers, and professionals seeking to design buildings that respond to the city's subtropical climate, urban character, and outdoor lifestyle.[5] In Japan, urban microclimate efforts at the the urban heat island effect. Box 3 describes the Singapore case.

Nature-based solutions for cities can also help address the rising contributions of air conditioning to climate change by reducing the use of air conditioning for space cooling. According to the International Energy Agency (IEA), use of air conditioners and electric fans to stay cool accounts for nearly 20 percent of the total electricity used in buildings around the world today. Cooling is the fastest-growing use of energy in buildings. By 2050, around two-thirds of the world's households could have an air conditioner. China, India, and

Box 3 // EXAMPLES OF INTERNATIONAL BEST PRACTICE: NATURE-BASED SOLUTION POLICIES TO COOL SINGAPORE

Singapore has put in place a policy for cooling the urban fabric through intensive greening with breathing urban fabric and "gardens in the sky"—greenery growing on rooftops and other elevated spaces. Hundreds of kilometers of green spaces—pedestrian park connectors, pocket parks, and sky gardens—mean that people have constant and easy access to green space despite high-density living. Between 1986 and 2007, green cover in Singapore grew from 36 percent to 47 percent, despite a 68 percent increase in population (Tan, Wang, and Sia 2013). Average temperature diminished by between 0.5°C and 5.0°C (Jusuf et al. 2007). This decrease contributes to resilience to climate change while also mitigating GHG emissions, as a drop of 1°C in air temperature lowers peak electricity demand by as much as 4 percent, which translates into reduced energy consumption and emissions (Tan, Wang, and Sia 2013). The government now requires property developers to replace any greenery lost during construction. Green plot ratios in projects by the WOHA architectural firm in Singapore range from 110 percent to 1,100 percent. An example is Kampung Admiralty, a Housing and Development Board's mixed-use development.[a]

The Singapore government covers 50 percent of the costs for installing green roofs and walls on existing buildings. This spurs innovations to develop lighter and more robust rooftops and vertical greening systems, which are also cheaper. In part because of these innovations, the cost of greening fell from S$150/m² to S$100/m² in a two-year period (Newman 2014).

Figure 4 // TWO VIEWS OF KAMPUNG ADMIRALTY, SINGAPORE, DESIGNED BY WOHA.

Credit: K. Kopter

Credit: Patrick Bingham-Hall

a. Green plot ratio calculates the quantity of landscaped surfaces compared to a development's site area. This measurement includes all new and preserved vegetation, vertical and horizontal landscaping, water features, lawn, trees, raised planters, and urban farms.

[5] Brisbane City Council, "New World City Design Guide: Buildings That Breathe," https://www.brisbane.qld.gov.au/sites/default/files/20160929-nwc-design-guide-btb-full-document.pdf.

energy demand for space cooling will more than triple by 2050—consuming as much electricity as all of China and India today (IEA 2018). Reducing the ambient and peak temperature of cities with nature-based solutions will reduce this demand. Moreover, critical to the optimization of building systems is a rethinking of air conditioning and development of approaches that can integrate nature-based solutions within hybrid cooling systems. An example is a net-zero energy building developed by the School of Design and Environment, National University of Singapore, which is briefly described in box 4.

Box 4 // NET-ZERO ENERGY BUILDING, SCHOOL OF DESIGN AND ENVIRONMENT, NATIONAL UNIVERSITY OF SINGAPORE (NZEB@SDE)

The School of Design and Environment is the first net-zero energy building of its kind in the tropics. The building design makes use of the "floating boxes" architectural concept. Its shallow plan depth and porous layout allow for cross breezes, natural lighting, and outdoors views. The key design concept is the separation of building masses with a language of platforms and boxes. Weather permitting, rooms can also be open to natural breezes, and air conditioning is used only as needed, reducing the electricity usage of the building.

Figure 5 // NZEB@SDB IN SINGAPORE.

Credit: ©Francoise Labbe

A rethinking of air conditioning—typically the biggest consumer of electricity in Singapore buildings—resulted in the design of an innovative hybrid cooling system. Actuated by sensors, the system supplies rooms with cool air, which is augmented with elevated airspeeds from ceiling fans. The cool, moving air creates significantly better comfort than the overcooled rooms common in Singapore.

Guangzhou Context and UHIs

Guangzhou is the third largest city in China, with a population of roughly 20 million people. The total surface area of Guangzhou is 7,434 km^2, one-third of which is available for urban development. From 2010 to 2020, average annual population growth was about 4 percent—in other words, around 600,000 people were added to the city each year.

Guangzhou is located in a subtropical coastal area in a monsoon climate zone with long summers and short winters. Developers seeking to create a comfortable urban habitat in Guangzhou have always faced challenges. Since the 1990s, the annual average temperature has increased by approximately 1.4°C, while the average annual UHI magnitude has increased by about 1°C, contributing to more than 70 percent of the temperature increase. Heat islands have occurred in the downtown core urban areas and expanded to the

Figure 6 // CITY OF GUANGZHOU

Credit: wonry I istock.com

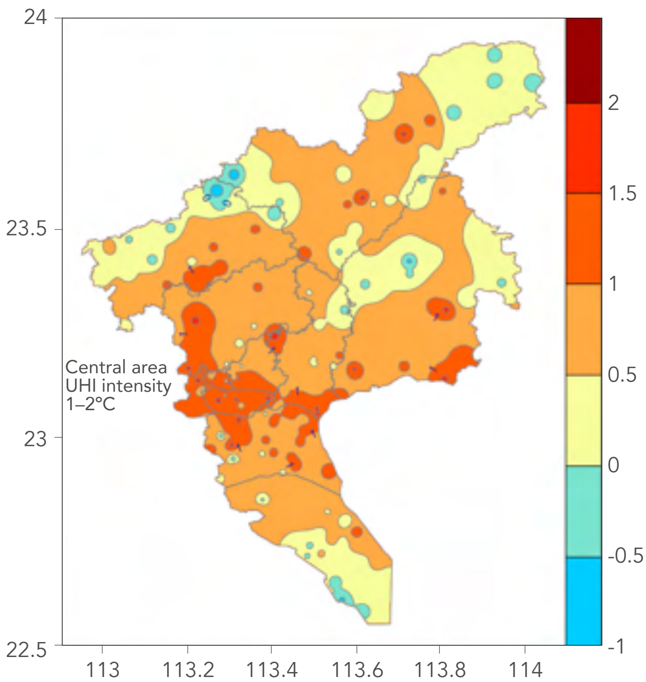
Figure 7 // LOCATION OF GUANGZHOU.

Source: World Bank.

subcenters. During heat waves, the UHI magnitude in the old city and downtown area may peak at 3°C higher during the day than temperatures in the suburbs.[6]

Various factors have contributed to UHIs in Guangzhou. Rapid urban expansion has encroached on farmland and local waters, replacing them with dark, impermeable surfaces. Construction sites and roads have replaced natural landscapes. Urbanization has had a huge impact on Guangzhou's natural ventilation environment, a key component for removing hot air from urban cores. Wind speed in the inner city has been reduced significantly. The annual average wind speed in every district in Guangzhou except Conghua District has fallen by approximately 30 percent in the past 20 years. (Guangzhou Meteorological Bureau)

Figure 8 // DISTRIBUTION OF LAND SURFACE TEMPERATURE (2021).



Source: Guangzhou Meteorological Monitoring Center

[6] Data shared by Guangzhou Meteorological Bureau.

Guangzhou's Urban Plan and Strategy

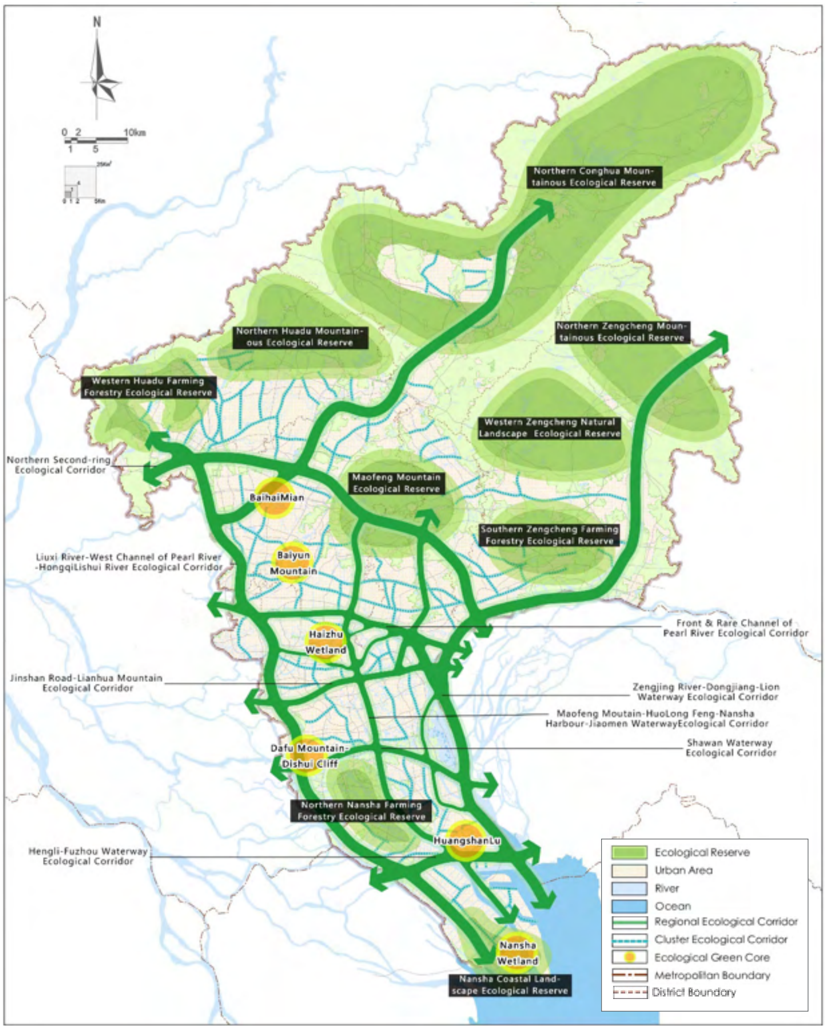
Chinese cities are at a critical juncture as they shift away from expansion toward regional revitalization and urban regeneration. New policies that integrate the renewal of old city districts with the development of new urban areas aim to optimize the distribution of urban space, promote green urban development, and preserve cultural heritage.

These new national priorities are reflected in Guangzhou's local planning efforts. The city is working on its 2035 Master Plan and has articulated Vision 2035: a vibrant, livable, and global City of Flowers.[7]

The Guangzhou 2035 Master Plan limits urban expansion, protects ecology, and integrates climate change mitigation. It accommodates population growth with a greater focus on infill development and urban land regeneration. It promotes economic growth with a strong connectivity policy, and is designed to manage and protect the natural ecological network by optimizing the pattern of land for protection or development.

Guangzhou's landscapes offer opportunities for ecological planning and bioclimatic design. The city comprises diverse landscapes, consisting of 50 percent mountainous area, 40 percent plains, and 10 percent water bodies. To take advantage of this complex topography and hydrology, the spatial pattern of Guangzhou is a polycentric and clustered spatial network connected by ecological and wind corridors. The Master Plan conserves the nine major ecological areas of the city and builds a three-level (regional-district-community) ecological corridor. The plan calls for constructing a blue-green infrastructure network that will help the city increase resilience. It aims to reconnect nature, society, and the city, adaptively responding to the changing climate through five guiding principles: sustainability, nature-positive approach, carbon neutrality, resilience, and cultural vitality.

Figure 9 // NETWORK OF GUANGZHOU ECOLOGICAL CORRIDORS.



Source: Guangzhou Urban Planning & Design Survey Research Institute.

7 Guangzhou Municipal Planning and Natural Resources Bureau, Guangzhou 2035 Master Plan Master Plan Public Consultation Draft

Guangzhou's Climate Actions

On September 22, 2020, China announced at the UN General Assembly that it would aim to peak its carbon dioxide (CO_2) emissions before 2030 and reach carbon neutrality by 2060. Carbon neutrality refers to a status where CO_2 emissions and removal balance to zero, usually accomplished through carbon offsetting or elimination of CO_2 emissions. This major strategic decision demonstrates China's determination to pursue green and low-carbon development. However, the challenges are tremendous. Reaching carbon neutrality would require a paradigm shift in China's urban management system.

Guangzhou's public sector was leading the way to cut energy use by one-fifth in large public institutions at the end of 2017.[8] To move toward carbon neutrality, the Guangzhou government is now committing to exploring comprehensive low-carbon development through integrated transformations that involve various sectors, such as land use, energy, transportation, and construction. Meanwhile, a cooling city action plan will be included in the overall climate strategy. This will help Guangzhou become the leading city in China to reach emission peaking before 2030 and achieve carbon neutrality before 2060.

Challenges and Opportunities in Addressing UHI in Guangzhou

Like many Chinese cities, Guangzhou faces the typical environmental challenges of a megacity. Urban growth continues to take up large ecological space. The consumption of water, energy, and other resources is significant. Environmental pollution, including water and soil pollution, is substantial. Global climate change increases the risk of storm surges and sea-level rise. The heat island effect is prominent in both summer and winter. Extreme weather events such as heavy rain and sustained high temperatures occur frequently. Like most growing global cities, Guangzhou also faces competing demands. The city plans to limit land expansion and protect its ecological assets while accommodating sustained population growth, creating jobs, and maintaining a vibrant economy—a difficult balance to achieve. The population and construction density are already high, with roughly 1.4 billion m^2 of construction in the municipality. In some especially populous districts, the population density is more than 30,000 people per km^2.[9]

In this dense urban environment, the UHI effect poses specific challenges for urban planners. Excess heat is trapped in impermeable surfaces and narrow spaces. To obtain thermal comfort during hot summers, more and more modern buildings and residences resort to air conditioning, which in turn generates more anthropogenic heat. Natural ventilation and other nature-based solutions from traditional architecture have been lost to modernity. These factors result in a continuously heating city with a continuously rising cooling demand. Sustainable urban cooling solutions are necessary to both restore nature and ensure a comfortable urban habitat, giving residents more opportunities to pursue outdoor activities.

Implementing such solutions poses many challenges, however.

First, formulating standard clauses and regulations is a complicated and lengthy process. There are significant institutional barriers to establishing a policy or statutory framework that mandates the installation of cooling measures.

Second, it may take some time to achieve a profitable return on investment for specific cooling methods, so stimulating the initiative of private developers is a significant challenge. It is also difficult to balance the economic interests of all parties, including the government, local developers, and private sector actors, during the urban development and regeneration process.

[8] As indicated in ADB (2018): "Guangzhou has instituted a plan requiring large public institutions, such as government agencies, hospitals, schools, and cultural and sports venues, to complete comprehensive energy audits and undertake energy efficiency improvements by the end of 2017. To target the biggest energy consumers, the plan applies to 206 institutions with annual power consumption of at least 1,500 MWh or a gross floor area of 20,000 m^2, mandating a 20% reduction of energy demand per unit of floor area after improvements are completed. The plan builds on impressive results from previous years, in which 31 energy efficiency improvement projects implemented at public institutions in Guangzhou cut annual power consumption by 21,000 MWh and reduced CO_2 emissions by 12,000 tons from 2012 to 2015. The intent of requiring energy audits and efficiency improvements for these key energy consumers is to provide examples of green public buildings, and formulate the energy consumption standard for all public institutions in Guangzhou."

[9] Guangzhou Municipal Planning and Natural Resources Bureau. The Green Vision and Strategies for a Dynamic Global City, Presented at World bank Green and Resilient Development Seminar Ningbo, 2019.

Finally, urban cooling is a cross-disciplinary intervention that requires systematic coordination involving spatial planning, transportation, and conservation. Addressing challenges requires collaboration among multiple agencies such as planning, environment, and economic development.

Guangzhou presents strong opportunities to test and scale up nature-based solutions for urban cooling, as the city is developing robust, integrated planning policies and frameworks. Green and ecological space protection is an established long-term policy in Guangzhou. The city is promoting the construction of a low-carbon city through application of land management practices, ecological restoration, and cooling measures.

The World Bank, in collaboration with the Guangzhou Municipal Planning and Natural Resources Bureau and the Guangzhou Urban Planning & Design Survey Research Institute, conducted pilot activities at three sites:

- **An old town renovation in Yongqing Fang:** This pilot focuses on infill development in the urban core to tailor strategies to the local context and traditions. It deploys small-scale interventions for greening and ventilation and increases the solar reflectivity of the urban fabric to mitigate the UHI effect. Moreover, through engagement with the private sector, the project identifies methods to assess the financial value of investments in cooling measures.
- **A new town development in China-Singapore Guangzhou Knowledge City to create a low-carbon, green, ecological district:** This pilot explores new ways to intensify greening, shape the urban layout to create wind corridors, and leverage larger green spaces and water infrastructure.
- **Haizhu National Wetland Park:** Using the InVEST modeling tool, the cooling effects and economic value of the city's natural asset—an 11 km^2 wetland located in the downtown core—are evaluated. The model puts a price on selected ecological services provided by the wetland (e.g., cooling, health, carbon storage, etc.) to raise awareness of the economic benefits of the natural asset.

The three pilot activities aim to (1) contribute to the city's efforts to scale up comprehensive nature-based urban cooling solutions and integrate them into urban planning; and (2) implement natural resource asset management. They also complement Guangzhou's efforts to protect urban ecology, optimize land use planning, and position itself as a carbon-neutral city within the next 30 to 40 years.

The one and half year implementing period (from 2020 to 2021) coincided with the COVID-19 pandemic. Nonetheless, the two partner institutions—Guangzhou Municipal Planning and Natural Resources Bureau and Guangzhou Urban Planning & Design Survey Research Institute—closely collaborated with the World Bank team to collect local data and to design, monitor, and measure the results of the pilot projects. The tangible experience and local performance data gained through the project activities helped build capacity and confidence among the policymakers and also raised the awareness of and engagement with the public. The pilots led to a better understanding of how to address regulatory gaps and incorporate natural assets and cooling by design into the spatial planning and urban form. The experience gained and lessons learned are valuable not only to the city of Guangzhou but to many other cities facing similar challenges, both in China and around the world.

The following two technical reports provide greater detail on the piloting activities, the approach, the process, and lessons learned:

- "Piloting Nature-Based Urban Cooling Options in Urban Regeneration and New Town Development: Guangzhou Yongqing Fang Pilot and China-Singapore Guangzhou Knowledge City"
- "Economic Evaluation of Key Ecosystem Services by Urban Natural Asset: Haizhu Wetland in Guangzhou"

Based on the experience from the piloting activities, the following guidelines were developed to provide general recommendations to urban planners and practitioners:

- "Guidelines on Integrating Nature-Based and Passive Cooling Options into Urban Planning and Design"

This overview summarizes these reports and highlights the experience gained through the project activities. It covers lessons learned and recommendations for city leaders and urban planners in integrating cooling strategies in urban spatial planning and design, developing regulatory frameworks, involving the private sector, and engaging the public. Annexes 2–4 include a brief description of the three pilots.

Source: Guangzhou Urban Planning & Design Survey Research Institute

Key Findings and Recommendations

The pilots in Yongqing Fang and the China-Singapore Guangzhou Knowledge City (briefly described in box 5 and box 6) demonstrate the potential for urban cooling solutions in two very different environments. While the specific set of urban cooling solutions varied substantially between the locations, there were some important commonalities, which can be applicable in other cities. Both pilots highlighted the importance of robust institutional support in the planning and implementation phases. The Guangzhou Municipal Planning and Natural Resources Bureau and Guangzhou Urban Planning & Design Survey Research Institute played a central role in evaluating urban cooling measures and coordinating with the developers and other key stakeholders. The city government was also instrumental in developing a supporting programmatic and policy environment to facilitate financing and encourage the adoption of incentives. This section reviews the technical measures undertaken in both pilots, discusses the role of the Guangzhou Municipal Planning Authority, and makes recommendations for other cities based on Guangzhou's experiences.

Box 5 // YONGQING FANG PILOT

A pilot site and an individual pilot building were selected in the Xiguan area of Liwan District in the old town of Guangzhou. Different cooling measures were implemented in the construction process, with a focus on block-level and market-oriented modes.

Figure 10 // YONGQING FANG

Source: Guangzhou Vanke Co., Ltd.

Box 6 // CHINA-SINGAPORE GUANGZHOU KNOWLEDGE CITY PILOT

China-Singapore Knowledge City is a new town under planning. The planned area is 178 km^2, of which 90 km^2 will be developed. The Jiulong Lake District is the 12.6 km^2 pilot area situated in the heart of the Knowledge City. The district is expected to accommodate 140,000 people.

Figure 11 // AERIAL VIEW OF THE CHINA-SINGAPORE KNOWLEDGE CITY JIULONG LAKE AREA

Figure 12 // RENDERING OF THE JIULONG LAKE DISTRICT PLAN

Source: China-Singapore Knowledge City development and construction office.

The section is organized in three parts:

- **Part A: Technical Solutions.** This section describes what urban cooling measures were prioritized by Guangzhou, how they were implemented, and what lessons were learned in the process.
- **Part B: Institutional Support for Cooling Solutions.** This section describes the frameworks, policies, and processes that a city can use to identify, prioritize, and build support for an integrated urban cooling strategy.
- **Part C: Financing.** This section describes how to pay for urban cooling investments.

Part A. Technical Urban Cooling Solutions

A wide variety of measures and practices can contribute to urban cooling. Cities must evaluate the mix of strategies that will be most effective in their area. Given its climate, resilience priorities, and other factors, Guangzhou prioritized natural solutions in its urban cooling pilots:

- Ventilation corridor to enhance natural wind flows
- Ecological connectivity with blue and green infrastructure
- Urban fabric to cool neighborhoods via increased shade, ventilation, and cool surfaces
- Use of modeling tools to quantify benefits generated by blue and green assets

Each technical cooling solution is briefly described below, along with how the solution was implemented in the Guangzhou pilots and what lessons were learned from the city's experience.

Urban cooling solution 1

Ventilation corridors to enhance natural wind flows

Allowing natural wind flows through urban areas helps to dissipate heat, polluted air, and small particulate matter. It can also prevent the aggregation of air pollutants, reduce the transmission of infectious diseases, and protect public health. Over the last century, modern urban design and development have often ignored these natural ventilation lanes. Any barrier to, or stagnation of, natural airflow may hamper outdoor thermal comfort and exacerbate an urban heat island effect.[10]

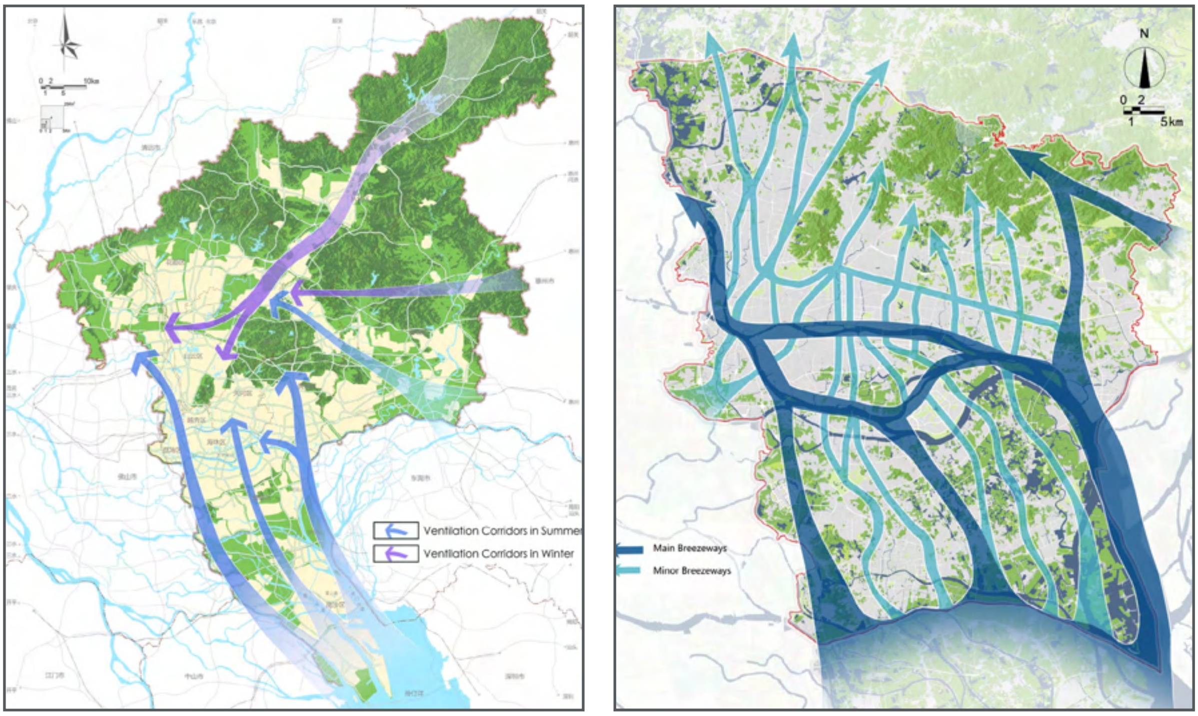
Guangzhou's experience

Guangzhou evaluated a plan for developing six major corridors that would create a citywide ventilation system. The main corridors would be oriented north-south, with support from east-west secondary corridors. The corridors will seek to maximize the movement of cool air from natural cooling sources (typically water, large parks, or green infrastructure) toward urban hot spots as illustrated in Figures 13, 14 and 15, and boxes 7 and 8. According to weather monitoring data, Guangzhou's most frequent wind frequency is 0.5–3.5m/s. The main purpose of these ventilation corridors is to increase soft breezes in the inner city during summer seasons. The speed of a soft breeze enhanced by corridors is unlikely to reach the risky speed level of wind disasters. However, cities from other regions with different climate conditions should carry out cost-benefit analysis to ensure they can maximize cooling benefits while preventing disasters related to winds.

[10] When creating ventilation corridors, cities should simulate the effects of extreme wind events to anticipate possible risks. They should carefully analyze trade-offs between accelerating breezes and risking extreme wind events.

Figure 13 // **PROPOSED VENTILATION SYSTEM AT CITY LEVEL (LEFT) AND CENTRAL AREA LEVEL (RIGHT).**

The six major ventilation corridors run along the mountains and rivers parallel to the wind direction. The central area will benefit from five major breezeways and 22 minor breezeways.



Source: Guangzhou Urban Planning & Design Survey Research Institute.

Box 7 // VENTILATION CORRIDORS IN KNOWLEDGE GREEN VALLEY

The Knowledge Green Valley plan aims at maximizing site ventilation. Open spaces and green spaces are interconnected to form a network to direct winds. A stepped building-height profile is adopted, in which the building height gradually rises backward from the river and lake to increase ventilation capacity. The orientation of waterfront buildings, and hollow-up and streamlined building forms, are well arranged to channel the river breeze. Blockage by buildings is reduced by subdividing the podium structure using voids and setbacks. The layout of the buildings is aligned with topography to form local microcirculation.

Figure 14 // **ILLUSTRATION OF VENTILATION CORRIDOR.**

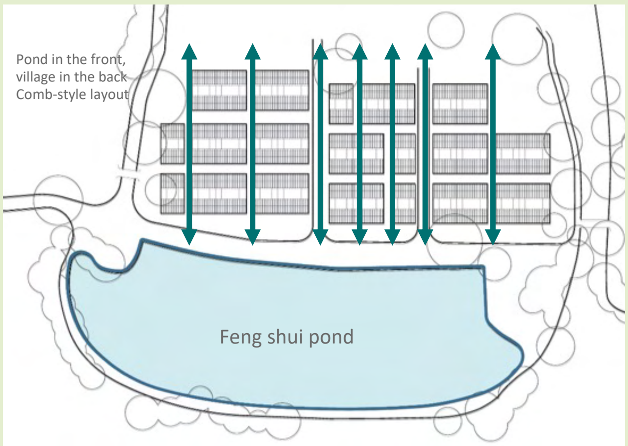
Source: China-Singapore Guangzhou Knowledge City Development and Construction Office.

Box 8 // VERNACULAR COMB-STYLE STREET LAYOUT IN GUANGZHOU

A comb layout (figure 15, left) is encouraged in the renovation of old towns in the south of China, along with construction of alleys to allow cooling ventilation. The street texture should follow the local wind circulation to facilitate the movement of cool air (figure 15, right).

The comb-style layout is a typical layout of traditional villages in Guangzhou. Most of the villages are located in the north and face south with feng shui ponds sitting in front of the village. Southeast monsoons are prevalent in Guangzhou in the summer, and the main lanes of the village run parallel to the prevailing summer wind direction. Thus the cool breezes from across the pond can reach into the village along the comb-style alleys. The fronts of the villages are low while the backs are high. This topography is used for effective water drainage. It can also direct the downward flow of wind into the rear of the village. The high-density layout of traditional Guangzhou villages, with high walls and narrow alleys, is highly adapted to the climate of the region. Most of the activity spaces are in the shadows of buildings to reduce solar radiation. Gables extending from the building surfaces also offer shade from the rooftops.

Figure 15 // COMB-STYLE LAYOUT OF TRADITIONAL VILLAGE TO ALLOW MOVEMENT OF COOL AIR



Sources: Guangzhou Urban Planning & Design Survey Research Institute.

Recommendations to enhance natural wind flow

- Integrate ventilation corridors into the planning process as early as possible. This includes evaluating and identifying ventilation corridors in the master plan (e.g., using wind and thermal environment simulations) and implementing ventilation corridor control requirements in the unit plan. These solutions should be implemented at the city, neighborhood, and building levels with a consistent approach throughout. Prioritize ventilation corridors that connect open spaces and promote cooling from existing blue and green features (e.g., lakes, rivers, extensive forests).
- Improve control over land use and development projects, and increase the permeability of ventilation corridors. Examples include using the ecological corridor system to create ventilation corridors; strictly protecting open spaces in the ventilation corridors, such as water systems and green areas; monitoring any potentially harmful project proposals and forbidding the entry of any air-polluting projects; setting up a ventilation corridor indicator control system to enhance control over building height, building intervals, and density; and enhancing control over air intakes and windward zones.

Policy context for implementation

Construction and maintenance of ventilation corridors are mostly addressed in the early stage of the urban planning and design process. These solutions work best for rapidly growing cities seeking to manage development intensity in spaces reserved for wind corridors within new town development or urban renewal projects.

Urban cooling solution 2

Ecological connectivity to maximize cooling effects

The temperature of planted areas can be as much as 6–8°C lower than that in built-up areas due to a combination of evapotranspiration, reflection, shading, and cold storage (DeKay and Brown 2014). In addition, trees provide shade and minimize the heat from solar radiation. Urban parks can be built at a comparatively low cost in humid tropical areas because vegetation grows quickly there and irrigation needs are low. Proper distribution of parks and green areas can also increase the value of surrounding plots and provide recreational space for nearby residents, enhancing their well-being.

Planted areas may extend to buildings themselves in the form of green roofs and walls, or three-dimensional (3D) greening. These solutions allow ecological connectivity even in highly developed urban areas. In addition to cooling benefits, these natural interventions increase the insulation of the building envelope and promote energy efficiency.

The surface temperature of water is typically several degrees cooler than the surface temperature of the surrounding built environment; thus water can cool the ambient air through convective processes (Yenneti et al. 2017). Water landscapes near urban areas, such as lakes, rivers, and wetlands, contribute to "urban cooling islands" and may decrease the city's ambient temperature by 1–2°C (Manteghi, bin Limit, and Remaz 2015). Man-made water features can also be used to address cooling demands in crowded areas.[11]

Guangzhou's experience

In planning the pilot projects, the city took careful stock of its existing natural assets and opportunities to create or enhance man-made water infrastructure. The city planned its urban cooling interventions around these natural assets to take full advantage of their cooling potential and create ecological corridors. In both pilots, a priority was placed on developing modalities of 3D landscaping and greening through the use of green roofs, green walls, and sky gardens.

In China-Singapore Guangzhou Knowledge City, the 3D greening of the urban form has been extended across a 20 ha block. The design combines hilly microtopography and low-lying areas to form rain gardens and wetland parks. It creates an integrated landscape of green areas and water. The design uses stilts, three-dimensional setbacks, and other techniques in combination with natural features. Elevated and staggered floors are integrated with micro-hills through vertical greening to form a complete and connected 3D greening system. The use of a microtopography design will protect the original ecology, utilize the slope to form local breeze circulation, enable low-lying areas to form rain gardens, and create vertical green spaces (see boxes 9, 10 and 11).

[11] Misting facilities make use of the principle of evaporative cooling by sprinkling very small water droplets at high pressure to influence the surrounding air temperature and achieve local cooling. Under different climate conditions, misting facilities can reduce the temperature of the surrounding environment by 5–15°C. Such reductions can usually be achieved by setting up high-pressure misting facilities in crowded areas or by building fountains. Compared to long-term measures to change the climate of the area, misting facilities are an effective way to quickly change the microclimate of a specific location. The cost of installing misting facilities is relatively low. However, misting facilities are suitable only for small-scale installations in specific areas. They are not suitable for large-scale applications.

Box 9 // VERTICAL GREENING IN YONGQING FANG PHASE II PROJECT

Vertical greening offers effective insulation, reduces facade temperatures, and filters out glare and dust. Vertical greening grown on the ground makes use of the surrounding land spaces and vines grown along the facades to form natural green walls. The use of vertical greening grown from the ground presents four advantages:

1. It utilizes the ground soil to reduce the thickness of walls, thereby ensuring the maximum indoor functional area.
2. It is simple, low-cost, and easy to maintain for two- to three-story buildings.
3. It uses vines, which are fast-growing and highly resilient.
4. The green wall it forms offers history, tradition, and intimacy and is consistent with traditional urban landscapes.

Figure 16 // VERTICAL GREENING.

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

Classic plants grown on the ground, such as bamboo, can be used for vertical greening

Source: Guangzhou Vanke Co., Ltd.

Box 10 // USING BODIES OF WATER TO CREATE GREEN VENTILATION CORRIDORS IN JIULONG LAKE

The Knowledge Green Valley demonstration project keeps the existing Laohulong Reservoir and plans to build a linear park to form a landscape ventilation corridor together with Jiulong Lake, parallel to the prevailing winds. The plan places more vegetation in the green spaces and parks and controls vegetation density to avoid blocking winds. It lowers both air and ground temperatures through shading and evaporation.

Figure 17 // LOCATION OF BODIES OF WATER AND MAJOR GREEN SPACES IN KNOWLEDGE GREEN VALLEY.

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

Box 11 // LANDSCAPE DESIGN IN YONGQING FANG PILOT PROJECT

The landscape design in Yongqing Fang uses plants to increase shelter from both sunlight and rain. It combines the use of plants, spraying facilities, water features, and paving materials to create a sustainable water flow system and increase the active evaporative cooling effect. In sections not covered by stone slabs, the design selects the appropriate permeable materials and coordinates with the neighborhood colors and style. It uses permeable paving materials in small open spaces and considers using the gaps between slabs to store and drain water according to the topography.

Figure 18 // LANDSCAPE DESIGN

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

Recommendations to increase ecological connectivity

- Take stock of existing natural assets and opportunities to develop or enhance man-made green and blue infrastructure. Analyze the cooling potential and economic value of the ecosystem services, and use the valuation to inform incentives and other policies.
- Increase the tree canopy and create a network of green connected spaces. Cities should develop both large and small urban parks and areas of concentrated tree canopies, where plantings are feasible, and should create green corridors linking parks and urban canopy concentrations. This design will provide seamless cooling for pedestrians and increase access to areas of respite on dangerously hot days. Cities should prioritize neighborhoods that are vulnerable to heat stress and areas with heavy pedestrian traffic for new green space and tree plantings.
- Prioritize the use of water infrastructure and protect and restore water bodies. When possible, cities should enhance the control over riverside spaces and expand river cooling spaces to create an unobstructed, open cooling space along the riverside. These interventions can be implemented as part of a broader sponge city concept to take full advantage of water bodies' evaporative cooling. Water infrastructure enhancements should be integrated with green area development to form a networked area.
- Deploy green roofs and walls to extend the ecological connectivity into dense urban areas.

Policy context for implementation

These solutions can bring considerable co-benefits for cities that seek urban expansion and renewal while aiming for sustainable cooling and maintaining a nature-positive approach. Particularly in hot and humid areas, leveraging urban natural spaces for maximizing cooling is cost-effective due to the high vegetation growth and low irrigation needs for maintenance.

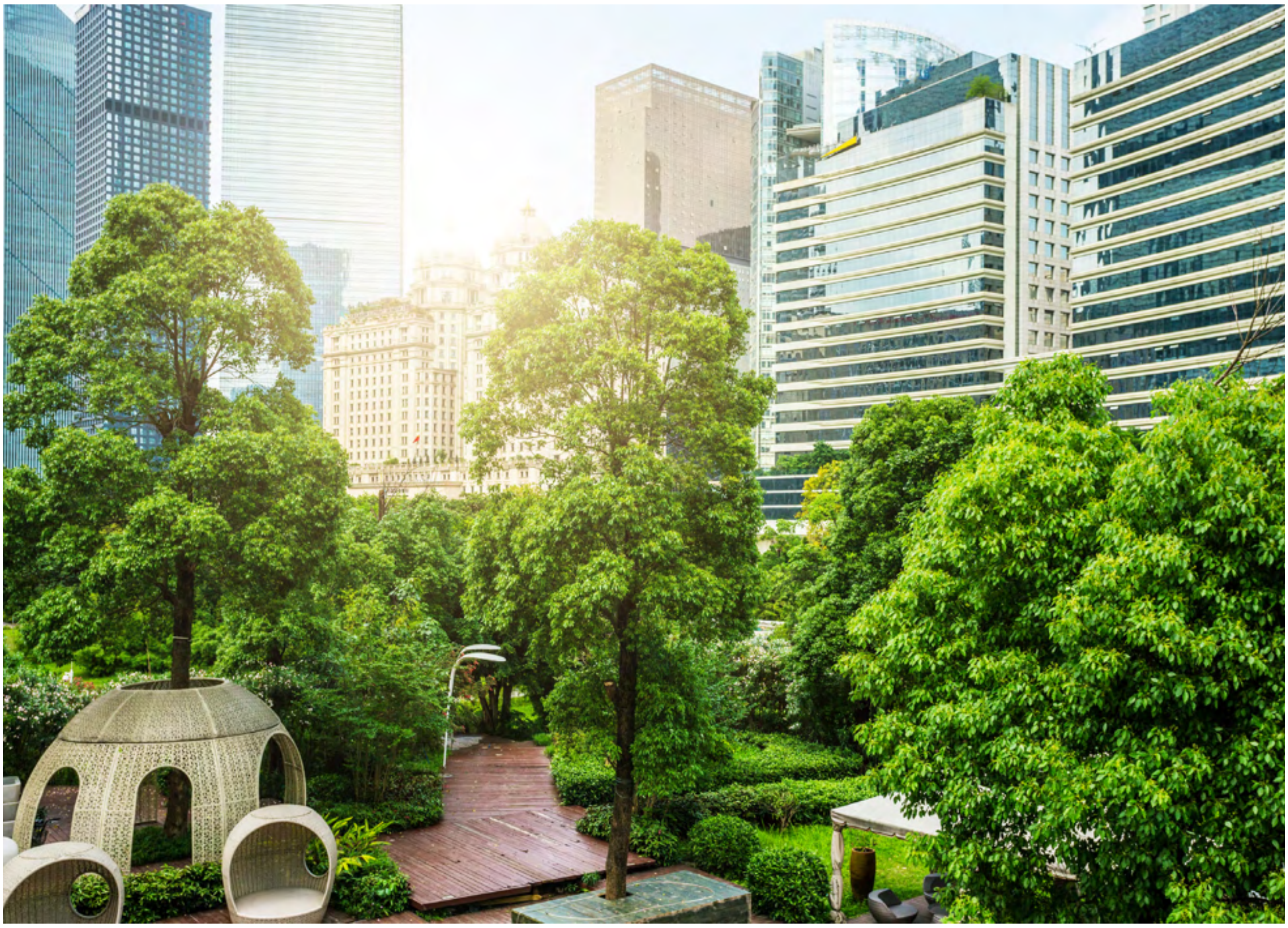


Photo: xijian | istock.com

Urban cooling solution 3

Urban fabric to cool neighborhoods

The urban fabric comprises the neighborhood morphology (streets, open spaces, buildings) and functions (human activities). Neighborhoods exhibit recognizable patterns in the ordering of streets, buildings, spaces, and functions. These patterns have a strong impact on the ventilation and shading potential, and thus natural cooling, of the neighborhood.

Urban fabric for cooling the city in hot and humid climates relies on a "breathing" urban texture, which allows air to flow in the external and internal spaces; it also relies on shading, which minimizes solar radiation, and on reflective materials to increase the amount of solar energy reflected from the surface. Urban fabric design for "cool" neighborhoods should be conducted at three levels: site, building, and landscape.

Guangzhou's experience in maximizing ventilation

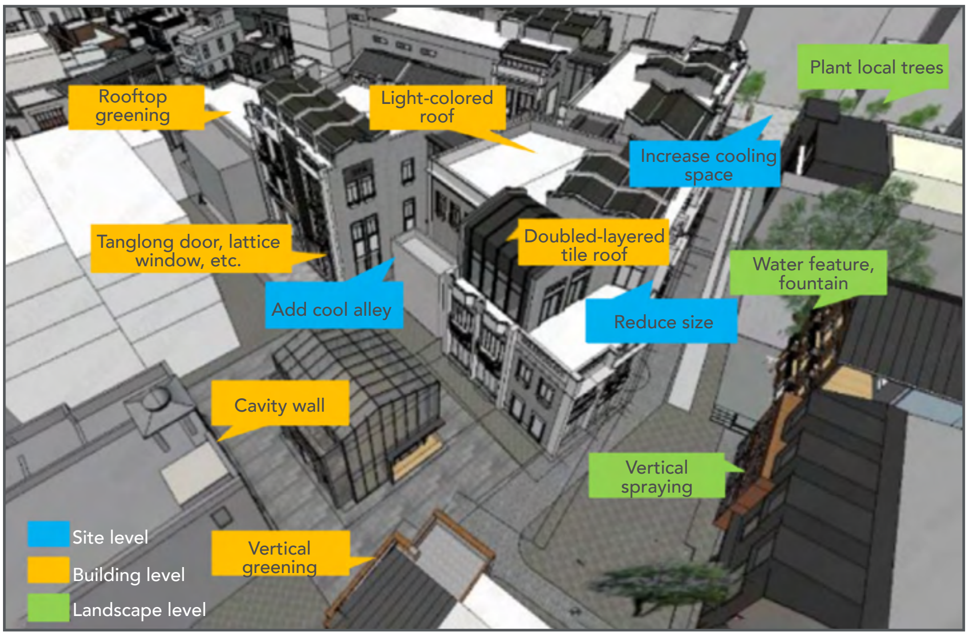
The Yongqing Fang Phase II project included a list of cooling measures at the site level, the building level (including roofs and facades), and the landscape level for the Jixiang section (table 1, figure 19).

Table 1 // COOLING MEASURES IN YONGQING FANG PHASE II PROJECT

Level	Recommended measure
Site	• Increase cool alleys and cooling spaces • Decrease the size of buildings and use bamboo-tube houses[a] • Widen the streets
Building	• Consider using traditional double-layered tiles on rooftops • Use light-color coatings and implement rooftop greening • Use cavity wall insulation • Create vertical greening in some of the west-facing areas as part of the landscape design
Landscape	• Plant local trees to increase cooling through evapotranspiration and create comfortable shaded areas • Install sprinkler facilities and solar-powered fans on building facades • Install water features and fountains in public spaces.

[a] See glossary and figure 20.

Figure 19 // INTERVENTIONS IN YONGQING FANG.



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

Figure 20 // **TRADITIONAL PASSIVE COOLING MEASURES IN LINGNAN.**

Source: Guangzhou Urban Planning & Design Survey Research Institute.

Recommendations for designing the urban fabric to cool neighborhoods

A breathing urban fabric incorporates cooling measures at the building, site, and landscape level to maximize cooling effects. Key recommendations are as follows:

- **Create major and minor breezeways.** Breezy streets oriented to the prevailing wind maximize air movement and increase the access of buildings to cross-ventilation. Linear streets and open spaces, where the prevailing wind flows, establish major breezeways.
- **Orientate streets to facilitate airflow.** The direction of streets controls the solar access inside and outside buildings, the permeability to airflow, and thus the passive cooling capacity. Streets aligned to breezeways support air movement and reduce UHIs.
- **Design well-ventilated walkways.** Urban designers should consider people's movement across the urban area and should align well-ventilated pedestrian walkways parallel to the prevailing wind.
- **Link open spaces into ventilation corridors.** The linkage of open spaces allows the prevailing wind along breezeways and major streets to penetrate deep into the city fabric.
- **Guide wind flows.** Building blocks should be oriented so that the longitudinal axis is parallel to the prevailing wind direction to channel or direct wind across the site, avoiding obstructions.
- **Accelerate wind flows with variation between building heights.** Urban design should arrange buildings according to ascending heights regarding wind direction to allow wind to reach the rear blocks. For an effective application, the taller building should be at least double the height of the shorter one.
- **Reduce building frontage.** Reducing the building frontage enhances wind penetration. The adoption of an aerodynamically shaped façade also facilitates wind flows around the building structure.
- **Create voids between and in buildings.** Gaps between buildings enable airflow toward the downwind areas. Permeability at the ground floor of buildings is a better option than an excessive widening of streets and outdoor spaces. Gaps increase permeability and encourage airflow through and around the buildings while introducing additional shaded spaces.

Key recommendations for maximizing shadow are as follows:

- Minimize solar radiation and maximize shadow through urban fabric geometry, including aspect ratio (height to width), sky view factor, and street orientation.
- Orient buildings to maximize shade, lower sun exposure, and minimize solar heat gains through the facades. Correctly oriented buildings can also provide shade on nearby outdoor structures such as sidewalks, public spaces, and streets.
- To achieve urban shading at street level, create deeper street canyons.

Key recommendations for increasing the amount of reflected solar energy are as follows:

Increase the amount of solar energy reflected from the surface, the efficiency with which a surface sheds absorbed heat, and/or the water permeability of the surface to promote cool surfaces. Cooling options exist for nearly all roof, wall, and pavement types and use cases.

Policy context for implementation

In cities with historic neighborhoods, especially in a dense urban environment with heat concentration, natural cooling and cultural benefits can be achieved by exploring and applying traditional architecture and cooling approaches to ventilation, shading, and heat insulation. Many of these solutions focus on building-scale and neighborhood design, of which the implementation requires adopting the urban design guidelines and building standards.

Urban cooling solution 4

Use of modeling tools to quantify benefits generated by natural assets

Urban natural assets such as wetlands, green spaces, and lakes, provide a wide range of benefits to urban residents. These benefits are characterized as ecological services and include easing air pollution, cooling the surrounding temperature, mitigating GHG emissions, managing stormwater, enhancing health, and providing recreation. However, many of these benefits are invisible to those who plan and develop urban spaces and remain poorly articulated for actionable decision-making. Understanding the ecosystem services provided by natural assets enables city officials and urban planners to make ecologically informed decisions about urban development. Quantifying these services or putting a price on the natural assets provides a critical basis for accounting "nature" as part of the municipal assets and thus supports assets' management and enhancement.

Global cities such as London and Singapore have already undertaken innovative approaches in accounting for ecological services provided by natural assets, including quantifying the economic value of cooling effects.[12]

Guangzhou experience

Using the InVEST modeling tool, an economic valuation of ecosystem services was conducted for the Haizhu wetlands. The tool assessed five types of services and their economic value: urban cooling, climate change mitigation, recreation, physical health, and mental health. A conservative estimate shows that the marginal value provided by the Haizhu wetlands via these five ecosystem services is at least US$221.8 million over the next 30 years, in addition to reduced mortality risk and increased workplace productivity in the surrounding landscape. (See annex 4 for a summary of the Haizhu wetlands project; for the full report, see Assessment of Key Ecosystem Services Provided by the Haizhu National Wetland Park in Guangzhou, Guangdong, China).

Drawing on the experience gained from the Haizhu wetlands modeling, the Guangzhou Urban Planning & Design Survey Research Institute used the InVEST tool for the design of China-Singapore Knowledge Valley. The outcomes show that cooling capacity of the site has been improved nearly 50 percent through optimized planning. These quantitative assessments provide solid evidence of cooling benefits brought by green spaces and land use changes; they can serve as supporting data during the planning process and enable planners to make informed decisions on cooling.

[12] See for example Vivid Economics (2017) and Global Platform for Sustainable Cities (2019).

Box 12 // HAIZHU WETLANDS

The Haizhu National Wetland Park is an 11 km^2 green space in the heart of the megacity of Guangzhou in Guangdong Province (figure 21). The wetlands support local biodiversity and provide essential ecosystem services to 7.2 million residents in the surrounding districts.. While the wetland is home to hundreds more insect and avian species than the surrounding city and received more than 60 million visitors over the last decade, many of its additional benefits remain unquantified.

Figure 21 // HAIZHU WETLANDS.

Source: Guangzhou Haizhu District Wetland Protection and Management Office.

Recommendations

Ecosystem services should be mapped and measured to quantify the extent to which nature supports human well-being. Quantifying these services provides concrete evidence to help planners and policy makers incorporate natural assets into land use planning, establish and leverage ecological connectivity to cool the city (as discussed under urban cooling solution 2), and increase urban resilience.

Part B. Institutional Support for Cooling Solutions in Planning and Implementation

Most cities have access to a variety of technical cooling measures, including those employed by Guangzhou and described in part A. The challenges lie in implementing those solutions on the ground.

The World Bank has developed a set of frameworks for selecting cooling measures that are appropriate for local conditions and that help build support for integrating cooling solutions into planning and implementation activities (ESMAP 2020b). Drawing on the recommendations from the World Bank, the Guangzhou pilot team undertook two major steps to facilitate the implementation: engaging stakeholders, and integrating technical solutions with design requirements.

Engaging stakeholders to raise awareness and identify feasible cooling solutions

Excess urban heat is a complicated challenge involving many city agencies, departments, private sector actors, the public, research institutions, and other stakeholders. Drawing from the World Bank's recommendations, Guangzhou Municipal Planning and Natural Resources Bureau set up a pilot office and conducted multiparty consultations with various agencies to take stock of the existing urban cooling work; the agencies involved were the Guangzhou Development and Reform Commission, Financial Bureau, Environmental Bureau, Urban and Rural Housing Construction Bureau, Water Affairs Bureau, Landscape and Forest Bureau, Meteorological Bureau, and Science Bureau. This exercise helped articulate the problem of urban heat in the local context and prepared stakeholders—in the municipal government, private sector, and broader public—for the planning and implementation activities to come.

The pilot office engaged with the private developer Vanke Real Estate (one of the largest real estate developers in China) and its construction team to understand and assess the feasibility of the proposed cooling options. This approach helped all parties agree on the specific cooling measures to be integrated into the planned urban regeneration activities.

In parallel, the Guangzhou Urban Planning & Design Survey Research Institute conducted a public consultation survey for the cooling project, collecting 9,000 questionnaires to analyze residents' perceptions of and opinions on thermal comfort in Guangzhou (see box 13). The stakeholder engagement process is illustrated in figure 22.

Box 13 // RESULTS OF PUBLIC CONSULTATION SURVEY ON URBAN COOLING MEASURES

Question 1

Residents' awareness of climate change

Guangzhou citizens have a relatively high level of awareness of global climate change. Survey results found that 96 percent of respondents care about global climate change issues; 37.6 percent believe that the biggest impact of global climate change on Guangzhou is damage to residents' health and to environmental quality; 35.1 percent believe that climate change will increase the risk of extreme weather and disasters; 9.8 percent believe that it will increase the energy demand for cooling; and 8 percent believe that rising sea levels threaten the safety of cities. Most of the respondents expressed their willingness to take relevant measures to tackle climate change. The measures chosen most often were engaging in low-carbon and green travel (79.2 percent), followed by saving electricity (48 percent) and choosing energy-saving appliances (31.7 percent).

Question 2

Residents' thermal comfort perceptions

Residents have a very strong perception of climate change's locally warming impacts in Guangzhou. More than 85 percent of respondents feel that the weather in Guangzhou has become hotter in recent years; almost 10 percent think that "there is no change" or "it is not so hot." Most people feel more strongly about the warming during the summer. Over three-quarters (76.2 percent) of respondents believe that climate change is mainly reflected in longer summers (41.6 percent) or hotter summers (34.6 percent), but about 30 percent of respondents believe that a "warm winter" is the most significant phenomenon of climate change.

More than 90 percent of respondents believe that the outdoor weather conditions in Guangzhou in summer are "hot" or "very hot," and more than 80 percent feel that their home is "hot" or "very hot" without air conditioning. However, when asked about temperature conditions of public indoor spaces during the summer, roughly 60 percent report that indoor temperatures were "slightly cold" or "too cold." This finding suggests that the temperature setting of public spaces is too low and represents an unnecessary waste of cooling energy.

Question 3

Residents' behavioral preferences related to heat

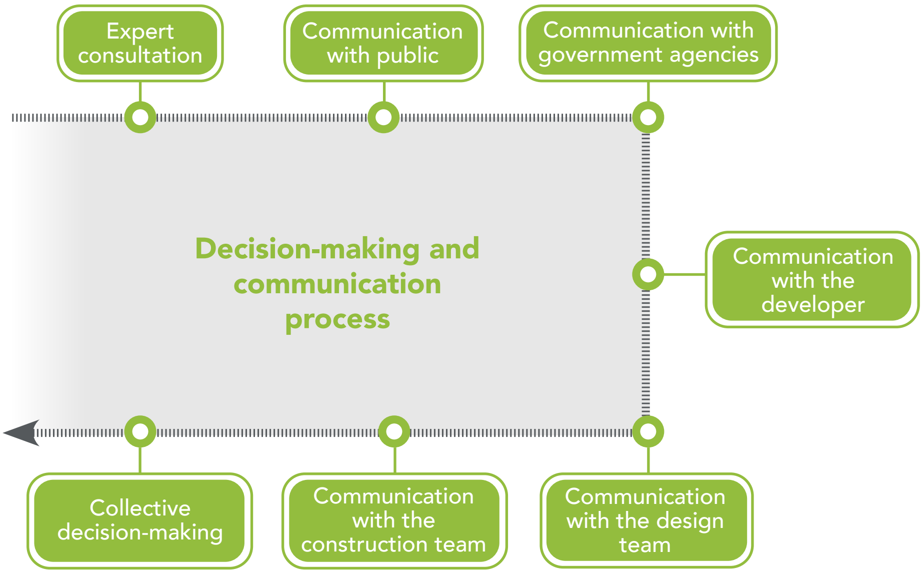
Guangzhou residents have a strong dependence on air conditioners throughout the year. Nearly 50 percent of respondents turn on the air conditioner before May, and most use it by July. More than 90 percent do not stop using the air conditioner until November. More than 40 percent of residents use air conditioners for more than eight hours a day for more than four months. However, respondents report good temperature-setting habits. More than 90 percent turn on the air conditioner when the temperature reaches 28°C or more in summer, and 67 percent of them turn on the air conditioner when the temperature reaches 30°C or more. Most households' air conditioners are set between 24°C and 28°C; 48 percent of respondents set it at 26°C, 15 percent set it at 25°C, and 13 percent set it at 27°C. Some 10 percent of respondents still set the air conditioner temperature below 23°C.

Question 4

Thermal comfort in the residential environment

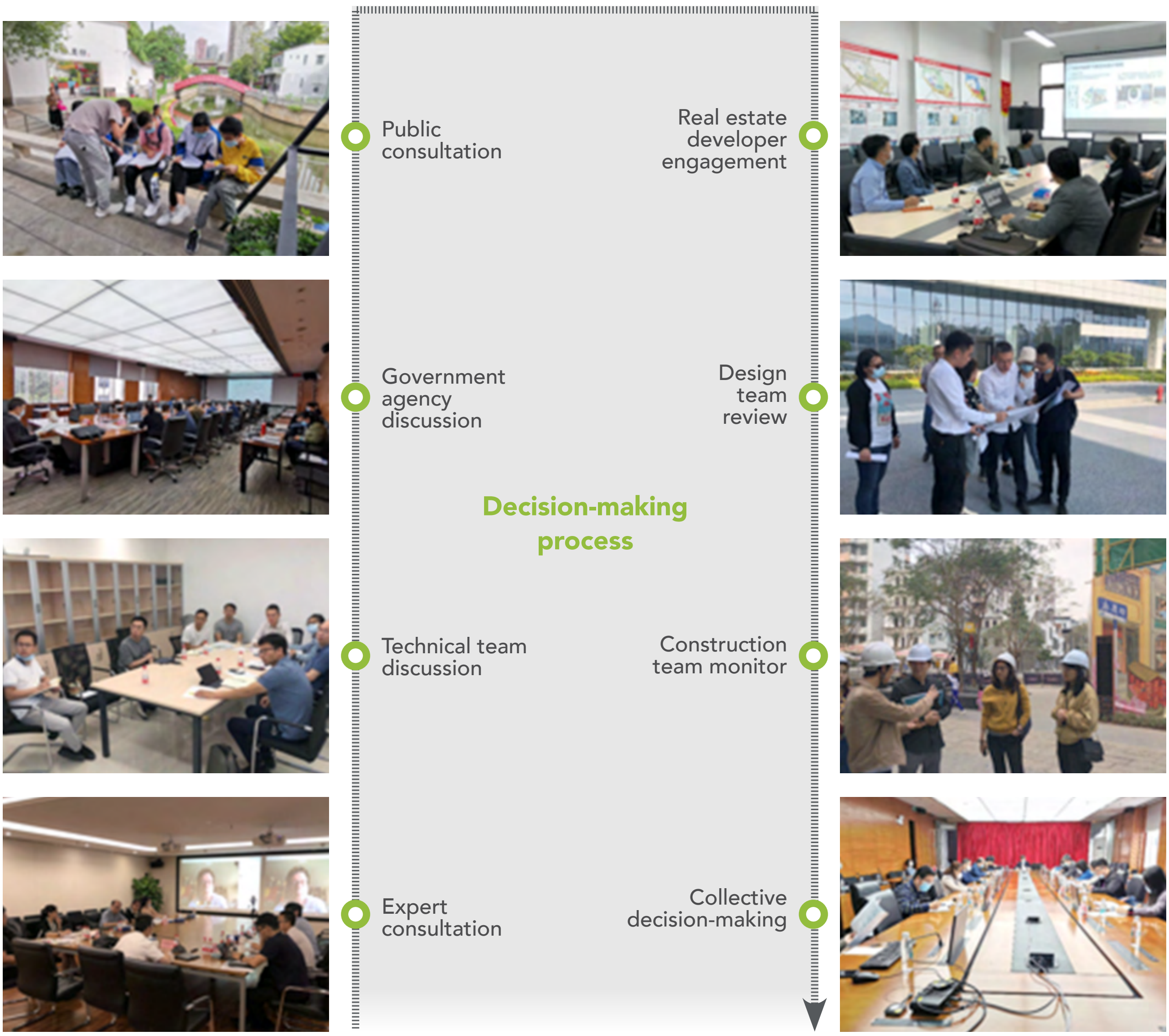
More than half of the respondents believe that the lack of green space is the main reason for the poor climate comfort of the residential environment, and 46.4 percent believe that insufficient shading of activity spaces affects the climate of public space. Nearly a quarter (24.3 percent) of respondents cite poor house layout and insufficient ventilation as the main reasons they are dissatisfied with the climate conditions of their living environment. Respondents generally believe that increasing greening is the most effective way to cool down the living environment. Over half (53.6 percent) of respondents chose to increase greening in their residential environment, and 28.03 percent chose to increase three-dimensional greening. In addition to greening, some respondents also hope to alleviate the high summer temperatures through other cooling methods; 22.8 percent believe that shading structures should be added to outdoor public spaces, and 21.8 percent believe that cooling spray facilities should be installed. Another 18.34 percent of respondents suggested enhancing wind corridors to improve urban ventilation.

Figure 22 // GUANGZHOU STAKEHOLDER ENGAGEMENT PROCESS.



Source: Guangzhou Urban Planning & Design Survey Research Institute

Figure 23 // MULTILATERAL ENGAGEMENT AND DECISION-MAKING IN THE JIXIANG SECTION DEMONSTRATION PROJECT.



Source: Guangzhou Urban Planning & Design Survey Research Institute

These engagement processes led to a better understanding and characterization of local urban heat challenges, helped identify existing activities and policies that support or hinder urban cooling, clarified the data needed to make informed decisions, fostered engagement of relevant stakeholders, and supported evaluation of policy options.

Building local support for urban cooling strategies and policies among relevant stakeholders both inside and outside municipal government is critical. Given the interdisciplinary nature of heat resilience challenges, urban leaders will need a strong network of stakeholders to provide technical, political, financial, and public support for urban cooling strategy implementation. Engaging the local ecosystem of nongovernmental actors—such as community organizations, developers, and contractors—will generate valuable insights into policy development and program implementation.

Community engagement in cooling projects can strengthen design proposals, speed up the process, and build a sense of ownership. Involving residents and stakeholders in developing a cooling plan significantly improves its feasibility; identifying constraints and opportunities at an early stage saves time that could otherwise be lost pursuing unviable options. Community engagement also gives inhabitants a forum to explore their targets and understand how to overcome potential barriers. It encourages collaboration, which helps in establishing ground rules and a shared vision. This consensus can improve project design and facilitate its passage to development. In recent years, various global and capital cities, including Madrid, Seoul, Delhi, Taipei, Bogota, New York, and Paris, have also started significant participatory budgeting processes to engage the public in project choices. The level of participation in Paris has grown significantly, from 40,000 voters in 2014 to 92,800 in 2016, which represents 5 percent of the total urban population *(Paris Municipality Ecology Agency)*

Integrating technical solutions with urban strategy and design requirements

It is important that cities have a clear understanding of local characteristics, conditions, and existing urban cooling policies. The next key step is to determine what combination of cooling strategies delivers the most immediate, high-impact results while minimizing negative consequences. Cities should consider an integrated suite of urban cooling strategies for maximum effectiveness. There is no one-size-fits-all approach to urban cooling. Cities must evaluate the individual and combined benefits of strategies and their potential negative consequences.

This integrated approach applies to selecting a portfolio of measures (e.g., solar reflective and permeable surfaces) as well as policy designs. Practitioners should consider the most effective policy approach for scaling urban cooling measures, including both incentives and government-mandated activities to encourage heat mitigation implementation in buildings and other spaces.

As a result of the piloting activities, the Bureau of Planning and Natural Resources has issued guidance that requires inclusion of cooling strategies in planning and managing urban renewal. The guidance emphasizes key strategies for urban cooling in terms of site, architecture, landscape, and facilities, and advocates protecting and utilizing natural open space to establish "cold sources" and "cooling corridors." It also calls for exploiting the climate adaptation wisdom of traditional Lingnan planning, specifically by encouraging passive ventilation with heat insulation as featured in Lingnan architecture. Designers are advised to optimize site planning and to maximize ventilation, shading, and dehumidification. They are also advised to enhance three-dimensional greening and roof greening to create a multidimensional urban "cooling surface." Urban development agencies are encouraged to propose and realize comprehensive urban cooling solutions and technologies in the planning and management process.

Some mandatory requirements are already included in the relevant regulations. For instance, Guangzhou Planning Bureau has incorporated the requirements of permeable pavement, sunken green space, and rainwater storage (based on the standards of sponge cities) into the planning and design terms of reference for all projects in the city. The outdoor ground permeability rate of residential buildings cannot be lower than 40 percent. Sidewalks, outdoor parking lots, pedestrian streets, bicycle paths, and external courtyards of construction projects must be provided with permeable pavement, and the permeable pavement rate should not be lower than 70 percent. In combination with the community's green space, facilities such as grass-planted ditches, rain gardens, and other facilities should be set up according to local conditions, and the rate of sunken green space should not be less than 50 percent.

In the building design codes of the Housing Construction Bureau, mandatory requirements for ventilation and shading have been set for different climate zones. For example, in areas like Guangzhou, which are hot in summer and warm in winter, east and west exterior windows of residential buildings must adopt building exterior shading measures. The open ventilation area of residential exterior windows should not be less than 10 percent of the floor area of the room or 45 percent of the area of the exterior windows. The external windows of the main function rooms in public buildings must be provided with ventilation devices. Besides guidelines for promoting passive cooling, regulating active solutions is also instrumental in embedding climate resilience in building standards. When a city initiates the process of building code revision, the energy efficiency standards for active cooling appliances must be upgraded in accordance with the heightened demands for green building standards or local energy saving plans.

Incentives to support the implementation of sustainable urban approaches have been developed. The Guangzhou Urban and Rural Technical Regulations provide floor area ratio incentives to projects with public open space that qualify for green building standards. Public open spaces that meet the technical requirements (including overhead floors, roof gardens, arcades, urban public passages in buildings, etc.) are not included in the floor area ratio calculation. This additional space is not included in the calculation of the plot ratio after review by the relevant urban and rural construction departments. Other incentives are listed in box 14.

Lessons learned and recommendations

The city of Guangzhou is committed to green and sustainable urban development, and also facilitates the review and application of leading urban cooling designs. However, one of the major institutional challenges facing implementation of cooling measures is that no specific governmental body is responsible for the related policy development, funding, and implementation. As a result, there is a significant lack of practical support for the actual implementation of cooling measures.

Box 14 // URBAN COOLING INCENTIVES IN THE CHINA-SINGAPORE GUANGZHOU KNOWLEDGE CITY PILOT

The China-Singapore Guangzhou Knowledge City Project explored incentive policies to promote the implementation of urban cooling strategies. The following incentive policies have been put forward: the area of outdoor shading corridor can be excluded from floor area ratio and building density, the sky garden is included as green area ratio. In addition, suggestions concerning indicator control methods such as interface continuity, green roof ratio, building permeability, and air ventilation assessment in the construction project review stage were proposed in this pilot activity. These measures, which combine both compulsory and incentive policies, can drive sustainable cooling value chain from planning to construction.

While sustainable cooling measures have been incorporated into urban design in the pilot areas, the challenges involved with their implementation are evident:

- To put the design details into action, the urban design plan needs to be converted to design guidelines. These guidelines should become part of the plot management plans and be included in the land transfer contract when proposing precise planning requirements.
- A district chief designer should 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 have been translated into visual language, provisions, and requirements on building height limits, dynamic interface, building form and style, architectural setback corridors, etc. Sustainable cooling requirements should be effectively passed on to the parties responsible for construction at the urban planning and urban design level.
- New buildings should follow cooling design regulations highlighted in the planning scheme and meet the requirements of high green building levels that are mandatory in some new town development plans. Green buildings should be required to regularly report monitoring data so as to ensure proper maintenance and operation.

Part C. Financing Urban Cooling Investments

Urban cooling projects are complex and require careful planning and implementation. While many cities have limited resources, various municipal financing mechanisms can be used to fund cooling initiatives. Selecting the appropriate mechanism depends on several factors: the municipality's fiscal situation, ability to borrow, and creditworthiness; local legal and regulatory frameworks; and the types of urban cooling measures considered. Some measures and their approximate costs are shown in table 2.

Table 2 // COST FOR COOLING MEASURES

Category	Measures	Size	Cost
Greening	Fixed rooftop greening	≈220 m^2	Increased cost ≈US$50,000
	Ground-grown vertical greening along walls	≈240 m^2	
	Movable rooftop greening	Total length ≈50m	
Architecture	Rooftop reflective coating	≈790m^2	Increased cost ≈US$35,000
	Double-layered tile roofs	≈350 m^2	
	Installation of shading structures on curtain walls of east, west, and south sides as well as on rooftop skylight	≈320 m^2	
	Installation of flexible windows and doors such as Tanglong doors and lattice windows	≈20	

Source: Guangzhou Vanke Co., Ltd.

Guangzhou's experience demonstrates that nature-based and passive solutions can often be affordable. For example, according to the preliminary estimates for Jixiang, the 1.52 ha pilot area in Yongqing Fang, urban cooling measures will incur an engineering cost of only US$80,000–90,000, compared to the construction cost for the entire Jixiang section of roughly 10 million dollars. These measures will not significantly increase engineering costs, which are covered by the developer. However, their benefits could be significant in the long term. According to relevant studies, for each US$1.00 invested in urban nature-based cooling measures, there will be net benefits of US$1.50–15.20, or return on investment between 50 percent and 1,420 percent (Estrada, Botzen, and Tol 2017). The residents living in the area and renters of local businesses will largely benefit from the cooling measures.

The pilot experience also indicates that partnerships with the private sector are necessary for sharing not only cost and risk but also technical capacity. The implementation of cooling measures in the old town area provides benefits to the developer, Vanke, one of the largest real estate companies in China. Vanke is committed to becoming a benchmark for real estate companies and has continuously innovated in its products and invested in green buildings. The Yongqing Fang project is Vanke's flagship project in the Guangzhou old town redevelopment initiative. In addition to offering economic benefits, this project also aims to achieve social impact. While Vanke is motivated to explore the application of sustainable cooling measures to its own developments, its key aim is to engage with other real estate developers and encourage them to become more socially responsible.

Many Chinse cities are currently exploring the concept of "ecological compensation." In Guangzhou's case, the economic model InVEST was used to assess the economic value of the ecological services of the 11 km^2 Haizhu wetlands located in the downtown core. When compared to a residential development, the wetlands reduce local energy expenditures for cooling by US$1.9 million, lower mortality risk by up to 1.27 percent in the surrounding area, and prevent up to 16.1 percent of heat-related reductions in workplace productivity (for detailed analysis, see annex 4). By putting a price tag on these natural assets, including the economic benefits of cooling effects, the city could potentially discover and apply innovative financial mechanisms to fund cooling (see box 15).

Box 15 // INNOVATIVE FINANCIAL MECHANISMS IN GUANGZHOU TO SUPPORT GREEN AND LOW-CARBON INVESTMENT

Photo: bingfengwu I istock.com

1. Develop a carbon-inclusive mechanism to motivate the public. The Guangzhou Carbon Inclusive Platform has certified monitoring, reporting, and verification methods for carbon reduction in more than 20 real-life scenarios. Citizens can register on the platform and record low-carbon behaviors such as using public transportation, saving water and electricity, and recycling old materials. The platform then issues carbon coins that can be exchanged for commercial discounts, incentivizing the public to continue the low-carbon behaviors. As the carbon-trading market continues to develop, the platform may consider including urban cooling measures—such as green roofs and cold roofs for enterprises, households, and individuals—among the eligible behaviors. This will broaden financing accessibility and strengthen incentives for social entities.

2. Leverage private sector capital through public-private partnerships based on the modality of build-operate-transfer (BOT). Yongqing Fang introduced social capital (Vanke) through the BOT model to implement urban renovation at local scale. Vanke Group signed a 15- to 20-year lease with Guangzhou for lands in Yongqing Fang that will be returned to the government after the operation period expires. Through the lease of state-owned land with historic and cultural value, the enterprise develops, operates, and maintains the land, financing the initial cost. This modality offers a financially viable approach to urban regeneration that draws from the Lingnan architectural style and urban fabric originally adapted to the climate. The BOT model enables seamless cooperation and communication between the government and enterprises, in turn facilitating the implementation of urban cooling measures in the project.

3. Effectively apply green financing tools. In April 2021, China-Singapore Knowledge City Group successfully issued the first carbon-neutral green mid-term note for local state-owned enterprises in the Guangdong–Hong Kong–Macao Greater Bay Area. The carbon-neutral green bond is a subcategory of green bonds. All funds raised through this instrument will be used for constructing the Guangzhou Knowledge City Plaza, which meets the highest three-star standard for green buildings and which will also use sky gardens, landscape atriums, and other ventilation and cooling technologies. The estimated annual energy savings are 21.3432 million kWh, equivalent to a total of 65.3957 tons of standard coal, which could reduce CO2 emissions by 14,600 tons per year.

4. Leverage ecological compensation to protect ecological assets as sources of cooling effects. Guangzhou provides compensation to local preservation-focused units, organizations, and individuals whose economic development is constrained by undertaking ecological protection responsibilities in areas such as ecological protection red lines, watersheds, ecological public welfare forests, and preserved farmland. Ecological protection red lines and ecological forests are important cooling sources in Guangzhou. Providing compensation to these areas can effectively promote mutually beneficial interactions between beneficiary areas and ecological protection areas, raising the awareness of local villagers that the ecosystem and ecological cooling source must be protected from development.

Lessons learned and recommendations

For the many cities that have limited resources to finance urban cooling projects, the Guangzhou experience offers several lessons:

- Some nature-based and cooling measures offer low-cost options that generate significant long-term benefits for the residents.
- Strategic partnership with the private sector is critical. Deploying a combination of policy, regulatory tools, and incentive measures can steer private sector investment. Companies committed to social responsibility and green development should be prioritized in the selection of private sector partners.
- Quantifying and recognizing the full economic benefits of urban cooling could establish a link to other financial instruments such as carbon trading, green bonds, and ecological compensation mechanisms.
- Promoting "green lease" and "green label" with private sector stakeholders can help ensure sustainable maintenance upon building construction. Under these models, tenants are mobilized to maintain the urban cooling assets and infrastructures through the gains they experience or bonuses. This approach could be mutually supportive since it allows the private sector to fulfill corporate emission reduction commitments through investing or leasing green buildings, while assets labeled by green certification can attract better investors through the higher property value.

Conclusion: Scaling Up Nature-Based Solutions within City Planning

The Guangzhou urban cooling pilots provide important insights and lessons for utilizing nature-based and passive cooling options for urban development. These pilots tested some recommendations included in the "Primer for Cool Cities: Reducing Excessive Urban Heat with a Focus on Passive Measures" (ESMAP 2020a). The pilots offered policy makers and urban planners an opportunity to learn how to address institutional and financial challenges in the implementation of cooling measures.

Urban heat is a major threat to cities. Early planning and implementation of suitable cooling measures are critical for cities seeking to address the threat and protect their citizens, especially vulnerable groups. While efficient space cooling plays a critical role in addressing urban heat, nature-based and passive solutions offer multiple benefits, such as cooling, improved health, and climate mitigation, and must be incorporated into a city's overall cooling strategy, planning process, and investment.

Photo: luxizeng | istock.com

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Annexes

Annex 1. Guangzhou Cooling Strategy at City Scale

Creating a comfortable urban habitat has been a consistent challenge for Guangzhou urban planners throughout history due to its humid and warm climate. The Guangzhou old town's location, urban plan, and Lingnan architecture all reflect a simple but effective older approach to living with nature and adapting to climate. South of Yuexiu Mountain off the Pearl River, Guangzhou's topography is flat and open with few obstructions. Nanling Mountain lies to the north of Guangzhou, and it wards off cold winds from the northwest during winter. Coastal oceans to the southeast allow summer monsoons to travel inland unobstructed. Guangzhou has a long tradition of using topography, water, and wind corridors to cool the city. The ancient city was built at the foot of Baiyun Mountain. This natural protective barrier creates local circulation between the city and the mountain, which allows valley winds to bring cooler air into the city. Builders of the ancient city also constructed the six-vein canal to connect vertically with the Pearl River system and thus channel the existing winds. Roads were built in the direction of the prevailing southeast summer wind, allowing sea breezes to flow into the city.

Today, Guangzhou is one of the most innovative megacities and is implementing ecological planning at scale. Guangzhou is a front-runner city and a living laboratory for innovative, replicable, and locally attuned nature-based solutions that have both acute and systemic impacts. The current development plan focuses on urban development along the Pearl River system. It is delineated by ecological corridors and interconnected by high-speed roads and rapid rail transit. Guangzhou's ecosystem protection policies have managed to keep the intensity of current urban land area development under 24 percent while maintaining forest cover at 42.3 percent. The ongoing 2035 Master Plan of Guangzhou specified three bottom lines for urban development: the ecological conservation zone, the boundary of permanent farmland, and the urban growth boundary.

To optimize urban ventilation and cooling, Guangzhou has established a wind corridor system utilizing various open spaces in the city, including rivers, green space, and roads. It is a multi-level system with six main corridors. Control measures and requirements for land development along the corridors are in place. The system controls building intensity and height in urban design.

The concept of a sponge city is also a key component of Guangzhou's urban development. The city aims to absorb and capture rainwater and alleviate heat island effects, while striving to apply runoff-controlling methods to all new developments.

Guangzhou's cooling strategy at the city scale comprises five dimensions; these are shown in figure 24 and described below.

❶ **Smart planning** includes nature-based solutions and natural ventilation. It uses open spaces, roads, and low-density areas to form a mountain-to-sea ventilation system, allowing fresh, cool air to flow into the inner city for humidity control and ventilation.

❷ **Smart surfaces** are green, permeable, and breathing. They improve the thermal performance of the city's three-dimensional surfaces by increasing natural, permeable, and reflective surfaces.

❸ **Smart design** maximizes ventilation and shading. It encourages urban texture and architectural design that is compatible with the prevalent wind and light paths.

❹ **Smart facilities** improve outdoor thermal comfort. They include shading and misting facilities in hot spots to improve outdoor thermal comfort.

❺ **Smart energy** involves green transportation and efficient cooling to reduce energy consumption and anthropogenic heat emissions.

Figure 24 // FIVE DIMENSIONS OF GUANGZHOU'S COOLING STRATEGY.

Source: Guangzhou Urban Planning & Design Survey Research Institute.

Annex 2. Yongqing Fang II Pilot Project

Project Overview

Yongqing Fang is located in the Xiguan area of the Liwan District in the old town of Guangzhou. The renewal plan follows the principle of micro-transformation. It retains the traditional layout and preserves the historical style while carrying out street regulation and landscape improvement projects. The Yongqing Fang project retains the original architectural style (a combination of flat surfaces and slopes), responds to the surrounding urban environment, and restores the traditional local roofing. Two sites were selected for piloting:

- The Jixiang section tested different cooling solutions that combined traditional local approaches and low-cost modern techniques.
- A building pilot tested integrated cooling solutions in new architecture on the east side of Taihualou.

Organization and Decision-Making Process

A multilateral, cooperative organization constituted by the government, technical teams, special experts, and design teams was established to promote multiparty participation, uncover the diverse demands of the public, and achieve joint development and governance in the area. On-site research meetings and workshops were held regularly to facilitate the formulation of a cooling proposal. These engagements also informed step-by-step construction drawings and the project's overall working concept. Simultaneously, the project completed on-site meteorological measurements. A final list of cooling measures was reached after in-depth discussion with the developer, the design team, and the construction team regarding complexity, feasibility, benefits, and challenges of implementing each cooling measure.

Cooling Options Implemented

The pilot project tested cooling measures applicable for traditional buildings and consistent with the area's historic style. The cooling solution had to be both practical and replicable. The pilot explored the application of ventilation, shading, and heat insulation measures frequently used in traditional Lingnan architecture for contemporary buildings and identified sustainable, low-cost cooling techniques with regional characteristics. It also explored the application of green building simulation technology in small architectural design projects within high-density, historic urban areas. With the area's specific wind environment in mind, it used indoor natural ventilation simulation analysis and building energy consumption simulation analysis to facilitate a coordinated design. It adjusted building forms, layouts, and facades according to the results to optimize buildings' physical environment. The pilot explored both traditional Lingnan passive cooling measures and modern technologies and techniques in the old town.

- Traditional Lingnan approach to ventilation, shading, and insulation. The project identified the traditional Lingnan passive cooling measures to be implemented in Yongqing Fang. In line with the existing architectural form and style, the project focused on the application of cool alleys, bamboo-tube houses, and patios. It preserved and promoted the use of flexible door and window structures, such as Tanglong doors and Manchu windows, to enhance indoor ventilation. More detail are in box 16.
- Application of modern technologies in the old town. The project selected low-cost cooling measures that could be easily promoted for widespread application in old towns. It focused on setting up rooftop greening in restaurants and other functional spaces, adding vertical greening to west-facing facades, creating pocket parks in public spaces, and increasing tree canopy and water features. Reflective surfaces and permeable paving are incompatible with the historical features of Yongqing Fang, where limestone and slate paving are common (see figure 26).

Cooling Measures

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

- At the site level, the original dense texture was broken up by introducing a cool alley, widened as appropriate, parallel to the building layout.
- At the building level, architectural shading and insulation measures were considered, including

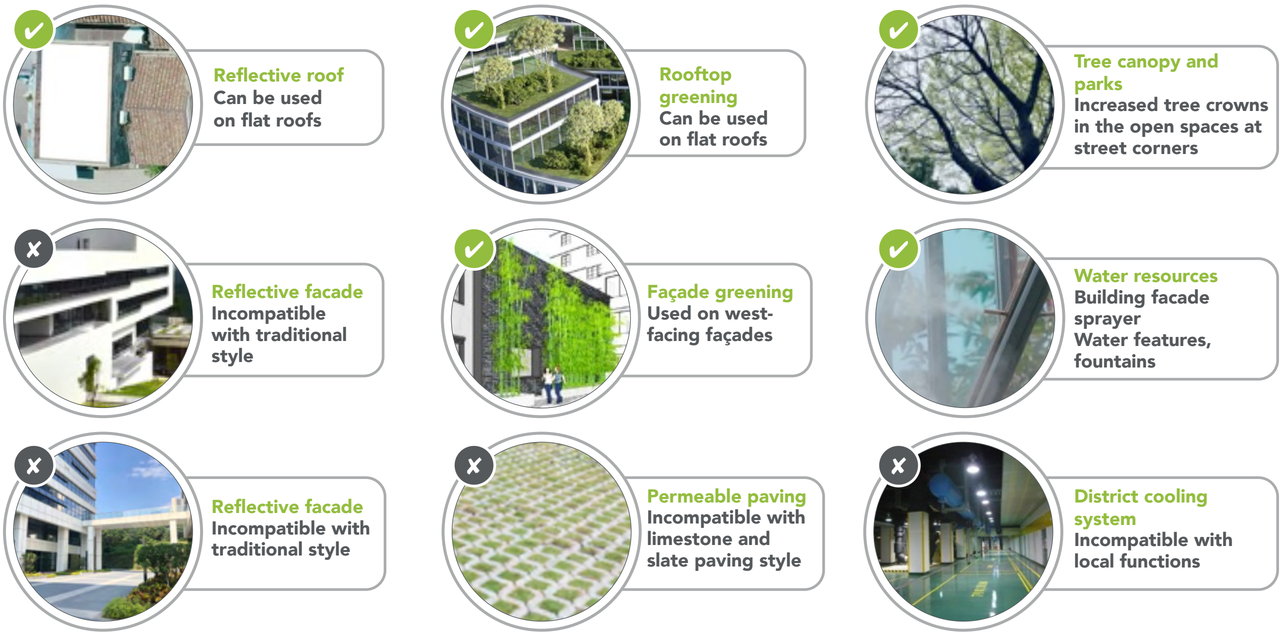
Box 16 // TRADITIONAL LINGNAN ARCHITECTURE IN GUANGZHOU

The old town regeneration project builds upon traditional Lingnan architecture. The style demonstrates distinct open layouts, smooth and simple shapes, and flexible and practical details. Comb-style layouts, cool alleys, and Tanglong doors are all examples of passive ventilation cooling structures with Lingnan characteristics. Traditional Lingnan architecture expresses deep respect for nature. It boasts a thoughtful combination of homes and gardens, and it demonstrates a microclimate design concept that uses natural landscape elements, such as vegetation and water bodies, to improve the building environment. During the adaptation process, structures with traditional Guangzhou characteristics emerged, including the comb-style layout, three-room and two-corridor design, bamboo-tube houses, and arcades. Installing patios, cool alleys, and void grounds achieves proper ventilation and cooling and makes dwellings more functional.

Figure 25 // A TRADITIONAL GUANGZHOU PATIO.

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

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.

integration of glass facades with sun-shading window blinds, along with double roofs, light-colored roofs, and rooftop greening, all of which can achieve better insulation. The focus was on preserving traditional-style windows and doors, which are good for both indoor and outdoor ventilation. For new buildings, all windows and doors installed were openable to ensure that every building was properly ventilated.

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

Three recommendations were made for designing the pilot architecture on the eastern side of Taihualou:

- Traditional Chinese flexible door and window structures should be used, and traditional walls should be incorporated for insulation.
- Flexible greening design should be used to connect the outdoors and indoors.
- Traditional architectural features should be incorporated in the design of eaves by adding lighter materials or using flexible eaves to enhance the shading effect.

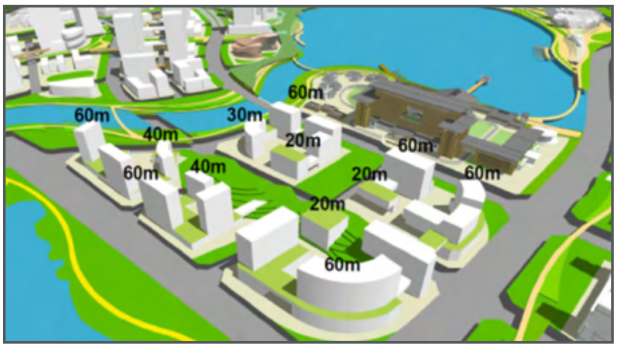
Lessons Learned and Recommendations: Maximizing Ventilation

- Interconnect open spaces and green spaces to direct the wind efficiently.
- Set open spaces in the northeastern and southeastern corners of neighborhoods to allow wind flow into neighborhoods.
- Design main ventilation corridors (using linear paths and open spaces) and secondary ventilation corridors (between buildings, across blocks, and inside buildings).
- In tropical areas, street alignment should follow the direction of the monsoon winds. Buildings should be at an angle of 30 or 60 degrees to the prevailing winds to prevent wind flow issues at the building level.
- When the site comprises rivers or large water bodies, the building height should gradually rise away from the water bodies to increase ventilation capacity. The orientation of waterfront buildings with hollow and streamlined building forms should be arranged to channel the breeze from the water.
- Vary height profiles. This includes strategically placing buildings of varying heights. The height of buildings should gradually decrease along the route of prevailing winds. The tallest buildings should be placed in the western part of the site, and the shortest buildings should be in the eastern and northern parts of the site.
- Strategically arrange the layout of buildings and open spaces. This includes controlling the interval between buildings and avoiding continuous walls of buildings; keeping the length of building street walls appropriate; designing buildings and open spaces so that they shade each other; combining open spaces with ventilation corridors to facilitate the flow of cool and fresh air; and designing street-side building interfaces that facilitate ventilation.
- Align and orient buildings following wind paths. The central axis of buildings should be parallel to the prevailing wind direction.
- Choose the right building combination and direct wind into the cluster. Main entrances should be in the southern, southeastern, and eastern sides of the plot to form air intakes. Air intakes should cover the entire plot.

Guangzhou's Experience: Maximizing Shade

In the Knowledge Green Valley, 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 (see figure 27).

Figure 27 // BUILDING HEIGHT VARIATIONS IN KNOWLEDGE GREEN VALLEY FOR MAXIMIZING SHADOW.



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

Lessons Learned and Recommendations: Maximizing Shade

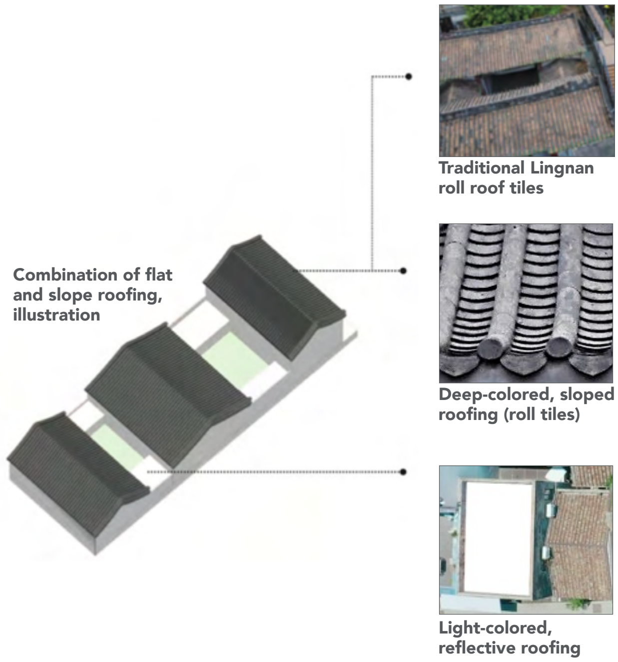
- Increase tree coverage inside the city and create natural shading infrastructure.
- Design the buildings to shade each other and minimize the solar heat gains.
- The tallest buildings (at site and block level) should be in the western part of the site. The shortest buildings should be in the eastern and northern parts of the site.
- Install open spaces in the center of the block to take advantage of the shadows provided by surrounding buildings.
- Open spaces should be linear (from north to south) or U-shaped.

- Pavement coverings should reduce pedestrians' exposure to sunlight.
- Move buildings further from the street to offer more shade to the pavement next to buildings.
- Build shading corridors or arcades in outdoor spaces such as pedestrian entrances, walking paths, rest areas, courtyards, and squares. More than 30 percent of outdoor spaces outside of a building's shaded area should be covered.
- Covers should be available in outdoor spaces to allow use of these spaces during wet weather.
- Covered pavement should be part of a network so that pedestrians can easily identify paths on major pedestrian routes.
- A rain cover can be built along a building, used as a link between buildings, or placed independently.
- At the building level, use window blinds, grilles, and other building-shading structures or surfaces. Large glass curtain walls are not recommended. Adjustable shading and rooftop shading facilities are recommended. The design should take account of Guangzhou's sun height angle in the summer.

Guangzhou's Experience: Solar-Reflective Surfaces

Traditional buildings in Guangzhou's urban area use a variety of roofing types, including sloped roofs, flat-and-sloped roofs, and flat roofs. Traditional sloped roofs typically use dark-colored tiles. After considering the cooling efficiency and the design requirements of the historic district, a combination of dark-colored, sloped roofs, and light-colored, reflective flat roofs was selected for buildings in the Jixiang section (see figure 28).

Figure 28 // ROOF TYPES CHOSEN FOR BUILDINGS IN JIXIANG.



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

Lessons Learned and Recommendations: Solar-Reflective Surfaces

- Ensure appropriate design of reflective roofs. This includes choosing the right reflective material for different roof forms and controlling the reflectivity of the roofing material.
- Identify the right technique for road construction on a piloting basis. This includes choosing the right reflective materials for different types of surfaces; considering the thermal vulnerability of different areas; and using reflective paving in areas of little traffic on a piloting basis.
- Control the reflectivity of tall structures and reduce the surface temperatures of buildings. This includes controlling the color of surface materials and combining architectural cooling with landscape.

Annex 3. China-Singapore Guangzhou Knowledge City Pilot Project

Figure 29 // JIULONG LAKE ECOLOGICAL BELT.

Source: Guangzhou Urban Planning & Design Survey Research Institute.

Project Overview

Knowledge Green Valley is an area of around 20 ha in China-Singapore Guangzhou Knowledge City.[13] China-Singapore Guangzhou Knowledge City is committed to creating a high-quality urban ecological environment with 100 percent green buildings, while also incorporating the concept of a sponge city. The Jiulong Lake District is the pilot area for the cooling project (see figure 29) .[14] It will be a medium-density block with scientific research offices and apartments. The land use plan for Jiulong Lake District focuses on nature-based solutions, such as connecting the green network to optimize land use and spatial layout, increasing the proportion of ecological land cover, and controlling building intensity. The scale of this intervention maximizes both the local impact and the potential for scaling up the tested nature-based solutions.

Figure 30 // KNOWLEDGE GREEN VALLEY 3D MODEL DIAGRAM (TOP)AND SITE PLAN (BOTTOM).

[13] China-Singapore Guangzhou Knowledge City is 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.

[14] The Jiulong Lake District is situated at the heart of China-Singapore Guangzhou Knowledge City, with an area of 12.6 km^2 and a population of approximately 34,000. The area surrounding Jiulong Lake is undeveloped; water resources, farmlands, and forests account for 82.9 percent of the total land area.

Cooling Options Analyzed

The following different urban cooling approaches were comprehensively analyzed:

- Increasing the ability of urban roofs, walls, and pavements to reflect, rather than absorb, solar radiation (reflective infrastructure)
- Increasing the vegetated and permeable cover (permeable infrastructure)
- Increasing the tree canopy (permeable infrastructure and shade)
- Increasing the number of and accessibility to natural and man-made water features (water infrastructure)
- Designing urban spaces to minimize heat retention (urban design)
- Enhancing thermal insulation of buildings (thermal insulation)

Cooling Measures Adopted

Six key measures were adopted:

- Establishment of an energy station, and use of district cooling systems to reuse waste heat for cooling purposes
- Integration of the sponge city initiative, with widespread use of permeable surfaces and study of permeable paving on roads with heavy traffic use
- Use of cooling pavement in part of the demonstration, and active use of highly reflective paving
- Promotion of 3D greening using greening species suitable to Guangzhou, and study of the technical standards for 3D greening to improve its applicability
- Sustainable management of water resources and use of semi-natural/natural systems to increase water infiltration and storage, such as sponge facilities (permeable paving, sunken lawns, and rainwater gardens)
- Laying out buildings so they are in line with wind direction and light paths to optimize ventilation inside buildings and between buildings and blocks

Implementation Measures

Under the current Chinese planning system, urban design is not a part of statutory planning. Rather, it is a technical approach to support the regulatory plan and identify relevant requirements and indicators in the regulatory plan. To incorporate sustainable cooling into urban design, implementation challenges need to be addressed. In the project, sustainable cooling measures in the urban design plan were translated into visual language, provisions, and requirements on building height limits, dynamic interfaces, building form and style, architectural setback corridors, etc. Sustainable cooling requirements were effectively passed on to the parties responsible for construction at the urban planning and urban design level.

Implementation recommendations included the following:

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

Lessons Learned

- The China-Singapore Guangzhou Knowledge City project shows that cooling measures can be converted into general requirements for sustainable cooling and included in the controlled, detailed planning of urban development.
- The sustainable cooling design methods that ensure maximum ventilation and shading—building height profiles, architectural interfaces, forms and facilities of buildings, ventilation corridors, and open spaces—were effective and can be adopted by other areas with a hot and humid climate to ensure good ventilation, good shading, and good cooling effect in built-up areas.
- The right combination of compulsory and incentive policies can drive sustainable cooling all the way from planning to construction. The Knowledge City project explored incentive policies to promote the implementation of urban cooling strategies. For

Credit: wonry | istock.com

example, the area of outdoor shading corridor can be excluded from floor area ratio and building density, the sky garden is included as green area ratio. Indicator control methods such as interface continuity, green roof ratio, and building porosity were explored, and an air ventilation assessment in the construction project review stage was suggested. Together these measures worked to integrate sustainable cooling in urban development.

- Various types of cooling-effect evaluation models can be useful in planning urban development that makes use of nature-based solutions. For the first time, the InVEST cooling model was used in the planning phase to perform cooling-effect modeling for different land use plans. Technologies such as CFD (computational fluid dynamics) simulations were used to compare differences in ventilation and shading of different land use plans, supporting the planning management process.

Annex 4. Haizhu Wetlands Project

Within Guangzhou sits the Haizhu wetlands, known locally as the "Green Heart" of the city. At 11 km^2, it remains the largest wetlands in the downtown core of any Chinese megacity and provides many services to residents. It is highly accessible from the central business district and other densely populated areas, making it a key source of green space for locals. From 2012 to 2020, the wetlands have provided recreational services to over 60 million visitors. Biological habitats have been restored through the implementation of zoning management that aims to achieve a harmonious coexistence between humans and nature. The result of biodiversity rehabilitation includes increasing the number of bird species from 72 to 180; fish species from 36 to 60; and insect species from 66 to 539.

According to local planners in Guangzhou, the Haizhu wetlands would likely be replaced by residential housing if the area lost its protected status. To determine the value of the wetlands, the project compared the ecosystem service values they deliver to those that would be provided by a residential development across the same area (see figure 31).

The flow of services and value that ecosystems provide to people is often called the "ecosystem service cascade"; see Haines-Young and Potschin (2012) and Tallis et al. (2021). The cascade integrates two key components:

- **A biophysical model** that describes how a landscape or seascape supplies an ecosystem service
- **A valuation function** that translates and quantifies how the service contributes to human well-being.

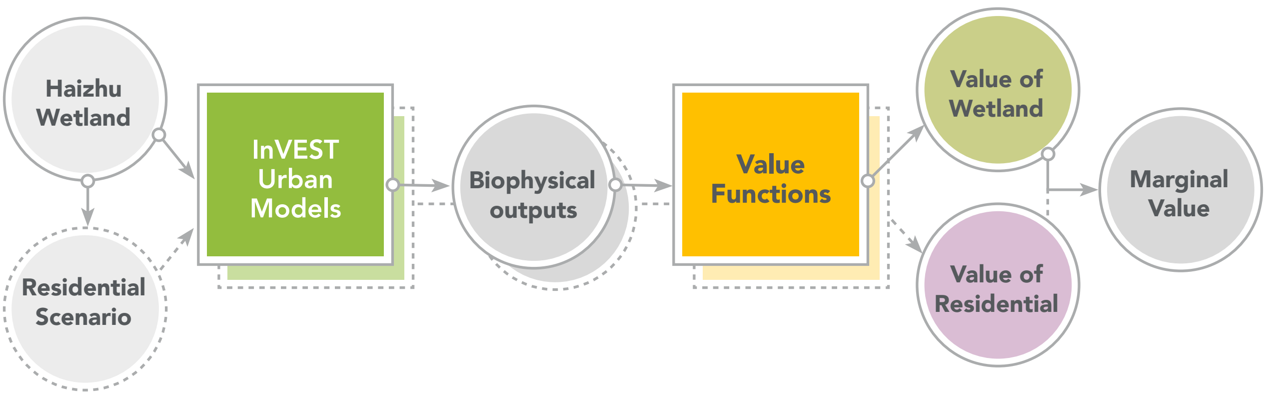
This integration allows decision makers and stakeholders to evaluate how potential changes in land cover affect the service provided.

Key results of the modeling are as follows:

- The modeling found that the combined climate impacts from landscape carbon and annual and embedded emissions under the residential scenario would amount to US$89.7 million in damages.
- Average air temperatures surrounding the wetlands vary between 30.7°C and 31.5°C. If the wetlands were redeveloped into extensive residential housing, the surrounding 600 m buffer would experience an average increase in air temperature of 0.25°C on a typical day. This figure increases to more than 1°C within the wetlands area itself[15].
- Converting the wetlands into a residential development would cause significant loss of annual workplace productivity between May and October.
- The increase in air temperature under the residential scenario would increase cooling energy demand during the summer months. Annual energy

Figure 31 // CONCEPTUAL MODEL ILLUSTRATING USE OF INVEST MODELING SUITE TO QUANTIFY THE VALUE OF SERVICES PROVIDED BY THE HAIZHU WETLANDS.

The process involves applying the ecosystem cascade to the Haizhu wetlands and comparing the change in value that would occur if the wetlands were converted to a residential development.



Source: Assessment of key ecosystem services provided by the Haizhu National Wetland Park in Guangzhou, China (World Bank, 2022)

[15] This represents the typical summer urban heat island effect; during an extreme heat wave, the loss of the wetlands could be expected to further exacerbate temperature rise.

consumption by buildings within 600 m of the wetlands would increase by 1.1 million kWh at a cost of US$119,800. Using a net present value approach with a discount rate of 5 percent and a 30-year time frame, this represents US$1.9 million.

- The surrounding 600 m buffer would experience an increase of between 1.23 percent and 1.27 percent in mortality risk each month between June and September, a pattern that is likely to worsen during extreme heat events.
- The Haizhu wetlands ensure that 63,000 local inhabitants have sufficient urban green space for recreation. The coupled monetary value is US$2.9 million annually, with a net present value of US$45.1 million over 30 years.
- If the Haizhu wetlands were developed into a residential area, the average contribution of green space to physical activity would drop from 9.3 percent to 7.0 percent in the 2,230m buffer zone, affecting about 230,000 people. The Haizhu wetlands buffer zone is currently valued at US$1.0 million/year for physical activity with a net present value of US$16.0 million over 30 years. This would drop to US$0.8 million/year with a net present value of US$13.0 million over 30 years if the wetlands were replaced by a residential area. Conservatively, this leads to a net present value loss of US$3.0 million over 30 years.
- The modeling also found that if the wetlands were replaced by residential development, the loss in natural areas would lead to an annual increase in mental health expenditures of US$2.90 million. This represents a net present value of US$44.6 million over 30 years at a 5 percent discount rate.

Table 3 // ASSESSMENT OF KEY ECOSYSTEM SERVICES PROVIDED BY THE HAIZHU NATIONAL WETLAND PARK IN GUANGZHOU

Ecosystem Service	Supply metric	Value metric(s)	Valuation modeling approach	Value of the wetlands (30-year horizon)
Urban cooling[a]	Air temperature	Productivity	Loss of workplace productivity as a result of temperature and humidity	Up to 16.1 percent in avoided productivity losses for nearby districts
		Private cost of cooling	Cost of cooling (and heating) as a function of temperature	US$1.9 million
		Mortality risk	Relative risk of mortality or morbidity as a function of temperature and region	Up to 1.27 percent in avoided mortality risks for nearby districts
Climate change mitigation[a]	Carbon stored or sequestered	Social cost of carbon	Net present value of change in damages from carbon emissions	US$77.8 million (7.4 million tons of avoided emissions)
Recreation[a]	Access (distance to parks)	Willingness to pay	Entry or use fees; willingness to pay	US$67.8 million
Physical health	Access to urban nature (e.g., distance to parks, tree-lined streets, urban gardens, trails, etc.)	Avoided cost of treatment	Change in costs associated with treatment to restore original physical health level	US$4.2 million
Mental health	Access to urban nature (e.g., views of greenery, distance to parks, number of trees in neighborhood)	Avoided cost of treatment	Change in costs associated with treatment to restore original mental health level	US$70.1 million

Source: Assessment of key ecosystem services provided by the Haizhu National Wetland Park in Guangzhou, China (World Bank, 2022)

Photo: HaiZhu Wetland Park. © Weiming Lin | Dreamstime.com

Glossary

Passive building design: Passive design uses urban layout and building form and orientation to reduce or remove mechanical cooling, heating, ventilation and lighting demand. Examples of passive design include optimizing spatial planning and orientation to control solar gains and maximize daylighting, manipulating the building form and urban fabric to facilitate natural ventilation strategies and making effective use of thermal mass to help reduce peak internal temperatures.

Sky garden: Sky Garden means a landscaped/green area usually provided on the top floor or intermediate floors of a building.

Sponge city: A sponge city is a new urban model for flood management, strengthening ecological infrastructure and drainage systems, proposed by Chinese researchers in early 2000 and accepted by China State Council as an urbanism policy in 2014. It can alleviate urban flooding, water resource shortage, and the urban heat island effect and improve the ecological environment and biodiversity by absorbing and capturing rainwater and utilizing it to reduce floods.

Green Plot Ratio: The green plot ratio, known as GPR, is a powerful metric in urban design and development. GPR is a metric utilized for assessing and planning the inclusion of greenery in cities, developments and buildings. Using GPR, a planner or an architect has a quantifiable measure to determine how much greenery should be incorporated to counteract the absorption of heat in a development and to enhance the qualities of open space.

3D greening: 3D greening means greening the building roof and creating sky gardens, green facades, balconies, and other spaces according to the characteristics of different plants. Three-dimensional greening of buildings contributes to the expansion of urban green space, the protection of biodiversity, and the creation of a good and healthy living environment. It also helps improve the microclimate within the building and its surroundings, which effectively mitigates the urban heat island effect.

Ventilation corridor: Ventilation corridors are protected from construction and designed as valleys and canyons to let wind flows and convey them in such a way to relieve the heat island effect. They enhance ventilation and contribute to the climatic and environmental enhancement in a city.

Ecological corridor: An ecological corridor is a functional zone of passage between several natural zones for a group of species dependent on a single environment. This corridor, therefore, connects different populations and favors the spread and migration of species and the re-colonization of environments that have been disturbed. For example, a footbridge that crosses over a motorway and links two forest areas is an ecological corridor. It allows flora and fauna to circulate between the two zones despite the almost impermeable obstacle of the motorway.

Urban fabric: The term 'urban fabric' describes the physical characteristics of urban areas. This includes the streetscapes, buildings, soft and hard landscaping, signage, lighting, roads and other infrastructure. Urban fabric can be considered the physical texture of an urban area. The term excludes traffic, people or socio-economic or political considerations.

Ecological compensation: Ecological compensation may be defined as creating, restoring or enhancing nature qualities to counterbalance ecological damage caused by infrastructure developments. Ecological compensation implies that specified natural habitats and their qualities, such as wetlands or old-growth forests, should be developed elsewhere when they are impacted by an approved project.

Ecological red line: Ecological conservation redlines demarcate areas that provide important ecological services with the aim of protecting them. These include shallow coastal waters, wetlands, glaciers and forests. The aim is to protect endangered species and their habitats, with simultaneous gains for the prevention of floods and sandstorms, provision of clean water and other ecosystem services.

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