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SUSTAINABLE URBAN COOLING HANDBOOK

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NOTE TO THE READER

The *Sustainable Urban Cooling Handbook* is undertaken within the framework of the UNEP Cool Coalition. The objective of the report is to present a comprehensive overview of sustainable urban cooling approaches, incorporating intervention strategies and supporting case studies that can be readily implemented at the city or district level in developed and developing countries.

The report is organized into 12 chapters.

- Chapters 1 through 3 provide the context around the urgent need for sustainable urban cooling, and the key interventions strategies cities can pursue.
- Chapter 4 includes guidelines for developing a citywide cooling action plan along with a framework for the synergistic implementation of interventions.
- Chapters 5 through 12 provide a deep dive into each primary intervention area, highlighting opportunities for action, including detailed case studies and examples from cities across the globe.

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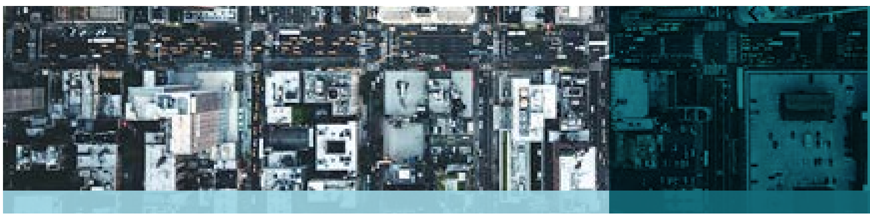

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INTRODUCTION 01

We are living in an increasingly warming world. According to the US National Aeronautics and Space Administration, 2020 was the hottest year on record, with the average global surface temperature around 1.3 degrees Celsius (°C) higher than the late 19th-century average – despite the absence of the short-term warming effect of El Niño (Barbosa 2021). The seven-year period from 2014 to 2020 was the hottest in 140 years of record keeping. This, researchers say, is a clear indicator of the ever-increasing impact of greenhouse gas emissions.

With growing populations – predominantly in the tropics – and rapid urbanization, the impact of global warming is felt most acutely in cities. Research shows that the world's cities are heating up at twice the global average rate due to the urban heat island effect (Energy Sector Management Assistance Program [ESMAP] 2020a) – a phenomenon where urban areas experience higher temperatures than outlying areas due to a combination of diminishing green cover, heat gain and thermal properties of the materials commonly used in urban surfaces, as well as waste heat from human activities (such as industrial processes, transport and air conditioning). A model by an international research team estimates that by 2100, cities across the world could warm as much as 4.4°C on average (Zhao *et al.* 2021) – more than double the Paris Agreement's goal of limiting global temperature rise to no more than 1.5°C.

Hotter cities could be catastrophic for public health, which is already being impacted by the effects of increasing heat. The urban population exposed to high temperatures – that is average summertime temperature highs above 35˚C (95°F) – is expected to increase by 800 percent to reach 1.6 billion by mid-century (C40 Cities n.d.). The latest Intergovernmental Panel on Climate Change (IPCC) report alerts of a faster warming trend and finds that unless there are immediate, rapid and large-scale reductions in greenhouse gas emissions, limiting warming to close to 1.5°C or even 2°C could be beyond reach, leading us to heat extremes that more often reach critical tolerance thresholds for health (IPCC 2021).

1.1 THE NEGATIVE IMPACTS OF WARMING CITIES

The ramifications of excess heat on urban systems are significant, with negative impacts to energy systems, the environment and society at large.

HEALTH AND PRODUCTIVITY LOSSES

As cities continue to grow warmer, extreme temperature events – referred to as heatwaves – are increasing in frequency and magnitude globally. According to the World Health Organization, the number of people exposed to heatwaves jumped by 125 million between 2000 and 2016 (WHO n.d.a). Extreme heat can have increasingly serious effects beyond 35°C, compounded further by high humidity (Zhang, Arens and Pasut 2011). In extreme conditions, heatwaves can result in excess mortality and cascading socioeconomic impacts such as lost work capacity and labour productivity.

The International Labour Organization (ILO) projects – based on a global temperature rise of 1.5°C by the end of this century – that in 2030, the equivalent of 80 million full-time jobs could be lost worldwide due to heat stress, resulting in global economic losses of US$2.3 trillion (ILO 2019). The impact will be unequally distributed around the world: low-income countries (which have fewer resources to adapt to excessive heat), especially in the hot regions of southern Asia and western Africa, are likely to be the worst hit, losing around 5 per cent of working hours due to excessive heat (Kjellstrom *et al.* 2019).

The global annual estimate for increases in heat-related deaths is 92,207 additional deaths in 2030 and 255,486 additional deaths in 2050 (assuming no adaptation) (WHO 2014). The situation is further compounded by the rising potential for major electric grid failures during extreme weather, which, when coinciding with heatwave conditions, can expose large populations to severe heat stress both outside and within buildings (Stone *et al.* 2021).

POWER SYSTEM IMPACTS

The escalating demand for space cooling is already putting pressure on electricity systems and will continue to strain the grids. Under a business-as-usual scenario, the energy requirement for space cooling is predicted to jump 300 per cent – from 2,020 terawatt-hours (TWh) in 2016 to 6,200 TWh in 2050. This is almost equivalent to the electricity consumption of the United States and Europe/Japan combined.[1] The rising use of air conditioners results in additions to grid infrastructure as well as increased greenhouse gas emissions and waste heat expelled into the environment. This further exacerbates the urban heat island effect, perpetuating a vicious cycle where mechanical cooling is further warming our cities – necessitating even more cooling – and disproportionately impacting those who lack adequate financial resources to procure mechanical cooling solutions.

1 Based on the 2019 annual electricity consumption, per Enerdata (2021).

As warming cities necessitate more air conditioning, the impacts would be felt most notably in the form of peak electricity demand. An assessment of 13 cities across different countries suggests that each degree of increase in the ambient temperature causes an average increase in peak electricity demand of 3.7 per cent (Santamouris 2019). By 2050, space cooling will account for an estimated 30-50 per cent of the peak electricity load in many countries (versus a global average of around 15 per cent today), with the biggest increase occurring in India (International Energy Agency [IEA] 2018). In some local grids serving large metropolitan areas around the world, by 2050 the cooling load is anticipated to exceed half of the total peak demand.

The economic consequences to manage the grid impacts and additional capacity are severe and underestimated. Many cities that have low ownership of air conditioners are now beginning to see a big surge in air-conditioning purchases. These cities may struggle to retrofit larger-capacity grids into existing urban areas due to limited space for the new wires and sub-stations necessitated by cooling. At the same time, unabated growth in cities is affecting the electricity supply to rural areas.

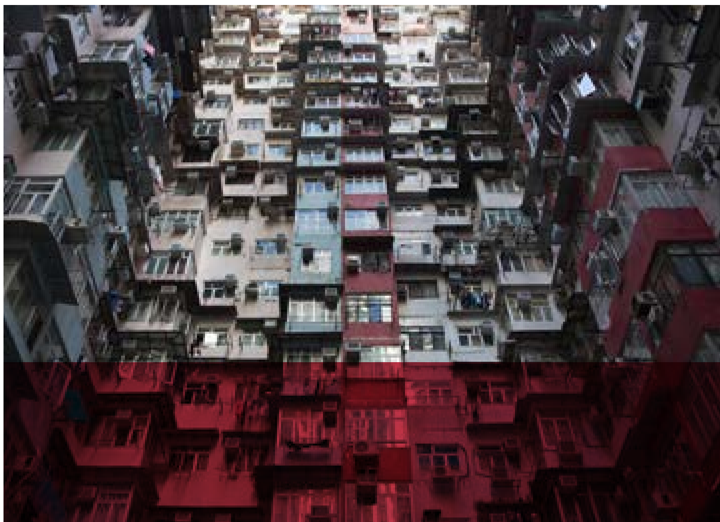
Cooling's contribution to peak electricity demand increases the risk of brownouts and blackouts, which can create a dire situation during extreme heat events. For example, major electrical grid failure events in the United States – those with a duration of at least one hour and impacting 50,000 or more utility customers – increased more than 60 per cent during a recent five-year reporting period (Stone *et al.* 2021). When such blackout events coincide in time with heatwave conditions, population exposures to extreme heat both outside and within buildings can reach dangerously high levels as mechanical air-conditioning systems become inoperable.

Globally, the total power capacity needed to meet the escalating demand for space cooling is expected to jump 395 per cent, from 850 gigawatts (GW) in 2016 to 3,350 GW in 2050. This increase of 2,500 GW is equal to the current total generating capacity of the United States, Europe and India combined (IEA 2018).

CLIMATE IMPACTS

Considering the cooling practices of today – largely dependent on fossil fuel-powered grids – the projected increase in global electricity consumption for space cooling will result in 18 per cent of the total increase in global carbon dioxide (CO_2) emissions between 2016 and 2050 (IEA 2018). Peak loads, which are often disproportionately served by fossil fuel-based generation, further exacerbate the power sector emissions associated with cooling.

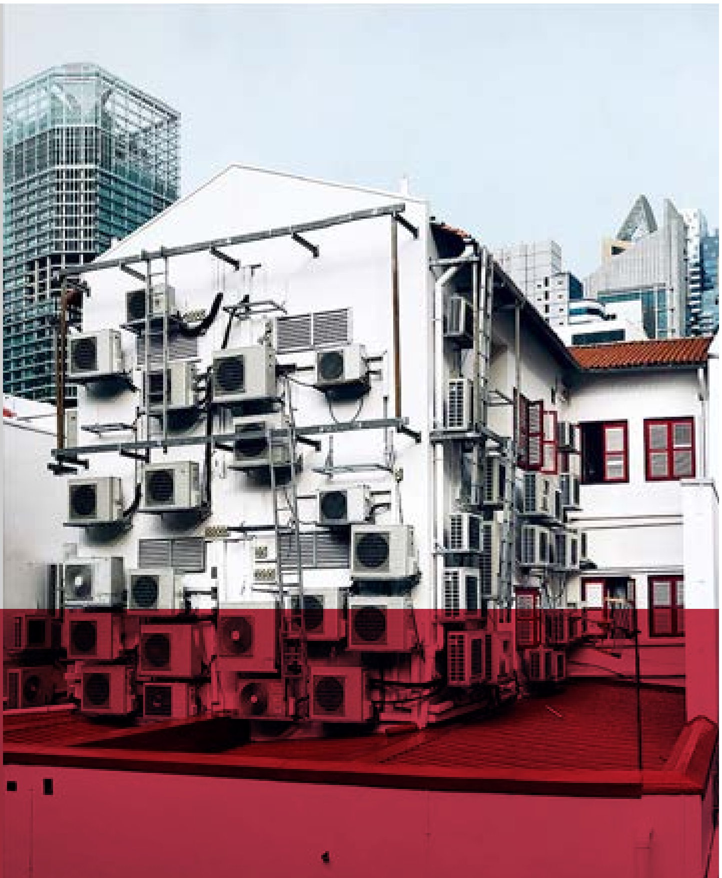
Despite the grid's declining emissions intensity due to ongoing clean energy efforts, an analysis by the International Energy Agency shows that the global annual indirect emissions associated with space cooling will almost double, from 1,135 million tons in 2016 to 2,070 million tons in 2050[2]. This doubling does not even take into account the direct emissions originating from many common refrigerants used in air-conditioning systems. Based on our current pathway, the cumulative emissions from air conditioning our residential buildings alone (not factoring in commercial buildings) could result in up to an estimated 0.5°C of global warming by 2100 (Sachar, Campbell and Kalanki 2018).



2 This estimate is for the Baseline Scenario, which takes into account the likely effect of current policies and targets.

ECONOMIC IMPACTS

The economic impacts of urban heat are pervasive and affect the common person, city governments as well as nations. Household spending to achieve space cooling already accounts for 5-15 per cent of the median income in many parts of the world, making cooling unaffordable for much of the population. With rising temperatures and increased demand for thermal comfort, the operation of air-conditioning units to provide cooling will only increase, also bringing a sharp increase in the purchase of entry-level air conditioners. Entry-level units are typically less energy efficient and lower priced (lower first-cost) than air conditioners that meet higher efficiency standards, but can cost twice as much to operate over their lifetime (ESMAP 2020b). The projected adoption of these entry-level units will lock in high operational costs for customers, resulting in a higher fraction of disposable income allocated to electricity bills.



For example, a study based on the US city of Phoenix, Arizona estimates an excess cost of air conditioning (operation and repair) of $436 million due to the seasonal 3°C heat island effect (Miner *et al.* 2016). These costs are generally invisible to the population, being subsumed into the usual repair and utility bills of everyday life. Moreover, they do not paint the full picture of economic impact to the city such as through productivity losses and health impacts. Phoenix is an example of a relatively low-density urban heat island; the economic impacts to the population can be even greater in more dense cities where the heat trapped in the thermal mass of buildings and infrastructure can intensify the heat island effect.

Recent research by an international team of economists, based on an analysis of the world's 1,692 largest cities, suggests that overheated cities face climate change costs that are more than twice those of the rest of the world because of the urban heat island effect (Estrada, Wouter Botzen and Tol 2017). The analysis takes into account various ways in which higher temperatures can damage the city economy, such as greater energy use for cooling, increased air pollution, worsening water quality and loss in worker productivity. For the worst-off cities, losses under a business-as-usual scenario could reach 10.9 per cent of gross domestic product (GDP) by the end of the century, compared with a global average of 5.6 per cent. The researchers state that, "Any hard-won victories over climate change on a global scale could be wiped out by the effects of uncontrolled urban heat islands" (University of Sussex 2017). This underscores the fact that local, citywide action is equally as important as global action.

National governments will incur costs as well, which generally trickle down to consumers or taxpayers. The anticipated increase in global power generation capacity required to serve the mounting space cooling needs would amount to an investment of $1.7 trillion in capacity alone (excluding associated fuel costs and transmission and distribution infrastructure costs) (ESMAP 2020b).

1.2 IMPACTS OF HEAT ARE NOT EVENLY DISTRIBUTED

Underlying socioeconomic inequities in cities make the challenge of cooling even more complex. Impoverished districts and populations are usually the most vulnerable to heat, placing the negative impacts of excess warming disproportionately on those who are least likely to be able to afford or access thermal comfort. For example, in India, where 24 cities are expected to reach average summertime highs of at least 35°C by 2050, the urban poor in these cities remain the most vulnerable to heat (Vijayawada 2018). In the United States, immigrant workers – typically minimum-wage employees – are three times more likely to die from heat exposure than the average American (Fleming *et al.* 2018).

Studies also point to spatial patterns linked to heat-related death, further underscoring that the impacts of heat are not evenly distributed. A recent study highlights the correlation between heat-related deaths and an area's green spaces (and thus its wealth), concluding that people living in less-vegetated areas have a 5 per cent higher risk of death from heat-related causes (Schinasi, Benmarhnia and De Roos 2018). Tree canopies and vegetation can lower surface and air temperatures in urban areas through a combination of shading and evapotranspiration, helping to reduce peak summer temperatures by 1° to 5°C (US EPA 2021).

If current trends continue, the existing heat inequity in cities, often reflecting social and racial disparities, will only deepen in the coming decades as our cities become warmer, posing a daunting challenge for cities to bridge.

1.3 THE COOLING CHALLENGE FOR CITIES

Proactively managing excess warming in our cities – through mitigation of urban heat islands and adopting more urban and climate-friendly cooling practices – is an urgent priority to ensure access to cooling where needed and to support many critical development goals without further warming the city environment.

While cooling is essential to many aspects of modern life, the focus in this publication is on *the role of cooling in protecting populations from extreme heat in the urban environment*. This entails providing thermal comfort – both indoors and outdoors – through temperature, humidity and air flow in the urban environment, of which buildings are a major part. Thus far, the response to rising urban heat has predominantly centred on enhancing indoor thermal comfort – that is, providing more space cooling.[3] The current market behaviour defaults to an increasing number of people relying on air conditioners to address rising heat. Already, 2.3 billion people in the increasingly affluent lower-middle class in developing countries are on the verge of purchasing the comfort of an air conditioner – typically the unit that is the most affordable, and likely the least efficient, on the market (Sustainable Energy for All 2018).

The space cooling practices of today are generally very energy intensive and largely reliant on fossil fuel-generated electricity and refrigerants that are harmful to the climate. Thus, rather than holistically addressing the systemic issue of rising emissions and urban heat islands in cities, the current practices are increasing the proliferation of inefficient cooling appliances. This, in turn, further exacerbates the issue of waste heat and emissions in the urban environment. Space cooling is one of the fastest growing causes of greenhouse gas emissions, further intensifying urban heat.

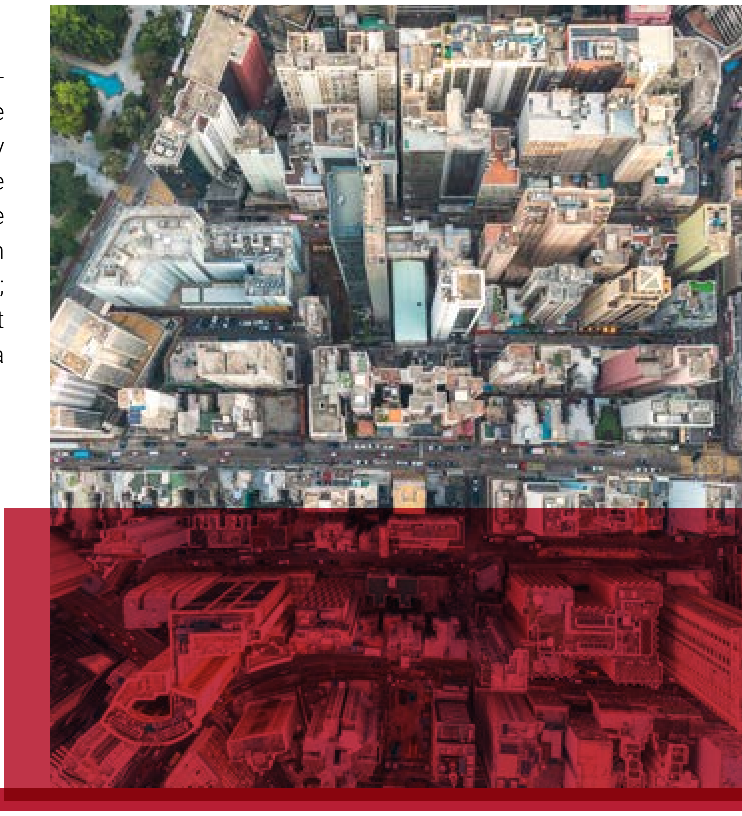
3 Space cooling, also known as "comfort cooling", refers to the means by which people are provided thermal comfort from heat by maintaining the optimum temperature, humidity and ventilation within the built environment.

Depending on the climate zone, the urban heat island effect can raise urban temperatures as much as 5°C compared with surrounding rural areas (IEA 2017). Rapid urbanization and a warming planet, acting in combination, will only intensify this warming effect, making access to thermal comfort for all city dwellers an increasing priority.

- **Rapid urbanization:** By 2050, 68 per cent of the world's growing population will be living in urban areas, up from 55 per cent in 2018 (UN DESA 2018). A major portion of this growth will be in developing countries in Asia and Africa: just three countries – India, China and Nigeria, which are already hot and populous – will account for 35 per cent of the projected growth in the world's urban population. If current growth trends continue, urban areas could increase in population by 80 per cent between 2018 and 2030 (Mahendra and Seto 2019) and will experience dramatic land-use changes such as reduced vegetation and a sharp increase in heat-trapping materials and surfaces.
- **A warming planet:** By 2050, under a business-as-usual scenario, the average number of cooling degree days[4] will increase by around 25 per cent globally (IEA 2018). A recent study predicts that by 2070, one out of every three people worldwide (in the absence of migration) will live in far hotter conditions, with average annual temperatures of more than 29°C; these conditions currently exist in less than 1 per cent of the Earth today, mostly concentrated in the Sahara (Xu *et al.* 2020).

GDP growth in developing countries (using as a proxy those countries that are not members of the Organisation for Economic Co-operation and Development, OECD) is projected to exceed 4.5 per cent by 2025. This increased purchasing power will provide increased access to cooling; as a result, many lower- and middle-income families around the world will be able to purchase their first air conditioner to combat the rising temperatures. Such purchases will not only have significant implications for growing energy demand and associated greenhouse gas emissions, but will also add dramatically to the waste (rejected) heat in urban areas, further compounding the problem.

The challenge for cities is the following: how to equitably serve the growing demand for cooling without multiplying the negative impacts, causing further warming and undermining the energy transition.



4 A cooling degree day is a measure of cooling and is defined as a departure of the mean daily temperature from a given standard: one degree day for each degree of departure above 65°F (around 18°C) during one day. The amount of energy required to maintain a building's temperature in the summer is generally proportional to the accumulated cooling degree days.

1.4 UNDERSTANDING THERMAL COMFORT AS THE FOCUS OF URBAN COOLING

Proving thermal comfort to the population is at the core of addressing the need for cooling in the urban environment. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines thermal comfort as the "condition of mind which expresses satisfaction with the surrounding thermal environment" (ANSI/ASHRAE 2013). While air temperature is the most commonly used indicator of thermal comfort, a combination of both environmental and personal factors affects human thermal comfort, as summarized in figure 1.1.

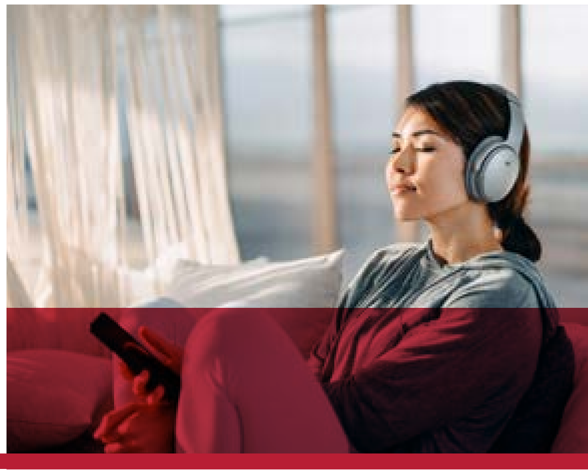


Figure 1.1 Environmental and personal factors for thermal comfort

ENVIRONMENTAL FACTORS FOR THERMAL COMFORT

Radiant Temperature: the heat that radiates from a warm object. Typical examples of radiant heat sources include sun fire, ovens, hot surfaces and machinery.

Air Temperature: temperature of the air surrounding the body.

Air Speed: the speed of air movement. Moving air in warm or humid conditions can increase heat loss from the human body through convection without any change in temperature, thus aiding in cooling.

Humidity: refers to water vapour in the air. The ability of air to hold water vapour directly relates to its temperature. The warmer the air is, the more humidity or water vapour it can hold.

PERSONAL FACTORS FOR THERMAL COMFORT

Clothing: appropriate clothing for climactic conditions.

Metabolic Rate: inherent and affected by a person's activity level.

Source: Adapted from ESMAP 2020b

Of the factors identified in figure 1.1, the most important ones with respect to thermal comfort in an urban environment are air temperature and humidity.

- **Air temperature** is influenced by the form of heat energy known as sensible heat. This is commonly understood as heat energy that can be sensed by touch and can be measured directly with the help of a thermometer.
- In urban environments, the "local" increase in sensible heat is largely the cause of urban heat islands. The key factors that cause sensible heat to increase in cities are: heat from dark surfaces such as rooftops, streets and parking lots that have been heated by the sun to temperatures hotter than the surrounding air and surfaces; waste heat from human-made sources; and lack of evapotranspiration due to impervious surfaces and diminishing vegetation.
- **Humidity** is commonly understood as the concentration of water vapour present in the air. Urban heat island effects are felt more strongly in cities with high humidity due to the inability of humid cities to efficiently convect heat to the lower atmosphere. For instance, studies suggest that urban heat island effects in Delhi, India – a hot and humid city – have increased temperatures by up to 6°C (Yadav and Sharma 2018).

  Humidity is critical to understand in the context of thermal comfort as well, because in humid conditions the ability of the human body to acclimatize to extreme temperatures – by increased sweating and the evaporation of sweat – becomes difficult, making heat stress harder to bear. For this reason, high wet-bulb temperatures – a function of both air temperature and relative humidity – are more dangerous to human beings than extreme air temperatures alone.

Recognizing the inescapable interactivity between local climate, urban surfaces and structures, natural vegetation, and management of waste heat is critical for holistically addressing the need for thermal comfort in warming cities. More air conditioning alone – as is the market default response – to combat oppressive city heat is not a sustainable solution. It only makes matters worse for the city as a collective whole. Instead, the urban cooling challenge has to be addressed sustainably and systemically – with parallel efforts to minimize sensible heat in cities, facilitate natural cooling to the fullest extent possible, and serve mechanical cooling requirements with the lowest possible environmental footprint.

1.5 A CALL TO ACTION FOR CITIES: SUSTAINABLE URBAN COOLING IS AN URGENT IMPERATIVE

We urgently need broad-based urban heat island adaptation and mitigation measures along with a shift to more sustainable cooling solutions that can provide access to cooling without further compounding the downward spiral where more cooling begets more warming. Sustainable cooling, in this context, refers to achieving human thermal comfort within an urban environment through urban planning and design (both nature-based and infrastructure-related), energy-efficient building design, efficient cooling technologies and practices, and sustainable refrigerant use approaches that collectively result in lower climate impact and greater access and equity than business-as-usual cooling approaches. Achieving this necessitates both policy and market-based interventions, as well as widespread awareness, to accelerate the shift away from current cooling practices and towards more sustainable cooling.

While the cost of doing nothing is huge – for cities and, as a result, for the world at large – the benefits of an accelerated transition to sustainable urban cooling are far-reaching. A recent report estimates that coordinated international action on energy-efficient, climate-friendly cooling could avoid as much as 460 billion tons of greenhouse gas emissions – roughly equal to eight years of global emissions at 2018 levels – over the next four decades and avoid $3.5 billion of the renewable energy build-out by 2030 (UNEP and IEA 2020). While these estimates are for cooling across all sectors, the major share is attributable to keeping our cities and communities cool.

Sustainable cooling can be an important enabler and significant contributor to cities' goals to lower emissions and reach net zero energy targets cost-effectively. It can also be an important contributor to national climate commitments as cities take targeted actions and demonstrate "local" leadership to align with national priorities. The multiple co-benefits to cities include the enhanced health, well-being and productivity of citizens; a more attractive environment for economic development; improved energy systems; and wider and equitable access to thermal comfort. Last, but not least, the positive impacts of local interventions to promote sustainable urban cooling will amplify global efforts to fight climate change.

WHY A STRATEGIC, WHOLE-SYSTEM APPROACH IS KEY TO SUSTAINABLE URBAN COOLING

02

Multiple factors contribute to the increase in warming in cities, often with inter-related effects. Therefore, strategies to address urban cooling need to be multi-pronged – addressing the urban heat island effect, neutralizing the emissions impact of current and future cooling needs, and enabling access to cooling where needed without contributing further to local warming. Such an approach – referred to as a whole-system approach – would bring integrative benefits and accelerate the shift towards sustainable urban cooling.

2.1 THE WHOLE-SYSTEM APPROACH TO OPTIMALLY ADDRESS URBAN COOLING

A whole-system approach to sustainable urban cooling is key to keeping our cities cool in an optimal and resource-efficient manner. This approach calls for three core steps that should be applied collectively to best fit a given urban context:

01 Reduce heat at the urban scale, through heat-resilient urban planning and infrastructure. This step includes strategies for efficient planning and design at the scale of the city or urban district, with an emphasis on heat-minimizing planning, the use of thermally favourable materials, and nature-based cooling practices designed to reduce the urban heat island effect – in turn also reducing cooling loads in buildings.

02 Reduce cooling needs in buildings, through energy-efficient and thermally efficient buildings. This step is for focused on enhancing the thermal performance of buildings and minimizing the mechanical cooling requirements as well as the overall energy and emissions footprint of buildings using passive building design practices. Key strategies include leading-by-example on city-owned buildings and raising the floor with building energy codes and standards.

03 Serve cooling needs in buildings efficiently, through efficient and best-fit cooling technologies and operations. This implies using cooling equipment that is an optimal fit for the application, is highly energy efficient, and that minimizes the use of refrigerants that have high global warming potential – at the building and home/room level – to deliver the required amount of cooling with the least amount of energy and emissions. Efficient, climate-friendly mechanical cooling also entails strategies to ensure efficient operations – including optimal operations and maintenance practices, refrigerant management, and demand-side management of cooling energy consumption including building automation and user-adaptation, etc. – designed to minimize energy use and emissions from the cooling of buildings.

Figure 2.1 Whole-system approach to optimally address urban cooling

Efficient planning and design at the scale of the city or urban district, with an emphasis on heat-minimizing urban form and design, nature-based solutions, and cool surfaces designed to reduce the urban heat island effect, in turn also reducing cooling loads in buildings.

Enhancing the thermal performance of buildings and minimizing cooling loads using passive building design practices with an emphasis on leading-by-example on city-owned buildings and raising the floor with building energy codes and standards.

Efficient and best-fit cooling technologies and operations to deliver the required amount of cooling with the least amount of energy, emissions and anthropogenic heat.

Source: RMI

The first step in the whole-system approach is focused on heat reduction at the urban scale (but also has cascading benefits at the building scale). The latter two steps are focused on the building scale. Together, the three steps have a powerful compounding effect: lowering urban heat results in less cooling load on buildings, thermally efficient buildings lead to reduced requirements for mechanical cooling, and the reduced cooling requirements can then be served with more efficient cooling systems. Thus, it is important to focus on all three steps – and sequentially – to the fullest extent possible.

Accompanying measures that leverage renewable energy sources for power will be important contributors to further lowering the greenhouse gas impact of satisfying the need for access to cooling and supporting cities' low-carbon goals. To effectively leverage the whole-system approach, cities have to enable coherent coordination across municipal departments – for example, between urban planning, energy and transport departments. Such coordinated response sets in the powerful integrative effect of the solutions achieved through a whole-system approach, which is more than just the sum of the individual solutions and programmes.

2.2 REDUCE HEAT AT THE URBAN SCALE: HEAT-RESILIENT URBAN PLANNING AND INFRASTRUCTURE

Aside from the geographic location and climate conditions, several variables influence how urban areas experience and accumulate excess heat. These include the existing land cover – including the distribution of urban surfaces, green spaces and tree canopy – the building density, construction practices, and commonly used materials, among others. Commonly used materials in urban surfaces – roads, pavements, roofs and walls – heat up and warm not only the surrounding air but also the atmosphere. In particular, the prevalence of dark roofs and impervious dark-coloured pavements, coupled with a declining vegetation cover, are significant contributors to the temperature differential between urban hubs and the surrounding areas.

Proven and demonstrated strategies exist that apply to these urban variables and can contribute significantly to keeping urban areas cooler while inherently reducing the mechanical cooling needs of buildings. These strategies can be broadly grouped in three inter-related categories: heat-resilient urban form and planning, nature-based solutions and cool surfaces. These strategies are summarized below, and the specific interventions within each are discussed in greater detail in chapter 6.

URBAN FORM AND PLANNING

Land-use planning and design control is generally the biggest lever for a developing city to proactively plan for mitigating future challenges related to the urban heat island effect. Appropriate changes to land use and design controls that prioritize green space and green infrastructure, and promote water-sensitive urban design, will help change the way that buildings and communities are constructed and designed. Land use and building design controls must be adjusted at several different scales – **at the city, district and neighbourhood level** – in order to maximize effectiveness and ensure that the density and form of new development is appropriate for future climate conditions.

Some key considerations are:

- **Leveraging cooling benefits of green open spaces and water bodies:** Distribution and planning of land use should include setting aside green spaces and water bodies for the purpose of mitigating future urban heat island effect challenges.
- **Promoting wind flow:** Appropriately directed wind flow can remove excess heat and polluted air away from urban communities and help maximize the movement of cool air from natural sources (water, green spaces) to urban communities. Some ways to achieve this are:

  • aligning buildings with the prevailing winds
  • orienting buildings to channel winds and
  • appropriately distributing and placing green areas.

- **Reducing waste heat:** Managing waste heat generated through human activities – such as transport and industrial processes[5] – is an important part of addressing urban cooling. Some considerations include appropriate land-use zoning for industrial areas, obligations to reuse waste heat on-site or in more collective systems such as heating or cooling networks, enhanced public transport and/or vehicle regulations to reduce heat, urban planning and development that minimizes the need for vehicle use, and an accelerated transition to electric mobility.
- **Planning for resource-efficient cooling through a servitization model:** In cities experiencing significant growth and development, opportunities for resource-efficient district cooling leveraging available heat sinks and sources, where feasible, will help to offset the effect of increases in cooling demand on urban heat and provide an opportunity for increased access to cooling. District cooling systems, by virtue of increased efficiency and the use of heat sinks, significantly reduce (cooling-related) emissions and waste heat compared to distributed cooling equipment.

NATURE-BASED SOLUTIONS: GREEN AND BLUE SPACES

Natural features provide cooling benefits through evapotranspiration and direct shade in the case of trees and other vegetation, and by acting as heat sinks in the case of bodies of water. As a result, integrating vegetation and water bodies (also referred to as nature-based solutions) in the urban fabric can reduce local and ambient temperature. Even in the case of existing development, there are opportunities to integrate urban greenery and water features (discussed in chapters 6 and 10, respectively). For example, urban tree canopies can provide shading, blocking sunlight from striking and heating urban surfaces such as sidewalks and buildings, thus facilitating cooling in the shaded areas. The US Environmental Protection Agency (2021) estimates that tree groves can be 5°C cooler than unshaded open ground around them.

5 Space cooling is also a significant contributor of waste heat in urban areas, but this is covered under the discussion on "Efficient and best-fit technologies".

COOL SURFACES

A shift towards reflective urban surfaces, such as for buildings and pavements, can make our cities cooler by reducing the amount of heat that is transmitted from the earth's surface and trapped in the city air. For example, when sunlight hits a dark-coloured roof, 38 per cent of its energy heats the atmosphere, 52 per cent heats the city air, and only 5 per cent is reflected back; in comparison, when sunlight hits a light-coloured reflective roof, 10 per cent heats the atmosphere, 8 per cent heats the city air, and 80 per cent is reflected (Global Cool Cities Alliance 2012). This characteristic of surfaces, which determines the fraction of sunlight reflected back into space, is known as solar reflectance or albedo.[6]

A study estimates that increasing the albedo of roofs and pavements in all major hot cities of the world could provide a one-time offset of the warming effect of 44 gigatons of emitted CO_2 (Akbari, Menon and Rosenfeld 2009). (This 44 gigaton offset is more than one years' worth of the 2025 projected worldwide emission of 37 gigatons of CO_2.) In addition, incorporating permeable surfaces in urban areas facilitates evaporative cooling and also reduces the need for storm run-off infrastructure. This can be achieved by using porous or permeable paved surfaces and by increasing vegetated cover. These and other passive strategies are discussed in detail in chapter 6.

This characteristic of surfaces, which determines the fraction of sunlight reflected back into space, is known as solar reflectance or albedo.[6]

These urban strategies have integrative effects and should be applied in combinations – at the city, district or neighbourhood level – to best suit the local context and environment. Effective implementation of suitable urban design and planning strategies can go a long way in minimizing urban heat islands and reducing the requirements for mechanical cooling, with several co-benefits, such as improved air quality and enhanced biodiversity.

A hypothetical "cool communities" programme in Los Angeles projected – two decades ago – that urban temperatures could be reduced by around 3°C after planting 10 million trees, reroofing 5 million homes and painting one-quarter of the roads; the estimated cost would be $1 billion, giving estimated annual benefits of $170 million from reduced air-conditioning costs and $360 million in smog-related health savings – that is, a simple payback period of under two years (Rosenfeld *et al.* 1997). While the theoretical knowledge has existed, making this more accessible to cities through adequate capacity-building and raising stakeholder awareness will support greater implementation.

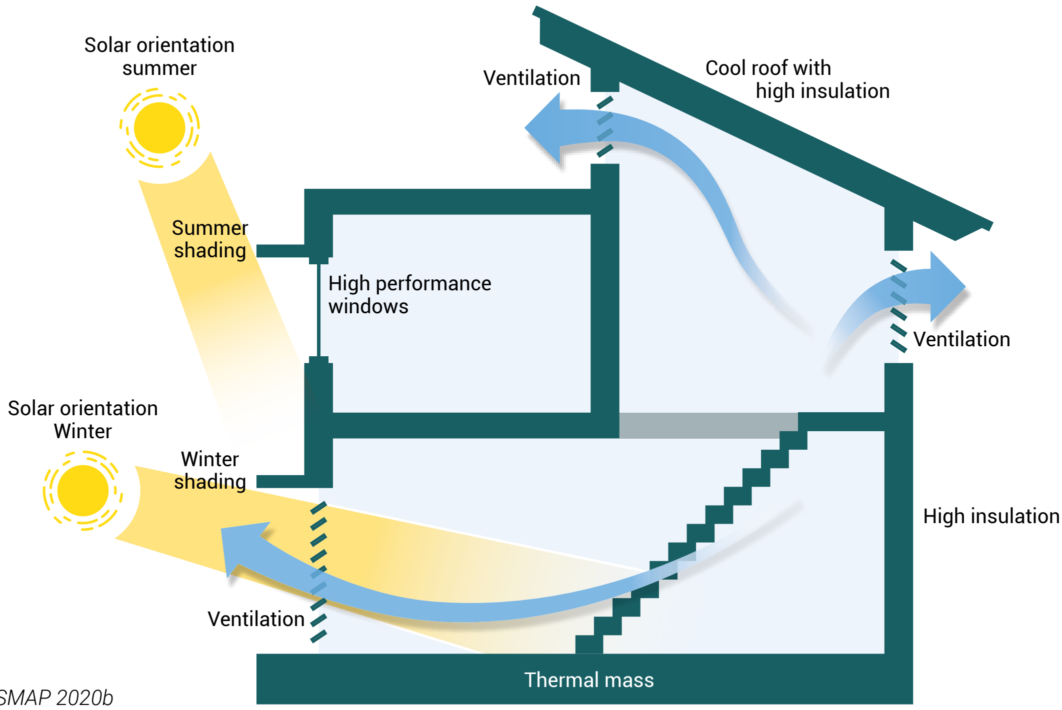
6 Albedo is measured on a scale of 0 to 1. A value of 0 means the surface is a "perfect absorber" that absorbs all incoming energy; a value of 1 means the surface is a "perfect reflector" that reflects all incoming energy. Fresh snow has one of the highest albedos at 0.9, reflecting up to 90 per cent of incoming solar radiation.

2.3 REDUCE COOLING NEEDS IN BUILDINGS: ENERGY-EFFICIENT AND THERMALLY EFFICIENT BUILDINGS

Strategies for passively cooled building design can also impact urban cooling in inter-related ways: by reducing the overall heat gain and heat island effects, such as through appropriate materials and surfaces; by reducing the cooling load (and associated emissions) in buildings; and by reducing waste heat through less mechanical cooling.[7] Particularly in hot and humid climate zones, mechanical cooling can represent a significant portion of building energy use: for example, vapour compression systems, in such climates, consume more than 50 per cent of the total energy used in buildings, increasing to 80 per cent at peak times (Katili, Boukhanouf and Wilson 2015). Passive cooling strategies have been proven to achieve a reduction in cooling loads of more than 25 per cent, even in very hot climates (ESMAP 2020b).

Key principles of passive cooling that help reduce mechanical cooling loads in buildings include: climate-appropriate building orientation; appropriate materials and design features in the building envelope – including insulation, windows and shading – to minimize heat gain due to thermal transmittance; natural ventilation (where temperature, humidity and air quality allow); and thermal mass to stabilize interior temperatures. These are summarized in figure 2.2 and are discussed further in chapter 8 of this report. Passive design strategies should be utilized and optimized based on the climate condition for a region.

Figure 2.2 Passive cooling principles



Source: Adapted from ESMAP 2020b

7 Data suggest that around 20 per cent of warming in urban residential areas is attributable to waste heat from air-conditioner use. See Takane et al. (2019).

Mandatory or voluntary building energy codes are the means to drive passive cooling strategies in buildings. Code adoption is commonplace in developed economies such as the European Union and the United States, and the cumulative positive outcomes are well acknowledged. For example, the model energy codes[8] in the United States are projected to result in cumulative benefits, from 2010 to 2040, of 841 million metric tons of avoided CO_2 emissions and 3,757 TWh of avoided primary energy. These savings equate to the annual emissions of 177 million passenger vehicles or 245 coal power plants (US DOE, n.d.).

However, in most developing countries, the adoption and implementation of building energy codes to deliver the benefits of thermally efficient buildings remains low. The Regulatory Indicators for Sustainable Energy (RISE) dataset (ESMAP 2018) suggests that of 65 low-income or lower-middle-income countries, only 16 have energy efficiency codes for new residential buildings, and 19 have such codes for new commercial buildings. While the theoretical potential of building energy codes is promising and well documented, in reality this potential remains largely untapped due to a number of implementation and enforcement barriers. These barriers result from a combination of factors, commonly including institutional challenges, regulatory challenges, lack of enabling mechanisms to create and sustain markets, low stakeholder motivation due to split incentives, and lack of awareness and capacities.

In addition to building energy codes, voluntary green building programmes have been promoting the mitigation of the heat island effect in several parts of the world. For example, under the US Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) Green Building Rating System, building sites can earn credits for taking action to reduce heat islands and minimize impacts on microclimates. LEED credits are available for buildings that use reflective roofing or green (planted) roofs and buildings that provide shade.

Another example is BREEAM (Building Research Establishment Environmental Assessment Method), a global green building rating system that is used to measure the environmental performance of new and existing buildings and infrastructure projects. The BREEAM rating system includes criteria such as energy, land use, materials, transport, and health and well-being, which are designed to promote more sustainable environments that enhance the well-being of the people who live and work in them, and help protect natural resources.

While passive cooling strategies generally are easiest and most cost-effective to incorporate during new construction – thereby avoiding a significant portion of the future cooling demand – they can also apply to (and benefit) existing buildings, especially at times of renovation and repurposing. Some passive cooling strategies that are particularly suited to existing buildings include installing high-performance windows, adding insulation, adding shading devices and implementing cool roofs.

8 The model energy codes are the International Energy Conservation Code for residential buildings and the American Society of Heating, Refrigerating and Air-Conditioning Engineers Standard 90.1 for commercial buildings (42 U.S.C. § 6833).

2.4 SERVE COOLING NEEDS IN BUILDINGS EFFICIENTLY: EFFICIENT AND BEST-FIT COOLING TECHNOLOGIES AND OPERATIONS

This step of the whole-system approach focuses on optimal cooling technologies and operations to deliver the required amount of cooling needs with the least possible amount of energy and emissions. The term "optimal" here implies the combination of the lowest life-cycle cost and the lowest environmental footprint to meet the functional need for cooling.

THE NEED FOR EFFICIENT AND LOW-CLIMATE-IMPACT COOLING TECHNOLOGIES

Multiple mechanical cooling options are prevalent to provide cooling and ventilation in buildings, such as vapour compression systems, fans and air coolers. Vapour compression-based air-conditioning systems – the most dominant space cooling approach today – constitute a broad category, including several technologies of varying complexity, such as room air conditioners, central unit air-conditioner systems, variable refrigerant flow systems and chillers.

Air-conditioning systems are expected to remain an important choice for space cooling in the foreseeable future, because they are easy to use, scalable and reliable. These systems cool the air to the desired temperature and, in the process, can also reduce the humidity of the air by condensing the water vapour, depending on the humidity content of the air. While air conditioners effectively provide space cooling in all climate conditions and applications, they also have a significant energy and environmental footprint.

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Air conditioning is energy intensive. It depends largely on grid electricity that is predominantly fuelled by fossil fuels in most countries, driving indirect greenhouse gas emissions. Further, it is associated with refrigerants that overwhelmingly have high global warming potential, responsible for direct greenhouse gas emissions. Finally, it rejects waste heat into the outdoors, contributing materially to excessive warming in the urban environment. Waste heat from cooling activity through vapour compression technologies can add between 1°C and 2°C to nighttime air temperatures in cities where mechanical cooling is common (ESMAP 2020a).

In addition, a substantial portion of air conditioning – room air conditioners, which account for around 75 per cent of the total number of installed air-conditioning units today[8] and are on a growth curve – is fraught with market failures resulting from first-cost bias. This has led to an industry largely focused on first-cost optimization. It is less focused on the reduced life-cycle costs of highly efficient sustainable cooling solutions that can deliver equivalent cooling at a significantly lower environmental impact. As a result, the average efficiency of room air conditioners sold today is less than half that of the commercially available best-in-class units (IEA 2018).

9 While predominantly used in residential buildings, room air conditioners are in use in a small portion of the commercial sector as well.

However, more efficient air conditioning is technologically well within our reach today and can deliver today's space cooling needs with less than half of the energy use while delivering a lower life-cycle cost to users and consumers (ESMAP 2020b). A high-level analysis by RMI calculated the results from switching today's space cooling equipment stock (1.6 billion residential and commercial air-conditioning units) to commercially available higher-efficiency equipment, in conjunction with cost-effective building envelope improvements. It found that:

- today's space cooling energy use could have been reduced by around 58 per cent (or 1,177 TWh), and
- the switch could have eliminated more than half (540 million tons of CO_2) of the current total indirect emissions (1,135 million tons of CO_2) from space cooling operations. In addition, the avoided space cooling capacity would have resulted in lower use of refrigerants and associated direct emissions (ESMAP 2020b).

Thus, while cooling technologies are a necessity to provide space cooling and enhance thermal comfort, their careful selection is essential to drive the transition towards efficient and best-fit solutions – that is, cooling technologies that serve the cooling needs in an energy-efficient manner with the least possible climate impact.

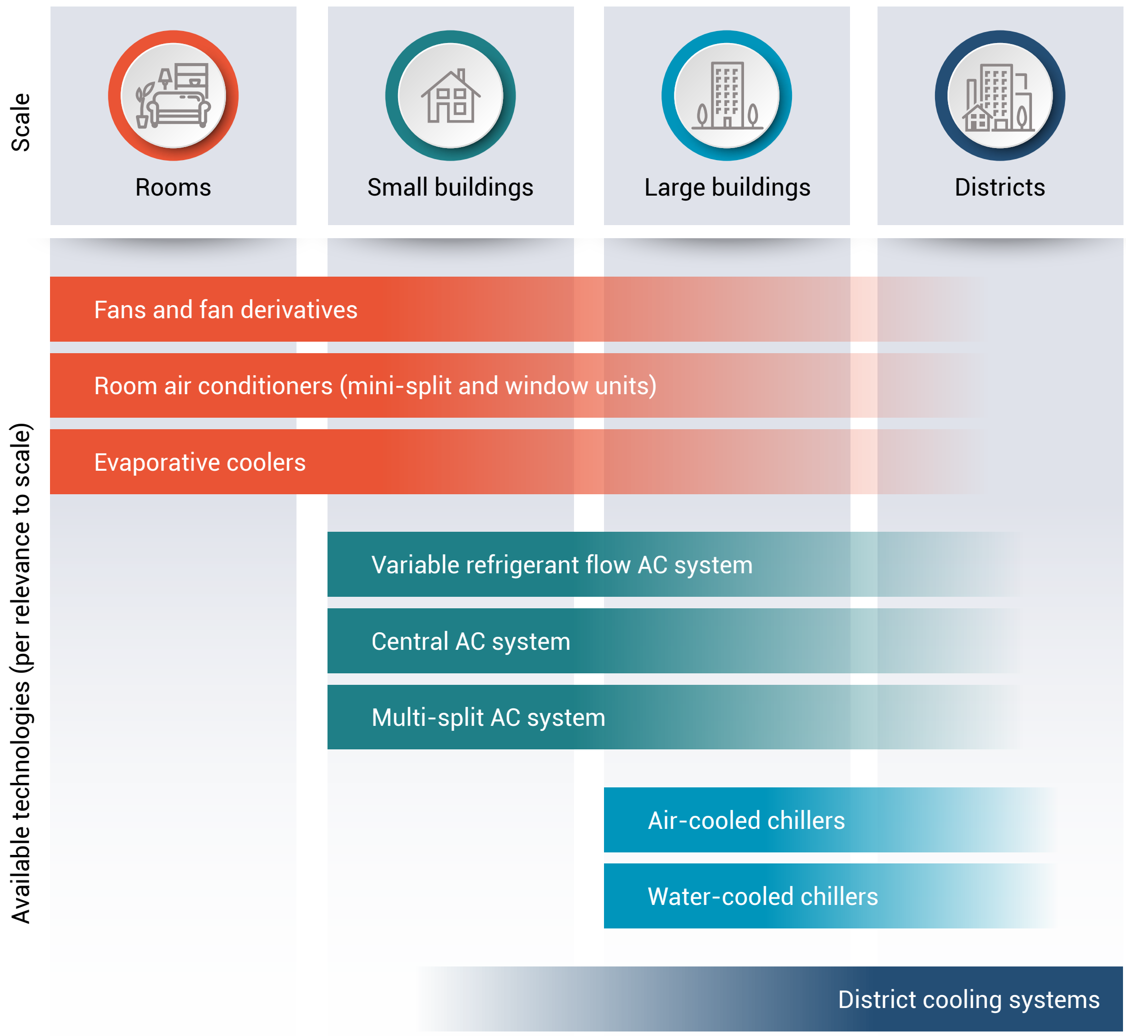
SELECTING THE OPTIMAL COOLING EQUIPMENT

With a wide range of cooling technologies available for mechanical cooling, the choice of the most suitable solution will depend on several factors. These include the building scale, type of construction (new or existing building), building ownership profile, climate zone, immediate environmental attributes and specific local factors (such as utility rates and service sector capacity and capability). These factors come together to determine the optimal economics and the choice of space cooling solution. While the factors apply in combination, a dominant determinant of the optimal space cooling technology is the scale of the built environment being addressed – that is, whether cooling is to be provided, for example, for a room, a single building, a campus or even a whole district.

As shown in figure 2.3, cooling equipment such as fans, air coolers and room air conditioners are operated across all levels; however, these are most widely used at the room, residential and small commercial scales. As the building scale moves towards offices and large commercial and industrial scales, cooling equipment such as multi-split air conditioners, variable refrigerant flow air conditioners and chillers become a more common choice, due primarily to better control, ease of maintenance and the improved overall efficiency of centralized systems over individual units. As the building scale expands to include multiple buildings within a region or entire district, district cooling approaches can become a viable choice subject to sufficient scale and density.

District cooling systems are discussed in greater detail in chapter 7 of this report.

Figure 2.3 Technologies to serve cooling loads



Note: Shading represents each cooling equipment's applicability at the corresponding building scale.
Source: Adapted from ESMAP 2020b

While each category of cooling equipment encompasses a range of efficiencies, the most efficient equipment types are often fans, fan derivatives and evaporative cooling. But these approaches do not provide the full utility that vapour compression cooling provides across all climatic conditions today. Within the vapour compression equipment types, those that are able to use heat sinks (typically water or geo-exchange) to increase the efficiency of the condensing cycle, limiting the release of heat into the urban environment, would be the most efficient – starting with district cooling followed by water-cooled chillers. Among air-cooled cooling equipment, the distinctions in efficiency between available solutions, outside of the incremental efficiency of inverter or variable-speed-drive compressors and fans, as opposed to fixed-speed compressors and fans, are less pronounced.

EFFICIENT OPERATIONS

The third strategy in the whole-systems approach pertains to all the means and solutions designed to minimize the energy and emissions footprint of "using" cooling. This is a broad category and includes human decision-making that influences cooling operations and the resulting emissions, including procurement specifications for cooling equipment, equipment maintenance practices, user operational preferences and behaviour adaptations, and servicing and refrigerant management practices.

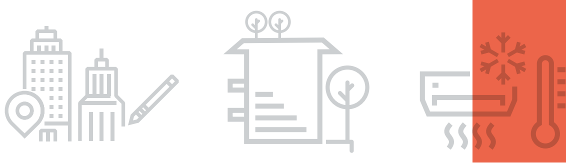
A wide suite of solutions is available to ensure that cooling is delivered only where and when it is needed and that system performance is monitored and maintained, thus optimizing cooling operations and minimizing emissions. Key solutions include:

- **Controls and sensors:** The use of controls and sensors can help eliminate wasteful use of cooling equipment (and energy). Depending on the scale of the building being served, the systems can range from simple – such as a programmable thermostat – to very complex, geographically distributed controllers that can control various processes throughout a group of buildings. Common methods to optimize cooling leveraging controls and sensors include:
  - sensing demand across zones through thermostats, occupancy sensors and air quality sensors;
  - modulating supply to meet demand by providing just enough cooling and delivering it only to the spaces that have demand (examples include variable air volume, variable refrigerant flow, and variable speed motors or inverters); and
  - optimizing the use of free cooling through sensors and motorized dampers, when outdoor weather conditions (temperature, humidity and air quality) are favourable.
- **Load shifting:** Peak load constraints can be alleviated by staggering the loads using demand-side management measures or thermal storage (an effective battery of cold in the form of ice or chilled water) as a buffer between power supply and cooling demand.
- **User adaptations and behaviour changes:** Consumers are often unaware of the amount of energy their cooling equipment consumes. This lack of awareness – coupled at times with low electricity prices – gives consumers very little incentive to better manage their cooling use. However, fostering energy-conserving behaviour can decrease energy use without sacrificing comfort, health or productivity. Common methods include nudges for behaviour change, using free cooling through open-window ventilation when outdoor temperature, humidity, and air quality allow, and adopting adaptive thermal comfort practices.[10] People in naturally ventilated buildings generally tolerate a wider range of temperatures, which can be conducive to adaptive thermal comfort practices.

10 The theory of adaptive thermal comfort suggests that human connection to the outdoors and control over the immediate environment allows people to adapt to – and even prefer – a wider range of thermal conditions than is generally considered comfortable.

- **Good operations and maintenance (O&M) and servicing practices:** With proper maintenance and servicing of cooling equipment, as much as a 50 per cent decline in system performance can be avoided (Carvalho, Maranion, and Polonara 2018). This impact could be even greater in developing countries, where poor maintenance practices are common and lead to reduced cooling capacity, greater energy use and refrigerant leakage. Establishing O&M guidelines – including requirements for efficient operations, regular maintenance and better refrigerant management during equipment servicing – not only maintains cooling system performance at design efficiency levels, but also reduces the environmental impact associated with the release of these refrigerants into the atmosphere .
- **Capacity-building in the service sector:** Closely related to good O&M practices is the need to build capacity in the service sector, to ensure a skilled workforce for appropriate equipment installation, maintenance and proper refrigerant management practices.

The combination of strategies that ***reduce heat at the urban scale, reduce cooling needs in buildings and serve cooling needs in buildings efficiently*** creates multiple variables and options to achieve sustainable cooling in cities. City interventions in these three areas underpinning the whole-system approach can directly address right-sizing of cooling demand and optimizing the cooling supply . However, the scope and range of cities' interventions in each of these areas will vary, given the constraints of state or national regulation; this is further explored in chapter 3. To identify the best-fit solution, the underlying question is: what is the optimal cooling solution in a given context – that is, one that achieves the right balance of lowest life-cycle cost and lowest environmental footprint to meet the functional need for thermal comfort.



11 Cities can leverage resources such as the United Kingdom's REAL Zero refrigerant containment programme that offers design and maintenance standards for preventing leaks, as well as training tools. More information can be found at IOR (n.d.).

12 In alignment with the whole-system approach, resources are available to guide cities in their transition towards sustainable urban cooling. One such example is the Global Platform for Sustainable Cities, led by the World Bank, which provides knowledge support to cities that are interested in incorporating cooling options into urban strategy and planning.

2.5 BENEFITS OF HOLISTICALLY ADDRESSING SUSTAINABLE URBAN COOLING

While urban cooling can be addressed in many different ways, an integrated whole-system approach to cooling will leverage synergies, minimize potential unintended consequences and maximize potential benefits. Adopting a whole-system approach to address urban heat islands, enhance the thermal performance of the built environment, scale access to sustainable cooling equipment and optimize the servicing of cooling loads will collectively achieve significant benefits for cities. It will also support several of the United Nations Sustainable Development Goals (SDGs) – for example: SDG 3 on Good Health and Well-being, SDG 7 on Affordable and Clean Energy, SDG 8 on Decent Work and Economic Growth, SDG 10 on Reducing Inequality, DG 11 on Sustainable Cities and Communities and SDG 13 on Climate Action.

Cooler cities support multiple positive impacts on:

- **Health and productivity:** Cooler urban temperatures promote outdoor activity, support social interaction, and enhance quality of life, leading to improved mental health and enhanced productivity. Significant productivity losses can be avoided, in particular, in outdoor work settings and in workplaces requiring manual labour – one study estimates as much as a 4 per cent loss in productivity per degree when temperatures rise above 27°C (Somanathan *et al.* 2018). Human health impacts are far-reaching as well. A study of the District of Columbia in the United States found that raising the average urban surface solar reflectance by 10 per cent and vegetated cover by 10 per cent results in a 7 per cent reduction in mortality during heat events (Kalkstein *et al.* 2013). A similar study extended to three other US cities – Baltimore, Los Angeles and New York – also found a correlation between increasing reflectivity and vegetated cover in urban areas and estimated reductions in mortality resulting from reduced outdoor ambient temperature (Vanos *et al.* 2014).
- **Power systems:** Addressing urban heat can reduce the demand for air conditioning to cool buildings, reducing the overall demand for electricity. An assessment of case studies spanning locations in several countries suggests that for every 1°C drop in urban temperature, the electricity demand for air conditioning could drop by around 3.7 per cent on average (Santamouris 2019).

Strategies for urban heat island mitigation can meaningfully impact the peak electricity loads in cities. The actual load reduction will be a function of the levels of penetration of air conditioning in the city, the specific energy and thermal quality of the building stock, the indoor set-point temperatures and the characteristics of the local electricity network. For instance, for cities with a high penetration of air conditioning, peak load savings of up to 12 per cent have been observed (Santamouris 2019).

In addition, a combination of high-efficiency air conditioners and thermally efficient building envelopes can further reduce power requirements. For example, data suggest that meeting today's space cooling needs with high-efficiency air conditioners in well-insulated buildings – that is, with envelope improvements achievable today that have demonstrated a lower life-cycle cost – could reduce the energy use for space cooling by over 50 per cent and shave off 500 GW of power requirement today (ESMAP 2020b).

- **Environmental benefits:** A significant benefit of sustainable urban cooling is the reduction in emissions, directly tied to a reduction in energy use for space cooling. In addition, urban trees can reduce nearby concentrations of particulate matter (PM2.5) anywhere from 9 per cent to 50 per cent, with the largest effects within 30 metres of the tree (McDonald *et al.* 2016). Appropriate selection of the type of trees is important to achieve these positive benefits. For example, a study of vegetation strips in Delhi and their efficacy in mitigating air pollution showed that certain kinds of trees (broadleaf trees in this case) were more effective in the filtration of air pollutants (Kumar, Jolli and Babu 2019). Temperature and ground-ozone formation are positively correlated, meaning that urban passive cooling solutions that reduce air temperatures also reduce hazardous smog (ESMAP 2020a).
- **Economic benefits:** All of the abovementioned benefits – such as reduced energy use for cooling, reduced air pollution and avoided loss in worker productivity – add up to significant economic benefits, both for populations and for cities. While reliable quantification of the full range of economic benefits is not yet available, several data projections point to enormous benefits, including enhanced GDP for cities and avoiding millions in annual costs for air conditioning. Globally, the estimates for avoided power capacity alone translate to around $345 billion in capital investment that could be avoided today (not including the associated transmission and distribution costs) (ESMAP 2020b), and the avoided global productivity losses by 2030 amount to $2.3 trillion.

Other intangible benefits of sustainable urban cooling, such as enhanced personal comfort and public safety – which further support economic growth and an improved quality of life – cannot be ignored.

Raising public awareness about the benefits of sustainable urban cooling, including efficient cooling equipment, the trade-offs between indoor cooling and outdoor comfort, and reinforcement of sustainable cooling choices, has to be foundational to future efforts to sustainably expand access to cooling without further warming the urban environment.

03 BARRIERS TO SUSTAINABLE URBAN COOLING AND INTERVENTIONS TO ADDRESS THEM

Scaling up sustainable urban cooling practices has thus far been an implementation challenge due to factors broadly similar to those for the energy efficiency sector in general. These underlying market barriers – which are also inter-related and reinforcing – are the primary reason why market demand for sustainable urban cooling practices is limited. This chapter discusses the key barriers that apply across the range of sustainable urban cooling practices, and how through a whole-system approach the range of city interventions can help overcome these barriers.

3.1 BARRIERS TO SUSTAINABLE URBAN COOLING

The key barriers to holistic and sustainable urban cooling practices can be distilled into the following five: 1) lack of awareness, 2) lack of supportive policies and regulation, 3) financial barriers, 4) limited institutional capacities and 5) complexity of the solution set. These are explained as follows.

LACK OF AWARENESS

While rising urban temperatures have started to shake the systemic indifference to the urban heat island phenomenon, general awareness about its causes and inter-relation with urban infrastructure and anthropogenic heat remains low. Thus far, the default market response has largely centred around countering the rising heat with more air conditioning, which in turn not only exacerbates the urban island heat effect but also widens the divide between the cooling "haves" and "have-nots". The general public, government stakeholders, and the design and construction industry are often not sensitized to the need for and benefits of sustainable urban cooling.

Lack of information on sustainable urban cooling practices – including heat-resilient urban design, energy-efficient and thermally efficient buildings, and sustainable cooling equipment and operations – and the available tools to drive change further perpetuates the challenge. The role of education, training and re-skilling is thus exceedingly important, particularly for policymakers and for trade professionals, to ensure that norms and standards, and the everyday practices of architects and planners, are aligned with the technical possibilities and appropriate measures for sustainable urban cooling.

Lack of awareness can also manifest in the form of limited understanding or visibility of the benefits of sustainable urban cooling practices. These benefits are typically hard to attribute and generally not individually visible. For example, a community may perceive the benefits of retrofitting with permeable sidewalks, or switching to refrigerants with low global warming potential, only over a long period of time – if at all. Even where the benefits should be more tangible or direct, such as in the case of energy-efficient buildings and efficient cooling equipment, transparency and verifiability of cost savings can be challenging. Moreover, owners, operators and users of these buildings and cooling infrastructure are often not aware of or not confident in these savings materializing.

In the case of efficient buildings, in particular, the lack of appropriate valuation of a building's energy or thermal performance is common, particularly in developing countries where awareness and institutional frameworks to support building sector interventions are less mature. Therefore, the markets do not recognize, nor are they primed to pay a premium for, a high-performance building, contributing to a lack of demand. Lack of reliable normalized data to validate cost savings and other benefits further reinforces the systemic indifference to sustainable urban cooling practices.

LACK OF SUPPORTIVE POLICIES AND REGULATION

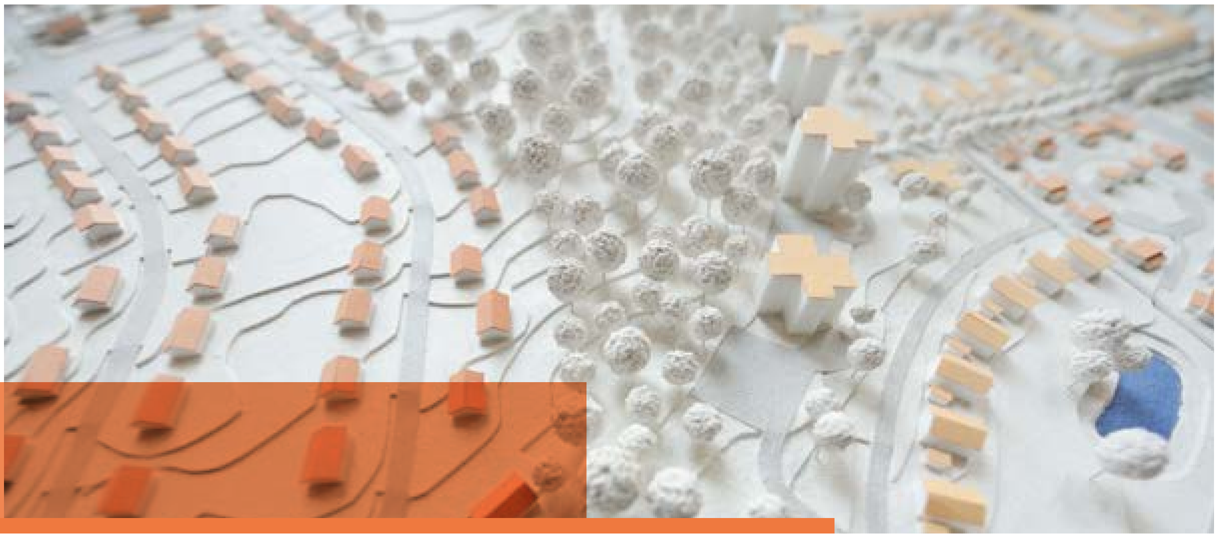
While policies and regulation have helped push the agenda for sustainable cooling in some cities, these pushes have been incremental and mostly atomistic in nature. In many cities, holistic policies and regulation to advance sustainable urban cooling either do not exist, or their implementation suffers due to enforcement challenges. A common factor resulting in an inadequate policy push towards sustainable urban cooling is the lack of clear "ownership" of the responsibility to address cooling. Due to its cross-cutting nature, aspects of urban cooling fall across multiple government departments (such as city planning, housing, public works, transport, parks and recreation, health, etc.), often with inter-related impacts, and this poses complexity in terms of leading a unified policy action on cooling. Sustained inter-departmental collaboration, as well as a champion (or nodal entity), is essential to drive unified action.

The absence of demand signals – fuelled by a lack of awareness – in combination with minimal or no policy push, presents no impetus to the market/industry for accelerating the adoption of good practices and innovation in sustainable urban cooling. Therefore, a supportive policy and regulatory environment, including government leadership by example, becomes a critical enabler of the right ecosystem to scale up access to sustainable urban cooling practices.

The range of potential policy actions can be categorized broadly as control (regulatory) or facilitative. The regulatory policies may include legislation, regulation, guidelines, standards and procedures that, working within the framework of national or statewide policies, city governments can establish to drive the implementation of urban cooling strategies. For example, while the establishment of some policy options, such as minimum energy performance standards for cooling equipment, is typically outside of municipal control, cities can adopt procurement guidelines and, in some cases, more stringent building energy codes that will create a pull for higher-efficiency cooling products. Other examples include heat-sensitive urban design requirements, zoning statutes for land use and transport, transport initiatives that reduce reliance on car travel, municipal procurement specifications, stand-alone ordinances for building energy performance and similar mechanisms. Cities should consider how mandates will be monitored and enforced once adopted.

Facilitative policies may include measures for enhancing information and awareness among the public and other stakeholders about urban heat mitigation, as well as financial instruments for encouraging the adoption of sustainable urban cooling solutions, such as subsidies and incentives for energy-efficient buildings and efficient cooling technologies. (The latter are discussed in more detail under "Financial barriers".) Generally, regulatory and facilitative policies applied in parallel will maximize benefits through complementary effects. Cities should assess the right mix of policies and programmes that would best suit their unique context for accelerating the transition to sustainable urban cooling.

Cities should also examine their existing policy landscape to ensure that there are not any misaligned policies that could inadvertently hinder the adoption of energy efficiency and sustainable urban cooling practices. A common example is the procurement policies typically followed by city governments that favour lowest first-cost procurement or prohibit third-party ownership ("as-a-service") business models. This does not allow room to consider the high-efficiency alternatives that, although not the lowest first-cost, have lower life-cycle costs as well as other co-benefits.



FINANCIAL BARRIERS

Financial barriers apply across the breadth of the stakeholder groups – from consumers to implementers. These barriers are rooted in, as well as perpetuate, underlying market behaviours, which include:

- **First-cost bias:** An overarching market characteristic that has impacted sustainable cooling practices is that the decisions made by those specifying and procuring infrastructure, buildings and cooling systems are typically made with a focus on the first-cost. This skews decisions away from sustainable cooling options that typically have a higher first-cost but lower life-cycle cost due to lower operating costs. This first-cost bias is further reinforced by insufficient awareness or transparency of the broad benefits of sustainable cooling practices, lack of clarity or understanding of their lower life-cycle costs, or a general lack of awareness of the available options and their applicability. Without awareness of the longer-term benefits of efficiency and sustainable urban cooling options and transparency of the benefits, there is little or no demand.

  The focus on first-cost is more prevalent with infrequent buyers, such as residential consumers, but is often reinforced by policy with professional buyers who may be compelled to procure the lowest first-cost conforming bid. First-cost bias is particularly prevalent in developing countries where affordability is an important consideration and there may be competing priorities for the cash-in-hand. At times, even when there may be awareness that the overall costs are lower over time, the combination of upfront affordability, high discount rates (implicit or stated) and lack of financing drives the buyer to the lowest first-cost option.

- **Split incentives:** Often, the developers (or purchasers, in the case of cooling equipment) are not responsible for the long-term use and associated energy bills of a building or development. They therefore are rarely motivated, unless specifically incentivized, to pursue passive cooling measures in buildings or energy efficiency in cooling equipment – options that typically come at a higher first-cost. This further reinforces the first-cost bias in the sustainable cooling sector.

Lack of financial resources can pose a challenge for municipal government initiatives towards sustainable cooling. Also, a lack of fit-for-purpose financing can hinder developers, facility owners and consumers from opting for the usually higher first-cost energy-efficient buildings or sustainable cooling equipment (further reinforcing the first-cost bias).

Fit-for-purpose financing refers to financing structured to meet the specific market needs for affordable financing of sustainable cooling interventions. These market needs can include a need to enhance credit risk through securitization, address performance risk in relation to the realization of savings, provide appropriate accounting characterization of the financing, and mitigate split incentives by matching the flow of benefits with the obligation of loan repayment. Cities can enable public and private adoption of sustainable urban cooling practices at the level of the building and for equipment, but it is often much more challenging to do the same with city-scale or public infrastructure, where the benefits are diffused and dispersed. That is, public investment (in green spaces or cool pavement, for example) yields downstream benefits (for building occupants or the healthcare system, for example) that can be incredibly challenging to trace or design financing mechanisms around.

Future efforts to recognize and quantify the full economic benefits of sustainable urban cooling interventions – including both energy-related as well as non-energy benefits, such as improved human health and productivity, climate-resilient assets and more-resilient grid infrastructure – would be important for alleviating some of the uncertainty around performance and credit risks associated with these solutions. Such quantification will enable meaningful cost-benefit assessments informing budget decisions, support cities' creditworthiness[13] and increase the range of available financing options.

LIMITED INSTITUTIONAL CAPACITIES

Even where policies exist, they may face implementation and enforcement challenges due to inadequate institutional capacities and skills. The effectiveness of policy – with respect to mandatory actions and requirements in particular – will depend on the capacity and ability of authorities to enforce them (the enforcement of building codes, for example). Training and capacity-building for city authorities and critical institutions should be supplemented with effective monitoring and evaluation systems. Parallel measures to encourage technical capacity within trade institutions, such as the construction industry and the heating, ventilation and air conditioning (HVAC) service sector are also important for the appropriate delivery of sustainable cooling solutions.

For example, cities may work with industry players to provide technical training, or establish public procurement policies that require engaging the services only of trained and certified service technicians.

COMPLEXITY OF THE SOLUTION SET

Diverse strategies to address urban cooling – for example, urban planning strategies, nature-based solutions, passive cooling, simple appliances, complex cooling systems, and smart controls and automation – and their interplay add significant complexity in selecting the best-fit cooling strategies. These strategies apply at different scales – from an individual room or building all the way up to a district or city – and their implementation can range from individual decisions to municipal models. City officials (or their consultants) and consumers may lack knowledge of the appropriate applicability of the range of available solutions, and, as a result, their decision-making is limited to what they know and often defaults to the lowest first-cost.

13 Credit rating agencies are now beginning to include municipal climate adaptation and mitigation programmes and climate risk in their credit analysis methodology. Moody's Investment Services acquired Four Twenty Seven in July 2019, a leading provider of data, intelligence and analysis related to physical climate risks, and issued this statement: "The addition of Four Twenty Seven enhances Moody's growing portfolio of risk assessment capabilities and underscores its work to advance global standards for assessing environmental and climate risk factors. Four Twenty Seven will also strengthen Moody's growing thought leadership and research on incorporating climate risk into economic modeling and credit ratings."

3.2 KEY INTERVENTION PATHWAYS FOR SUSTAINABLE URBAN COOLING

More often than not, a combination of barriers will be at play in any city, with inter-related effects. Thus, addressing the cooling challenges in cities effectively requires a multipronged approach – one that combines policies and regulations that spur demand for sustainable urban cooling with financial instruments, awareness-building and capacity-building that facilitate the supply for addressing the demand. Furthermore, the city's response should be rooted in the whole-system approach and tailored to local realities.

Typically, the city interventions to advance sustainable urban cooling would fall within three broad categories, described as follows:

- **Control strategies:** By leveraging the authority of city governments – such as decisions on urban planning and infrastructure investments – interventions in this category are designed to directly control and steer actions that lead to sustainable urban cooling. Typical interventions include city-wide legislation, regulation, planning and standards.
- **Combination strategies:** Combination strategies, in the context of this report, are interventions where cities may not have full and direct control but can apply partial or modified control, and these generally also include a facilitative or influencing aspect. One such intervention is cities leading by example through beyond-code efficiency mandates for city-occupied buildings. This is considered a combination strategy because it applies not just to the city-owned portfolio but also to city-leased buildings (through procuring and directing to these efficiency levels for the leased buildings). This intervention also intends to demonstrate benefits and may in turn influence broader market confidence and adoption of more efficient buildings and cooling practices.
- **Facilitative strategies:** Facilitative strategies enable cities to influence or facilitate actions towards sustainable urban cooling, such as through raising mass awareness, helping develop financial instruments to spur demand, and helping build capacity to meet demand. These strategies help amplify the impact of control and combination measures, and help re-enforce the actions generally regulated at the national or state level (such as product labelling or minimum performance standards for cooling equipment).

These intervention strategies apply across the three areas underpinning the whole-system approach – **reduce heat at the urban scale, reduce cooling needs in buildings and serve cooling needs in buildings efficiently**. However, the scope and range of interventions that are available to cities within each of the areas will vary, given the constraints of state or national regulation (see figure 3.1).

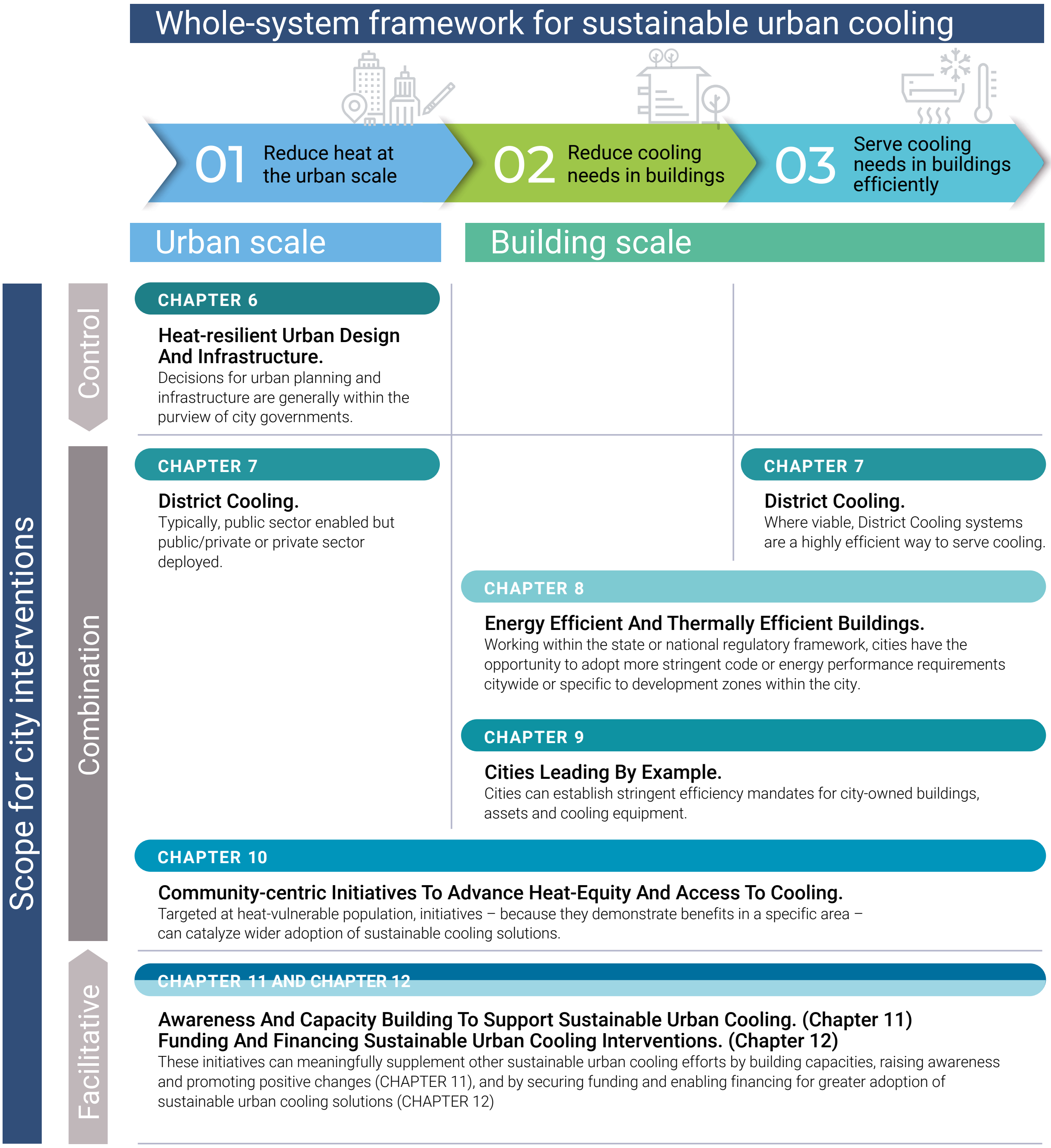
Many of the interventions in the *"reduce heat at the urban scale"* category are "control" strategies, because decisions for urban planning and infrastructure – such as zoning statutes, urban planning regulations for mitigating heat islands, transport planning and mandates for green cover – are generally within the purview of city governments. This category also includes "combination" measures, with a key example being district cooling systems, which are typically public sector enabled but public/private or private sector deployed.

In the *"reduce cooling needs in buildings"* category, the interventions are generally "combination" strategies. For instance, while working within the state or national regulatory framework, cities can adopt and enforce (implying modified control) building energy codes and disclosure ordinances and evaluate the opportunity to adopt more stringent requirements (referred to as beyond code or stretch code) city-wide or specific to development zones within the city.

Much in the category of *"serve cooling needs in buildings efficiently"* – other than enabling district cooling systems where viable – lies outside of the direct control of cities and generally is regulated at the national or state level (such as energy performance standards for cooling appliances). Therefore, interventions in this category are largely around influencing change through "facilitative" strategies.

Figure 3.1 maps the three city intervention categories, as well as the specific interventions discussed in this report, with respect to the whole-system framework. This figure also serves as a summary of the scale and scope of the interventions discussed in chapters 6 through 12 of this report.

Figure 3.1 Scope and range of city interventions for advancing sustainable urban cooling across the whole-system framework



Source: RMI

3.3 CONCLUDING NOTE

Collectively, a context-appropriate mix of control, facilitative and combination strategies provides cities with a range of interventions that play an important role in mitigating the underlying barriers and promoting positive actions to accelerate cities' transition to sustainable urban cooling. The integrative effects of interventions working in combination will be greater than those of individual interventions. Cities can maximize the potential benefits and positive impacts by holistically planning and implementing the interventions across the whole-system framework – that is, a multi-pronged approach to reduce heat at the urban scale, reduce cooling needs in buildings and serve cooling needs in buildings efficiently – to best leverage the synergies and integrative effects.

Cities can maximize the potential benefits and positive impacts by holistically planning and implementing the interventions across the whole-system framework – that is, a multi-pronged approach to *reduce heat at the urban scale, reduce cooling needs in buildings and serve cooling needs in buildings efficiently* – to best leverage the synergies and integrative effects.

04 GUIDELINES FOR CITIES FOR DEVELOPING A COOLING ACTION PLAN

This chapter presents guidelines for cities to support the development of a cooling action plan for integrative action. Each city will have its unique context – such as environmental attributes, climate, state and national requirements, and pace of development, etc. – as well as priorities. As such, the suggested guidelines are not meant to be prescriptive but represent a logical sequence of activities that will generally apply towards whole-system planning for sustainable urban cooling.

This chapter also presents a framework for cities to prioritize and organize the various interventions – which a holistic cooling action plan would identify – to advance action on sustainable urban cooling. While multiple factors will be at play in any given city, and the interventions will have to be tailored to local needs, contexts, and priorities, the framework presents a way to synergistically sequence the interventions along a range of possible trigger points that a city could experience.

4.1 GUIDELINES FOR DEVELOPING A CITY-WIDE COOLING ACTION PLAN

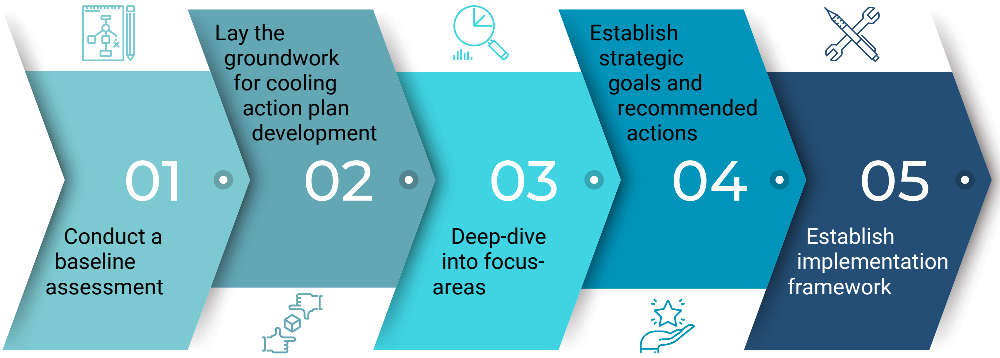
The suggested guidelines present an overarching process for cities to develop a cooling action plan. The process allows for discretion and flexibility to adapt to cities' unique context and needs – characterized by priorities, existing conditions, the availability and quality of data, and the availability of financial and human resources. At the same time, it provides a consistent framework for guiding the development of a cohesive cooling action plan.

Cities should keep in view several foundational principles as essential to the development of a holistic cooling action plan:

- **Adopting a whole-system approach:** The cooling action plan should adopt a multi-pronged approach to address urban cooling across all areas – that is, reduce heat at the urban scale, reduce cooling needs in buildings and serve *cooling needs in buildings* efficiently to benefit from integrative effects and maximize the potential benefits.
- **Multi-stakeholder and collaborative development right from the start:** The development process should actively engage a broad set of stakeholders, representing not just the municipal departments but also non-governmental stakeholders – such as academia, utilities and local businesses – that will be key contributors not only in the development of the action plan but also in the subsequent operationalization of it. Broad stakeholder involve-ment ensures buy-in and therefore supports the plan's implementation.
- **Appointing a cooling "champion" early on:** Identifying or appointing a champion early on is an effective strategy to build and channel the momentum towards sustainable urban cooling, including guiding the development of a holistic cooling action plan. As an example, the cities of Miami (Florida, United States) and Athens (Greece) have responded to the growing concerns about urban heat by recently appointing a "Chief Heat Officer" in their respective cities. This is a first-of-its-kind position, both in the United States and in Europe, created to address urban heat islands, proactively prepare for deadly heatwaves and explore new ways to cool cities down (Towey 2021).
- **Integrative and synergistic solutions:** The strategic direction and priorities of the cooling action plan should be established while keeping in perspective the inter-linkages and synergies between the various aspects of cooling. The other aspect of a synergistic approach is ensuring synergies and aligning city actions with climate agendas, including national and state-wide, and ongoing local initiatives. This brings integrative benefits and also strengthens the buy-in and support for implementation of the plan.

The process for developing a holistic, city-wide cooling action plan consists of five sequential stages, as discussed below.

Figure 4.1 City cooling action plan development process



Source: RMI

01 Conduct a baseline assessment

A baseline assessment essentially implies a "cooling due-diligence" for the city, mapping the overall context around urban heat, assessing the current and future need for cooling, assessing the impacts of business-as-usual growth in cooling, and identifying the key variables and stakeholders that intersect with cooling. Such an assessment serves as the essential starting point towards holistic planning and development of a city-wide cooling action plan.

An understanding of the city's baseline – including the existing urban heat island effect impacts and existing equity issues – and estimation of the cooling demand and future outlook together provide a view into the impacts of business-as-usual approaches to cooling. They also serve as an informed basis for cities to plan and prioritize actions towards neutralizing these impacts through sustainable cooling approaches. Chapter 5 discusses the baseline assessment in detail, explaining its objectives and key elements.

A baseline assessment will help create awareness about the cooling challenges specific to the city, which is a key step towards garnering support and catalysing alignment among multiple stakeholders. It also highlights the broader context of national or regional initiatives focused on climate action or cooling, and the relevant policy and regulatory framework, which is an important road map for aligning city actions. The baseline assessment ultimately provides a holistic view of urban cooling – and the related challenges – and points to priority areas that the city should further explore for a transition towards sustainable and equitable urban cooling.

02 Lay the groundwork for cooling action plan development

Developing a comprehensive cooling action plan is an involved process. This step covers the key aspects of preparation:

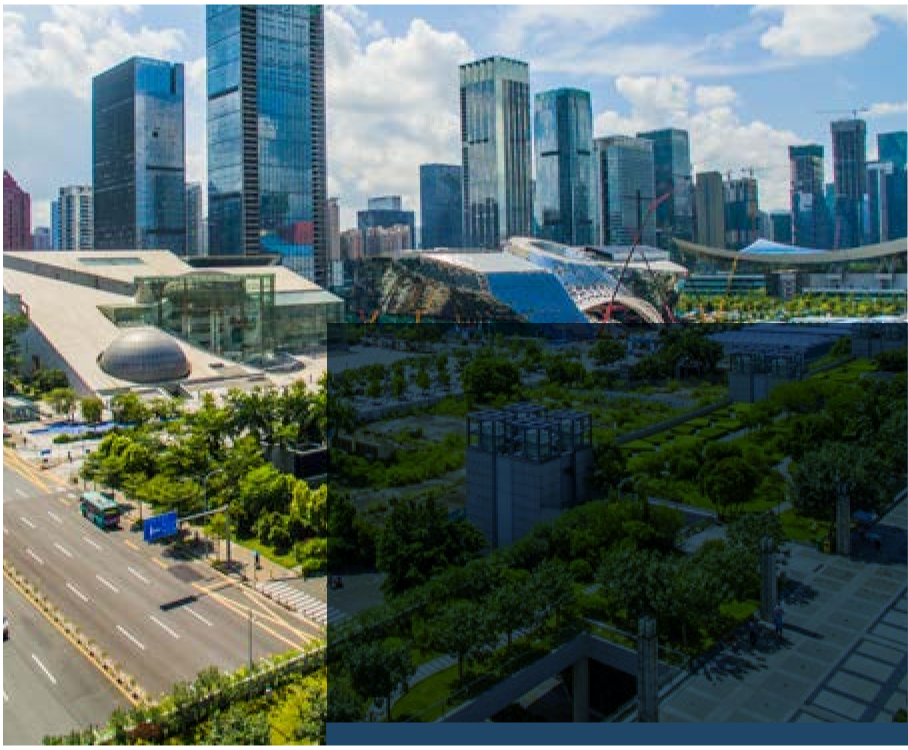
- **Dedicating resources:** To begin with, the city should establish a core team that will have ownership to drive the development process and ensure the continued engagement of relevant stakeholders. In parallel, it is important to facilitate skill development for staff to ensure that the latest insights and technological possibilities are factored into urban planning, design as well as procurement decisions. Once the cooling action plan is developed, ideally, the core team should also be engaged in the implementation and continuous monitoring of the city's progress towards sustainable urban cooling.
- **Ensuring engagement of relevant stakeholders:** A key part of the preparation is ensuring engagement of multiple stakeholders – both governmental and non-governmental – in the development process of the city cooling action plan, such that the plan has broad buy-in for immediate and cohesive action. The core team should engage relevant stakeholders including, for example, multiple city departments (such as city planning, energy and sustainability, housing, public works, transport, parks and recreation, health, etc.), knowledge partners such as academia and civil society organizations, and others such as utilities and local businesses.

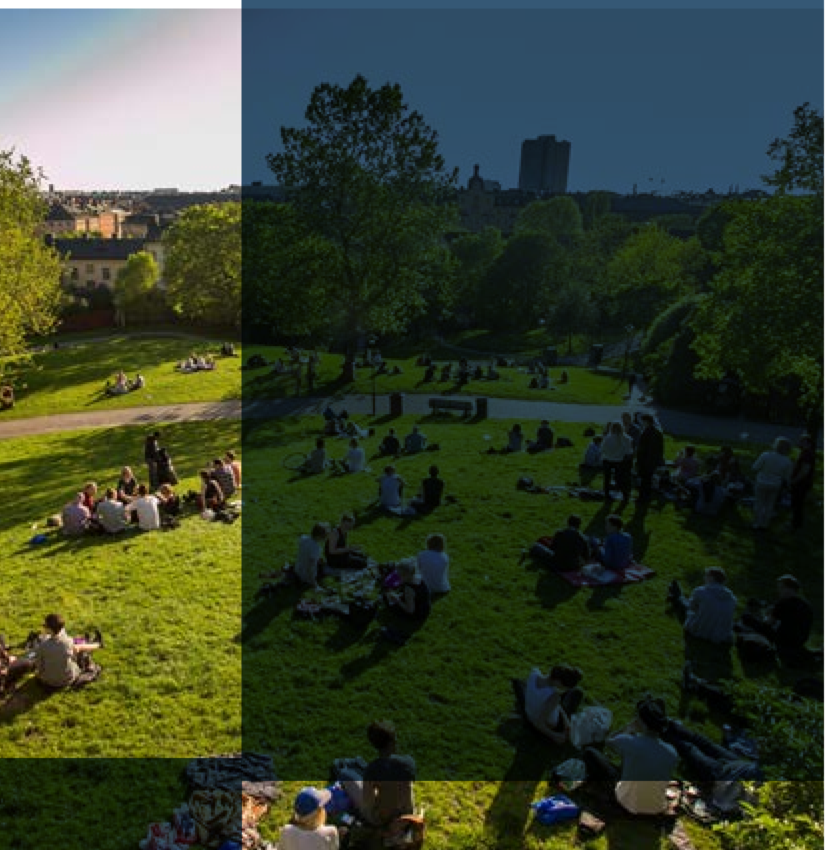
- **Establishing a collaboration framework:** It is important to establish a robust process for collaboration so that the benefits of multi-stakeholder engagement can be effectively leveraged. This includes but is not limited to a dedicated shared platform for knowledge and data related to the cooling action plan, setting a cadence for team meetings, and ensuring integration of stakeholder inputs. Cities may also consider inviting public inputs during certain milestones in the development process.
- **Charting the broad contours of the cooling action plan:** This includes (but is not limited to) identifying the key problems that the cooling action plan is trying to solve, the focus areas for deeper exploration, and the broader context – such as state-wide climate commitments or a national cooling action plan – that the city's cooling action plan should align with. This exercise lends focus to the development of the cooling action plan. Accordingly, appropriate teams – such as task forces or working groups – can be established to conduct a deep dive into specific focus areas.

03 Deep dive into focus areas

Building on the baseline assessment and on the inputs of the stakeholders, this step narrows down to the city's "gaps" and opportunities to sustainably address urban cooling. The deep dive involves qualitative and quantitative analysis of the potential opportunities within specific areas, their relative benefits – to the city population, energy systems and the environment – and the possible synergies from integrative solutions across focus areas. This can be a highly iterative process, assessing possible city actions in terms of the available resources, level of effort and expected impacts. Cities should also explore any available tools or resources to guide this process (some resources are listed at the end of this chapter).

Section 4.2 that follows introduces the preparatory and low cost/no cost actions, collectively termed ‚no-regrets actions' that can be taken across the intervention categories within the whole-system framework. Initiating early and visible action through such an approach helps build support and momentum and can be subsequently integrated into the city cooling action plan once fully developed.





04 Establish strategic goals and recommended actions

The next logical step in development of the cooling action plan is the integration of all inputs into a cohesive outlook for the city, and, based on that, establishing strategic goals and actionable targets – with broad stakeholder buy-in – for the city's transition towards sustainable urban cooling. Some important considerations include:

- Establishing strategic goals and actionable targets with an emphasis on the most vulnerable communities.
- Ensuring that access to cooling in cities is equitable on both social equity and racial grounds.
- Ensuring that the city actions are aligned within the broader framework of a national cooling action plan or a state-level cooling/climate action plan.
- Leveraging integrative effects of strategies across the whole-system framework – that is, a multi-pronged approach to reduce heat at the urban scale, ***reduce cooling needs in buildings and serve cooling needs in buildings efficiently.***

In addition, the cooling action plan should ensure synergies with ongoing city initiatives and agendas. This will garner strong stakeholder support that is critical for effective implementation.

As an outcome of the cooling action plan, once cities establish the strategic priorities and identify a range of actions (interventions) to pursue towards sustainable urban cooling, they will typically be faced with the task of organizing the actions to best balance the immediate priorities with the available resources. The next section of this chapter presents a framework as an illustrative road map for logical prioritization of the various interventions for sustainable urban cooling.

05 Establish implementation pathway

While the creation of a city-wide cooling action plan is a significant step in a city's transition to sustainable urban cooling, the real benefits will manifest from effective implementation of the plan. Thus, the cooling action plan should establish an implementation pathway – with adequate resources and governance structure – such that the goals established in the plan are effectively operationalized.

Key aspects to help manifest the benefits of the plan are:

- **Dedicating resources for implementation:** It is important to identify a champion/owner (such as a "Chief Heat Officer") for driving implementation of the cooling action plan, if not already done early on in the process. Cities should also establish a dedicated team that is responsible for managing and overseeing the implementation of the recommended actions.
- **Tracking compliance and progress:** The implementation team should monitor compliance and track impacts for continuous improvement. Depending on the progress, and also as new solutions or technologies become available, the goals and recommendations of the cooling action plan should be recalibrated as necessary. Cities should consider dedicating a web platform for collectively tracking the energy and non-energy impacts of the interventions. Besides tracking the progress against the city's commitments, this platform can become a powerful resource for guiding the planning and cost-benefit assessment of future actions.
- **Leveraging the power of positive communication:** Effective communication is a crucial part of the plan's implementation. Communicating the successes of sustainable urban cooling initiatives to residents, industry and other cities is a powerful tool for maintaining and even multiplying the momentum and awareness towards sustainable urban cooling. The abovementioned web platform, for example, can be an effective and transparent communication tool with a public interface to present the city's progress and benefits of sustainable urban cooling.[14]

14 One such example is the webpage run by the City of Vancouver: https://vancouver.ca/green-vancouver/greenest-city-projects-map.aspx

4.2 A FRAMEWORK FOR PRIORITIZING AND ORGANIZING CITY INTERVENTIONS TOWARDS SUSTAINABLE URBAN COOLING

The development of a city cooling action plan will typically point to multiple interventions that a city should undertake for urban heat island adaptation and mitigation, along with a shift to more sustainable and equitable cooling solutions. A city's implementation approach for these interventions will vary widely depending on the local context and priorities. While there is no single pathway that will work equally well for every city, the suggested framework serves as an illustrative road map for logical prioritization of the interventions that a city can take towards sustainable urban cooling.

The framework (figure 4.2) charts city interventions across six primary intervention areas (which are presented in detail in chapters 5 through 10 of the report). These are:

CHAPTER 5
- Baseline assessment (that is, stage 1 of the process map for developing a city cooling action plan)

CHAPTER 6
- Heat-resilient urban design and infrastructure

CHAPTER 7
- District cooling

CHAPTER 8
- Energy-efficient and thermally efficient buildings

CHAPTER 9
- Cities leading by example

CHAPTER 10
- Community-centric initiatives for advancing heat equity and access to cooling.

CHAPTER 11

CHAPTER 12

There are three essential steps to the framework. The first two are sequential and generally targeted at specific intervention areas, and the third is a set of cross-cutting facilitative measures (discussed in chapters 11 and 12) that should be applied in parallel with other interventions – depending on a city's context and needs – to enhance their effectiveness.

NO-REGRETS ACTIONS

As a foundational step, cities should undertake preparatory measures that will establish/ensure the authority to act when appropriate trigger points occur (for example, establishing the authority to apply covenants on land to be developed or redeveloped that can apply conditions beyond code). In addition, cities should undertake immediate implementation of low-cost/no-cost interventions – that is, interventions that are cost-effective, relatively simple to implement in terms of requisite dependencies, and have substantial environmental and/or social benefits. These immediate actions can also help mitigate future heat challenges, which can be crucial to avoiding larger future costs, especially in low-capacity urban regions.

While enabling policies may be needed to make these interventions widespread, a city can realize immediate cooling benefits through city-led actions and voluntary efforts. For example, a city government can make all its own roofs cool and offer low-cost cool roof treatments for residents even before enacting cool roof standards. Figure 4.2 lists the recommended no-regrets actions grouped by preparatory measures and the low-cost/no-cost interventions.

Ideally, the no-regrets actions should occur immediately and even prior to stage 1 of the cooling action plan development process (figure 4.1) – *Conducting a baseline assessment* – and if they are not already implemented, then stage 1 should act as a catalyst for driving the no-regrets actions.

CITY INTERVENTIONS CATALYSED BY TRIGGER POINTS

Stage 4 of the cooling action plan development process – *Establish strategic goals and recommended actions* – will identify multiple interventions suited to a specific city's transition towards sustainable urban cooling. While cities may choose to pursue these interventions at any time, depending on the local needs, there are certain trigger points whose occurrence offers synergistic implementation opportunities for specific interventions. These trigger points are a logical catalyst for dovetailing specific urban cooling interventions, as presented in figure 4.2.

Typically, a city will see trigger points falling within the following five broad categories:

1. **Planned new development and/or major re-development:** This category includes greenfield or brownfield development, new construction, re-development and major renovation projects. These events offer opportunities for integrating measures such as (but not limited to) designing the urban environment to ensure a network of cool corridors, adopting building codes and exploring the viability of district cooling to serve the cooling demand.

2. **Introducing or initiating city planning processes:** This category includes a city's planning initiatives in response to climate commitments – such as the development of a climate action plan or pathway to net zero energy – and in response to urban requirements, such as a master plan, transit plan, energy mapping, etc. Such planning initiatives are an excellent opportunity to conduct a baseline cooling assessment as a foundational step to developing a cohesive and coordinated response to the challenges of urban heat, and embed applicable strategies that are designed with urban heat mitigation, equitable access to cooling and emissions reduction in mind.

3. **Introducing new or updated codes/zoning requirements:** This category includes codes, zoning requirements and by-laws pertaining to urban planning and building construction activity. This trigger point presents an opportunity to incorporate high-impact, low-cost, beyond-code requirements (or by-laws), such as for cool roofs.

4. **Evaluating or initiating major city infrastructure projects:** This category pertains to projects such as city transit, street or utilities construction / re-construction, etc. These projects are an opportunity to incorporate heat-resilient strategies and planning.

5. **Evaluating city land acquisition/sale:** This trigger point is an opportunity to embed appropriate strategies for sustainable urban cooling – for example, setting aside green and blue spaces, or setting aside land that would be suitable for the development of district cooling plants.

CROSS-CUTTING STEP: FACILITATIVE INTERVENTIONS

Facilitative interventions enable cities to influence or facilitate actions towards sustainable urban cooling through policies and programmes that raise awareness, build capacities, secure funding and enable financing solutions. These interventions are typically supplementary in nature and, when implemented in conjunction with other interventions, can enhance their impact and positive benefits.

The requirement for facilitative interventions will vary driven by a city's context, capacities and needs. Figure 4.2 presents the no-regrets facilitative interventions that cities should ensure. It also presents some guidance on the facilitative interventions catalysed by trigger points. These trigger points include the activation of the baseline assessment, development of a cooling action plan or individual intervention strategies.

Figure 4.2 Framework for prioritizing and organizing city action towards sustainable urban cooling

PRIMARY INTERVENTION CATEGORIES

PRIORITIZING	Baseline assessment CHAPTER 5	Heat-resilient urban design and infrastructure CHAPTER 6
FOUNDATIONAL INTERVENTIONS THAT ARE NOT DEPENDENT ON TRIGGER POINTS AND ARE "NO-REGRETS" ACTIONS for any city aspiring to accelerate a transition towards sustainable urban cooling:		
NO-REGRETS ACTIONS – LOW/NO COST INTERVENTIONS: interventions that are relatively low cost and low effort (in terms of requisite dependencies) but have substantial environmental and/or social benefits.		■ Preserve and establish authority/process to set aside land for green and blue spaces. ■ Increase street tree coverage in high-priority areas. ■ Add shading structures in key public areas. ■ Apply cool roofs to all city-owned buildings. ■ Use reflective surfaces in areas that will not cause unintended consequences (*e.g.*, parking lots).
NO-REGRETS ACTIONS – PREPARATORY MEASURES: actions to establish/ensure the authority to act when appropriate trigger points occur	■ Identify city departments that will have a role to play in the baseline assessment. ■ Identify urban heat island equity issues between city communities and vulnerable communities.	■ Establish the authority to expand zoning and planning requirements to include: – minimum area and distribution of green spaces; – increased ventilation and waste heat management; – street trees; – cool and reflective surfaces.

→ GO TO CHAPTER 5

→ GO TO CHAPTER 6

District cooling	Energy-efficient and thermally efficient buildings	Cities leading by example	Community-centric initiatives for heat equity
CHAPTER 7	CHAPTER 8	CHAPTER 9	CHAPTER 10
	■ Introduce policies/ programmes for building energy disclosures.	■ Comply with stringent energy performance requirements for all new leased city buildings. ■ Comply with low-climate-impact performance standards for all new city assets (or during regular maintenance and retrofit cycles).	■ Identify and make available cooled spaces that are accessible to heat-vulnerable communities in the event of heatwaves. ■ Establish a heat alert system as a basic measure to alert the public for anticipated periods of heat. ■ Implement cool roof programmes for heat-vulnerable communities.
■ Establish the authority to apply positive covenants applicable to district cooling connection on land to be developed/re-developed. ■ Establish procedures to trigger evaluation of district cooling opportunity when cooling systems within large public facilities approach their end of life and replacements are being planned.	■ Establish the authority to apply covenants on land to be developed or re-developed that can apply conditions beyond code.	■ Assess opportunities for transitioning to more sustainable cooling approaches in city assets. ■ Establish procurement specifications, as well as contracting practices, that promote sustainable urban cooling by integrating life-cycle analysis and sustainable cooling considerations into regular maintenance, replacement schedules, and capital budgets for municipally controlled buildings and assets. ■ Establish beyond energy code (or stretch code) requirements for new city buildings or buildings planned for major renovation. Also establish stringent energy performance requirements (beyond code) for all new leased city buildings.	■ Identify vulnerable communities that have no local access to public cooling infrastructure and develop plans to make access available.

→ GO TO CHAPTER 7 → GO TO CHAPTER 8 → GO TO CHAPTER 9 → GO TO CHAPTER 10

Figure 4.2 Framework for prioritizing and organizing city action towards sustainable urban cooling

PRIMARY INTERVENTION CATEGORIES

PRIORITIZING

CITY INTERVENTIONS TOWARDS SUSTAINABLE URBAN COOLING THAT ARE CATALYSED BY RESPECTIVE TRIGGER POINTS (1 THROUGH 5):

	Baseline assessment CHAPTER 5	Heat-resilient urban design and infrastructure CHAPTER 6
#1 TRIGGER POINT 1 **Planned new development and/ or major re-development.** Includes greenfield or brownfield development, new construction, re-development and major renovation projects.	■ Ensure that mapping of future cooling demand is undertaken in conjunction with mapping of energy demand.	■ Prioritize mixed-use / transit-oriented development. ■ Ensure consideration of shade and ventilation in the urban form. ■ Set aside green and blue spaces. ■ Ensure a network of cool corridors.
#2 TRIGGER POINT 2 **Introducing or initiating city planning processes.** Includes city initiatives such as the development of climate action plan, pathway to net zero energy, master plan, transit plan, energy mapping, etc.	■ Conduct a baseline assessment as a foundational step to developing a cohesive and coordinated response to the challenges of urban heat. ■ Embed strategies that are designed with urban heat mitigation, equitable access to cooling, and emissions reduction in mind.	■ Prioritize mixed-use / transit-oriented development. ■ Set aside green and blue spaces. ■ Incorporate shading and ventilation in the urban form as part of the city master plan.
#3 TRIGGER POINT 3 **Evaluating or initiating major city infrastructure projects.** Includes codes, zoning requirements or by-laws pertaining to urban planning and building construction activity.		■ Incorporate high-impact beyond code requirements (or by-laws) such as for cool surfaces. ■ Set aside green and blue spaces.
#4 TRIGGER POINT 4 **Introducing new or updated codes/ zoning requirements.** Includes projects such as city transit, street or utilities construction/re-construction, etc.		■ Evaluate the opportunity to use thermally efficient construction materials. ■ Prioritize mixed-use/transit-oriented development. ■ Evaluate the opportunity to incorporate cool corridors
#5 TRIGGER POINT 5 **Evaluating city land acquisition/sale.**		■ Set aside green and blue spaces.

→ GO TO CHAPTER 5

→ GO TO CHAPTER 6

District cooling CHAPTER 7	Energy-efficient and thermally efficient buildings CHAPTER 8	Cities leading by example CHAPTER 9	Community-centric initiatives for heat equity CHAPTER 10
■ Explore the viability of district cooling to serve the cooling demand. ■ Where viable, apply positive covenants applicable to district cooling connection on land to be developed or re-developed.	■ Adopt building codes – adapted to the natural conditions – and ensure capacities and means to enforce code compliance. ■ Evaluate the opportunity to apply covenants on land to be developed or re-developed that can apply conditions beyond code, including cool surfaces.	■ Mandate stretch code compliance for new city buildings or buildings planned for major renovation.	■ Ensure appropriate prioritization of interventions for vulnerable communities.
■ Integrate mapping of future cooling demand.	■ Evaluate the opportunity to apply covenants on land to be developed or re-developed that can apply conditions beyond code.		■ Integrate the need for urban heat island mitigation and access to cooling for heat-vulnerable communities.
■ Where viable, apply positive covenants applicable to district cooling connection on land to be developed or re-developed.	■ Incorporate high-impact, low-cost, beyond code requirements (or by-laws), such as for cool roofs.	■ Update and enforce requirement for new city buildings to exceed code	
■ Evaluate the opportunity to synergistically integrate chilled water distribution system that would support a planned future district cooling system.			■ Ensure appropriate prioritization of interventions for vulnerable communities.
■ Identify and set aside land that would be suitable for district cooling plant development			

→ GO TO CHAPTER 7 → GO TO CHAPTER 8 → GO TO CHAPTER 9 → GO TO CHAPTER 10

Figure 4.2 Framework for prioritizing and organizing city action towards sustainable urban cooling

	FACILITATIVE INTERVENTIONS THAT CAN BE APPLIED IN PARALLEL WITH OTHER INTERVENTIONS – depending on a city's context and needs – to enhance their effectiveness and scale up a market transition towards sustainable urban cooling:	
Awareness- and capacity-building to support sustainable urban cooling. (Chapter 11) Includes policies/ programmes that raise awareness and build capacities, with partnerships and collaborations as an important underpinning. → GO TO CHAPTER 11	**IMMEDIATE ACTIONS:** ■ Take action for enhancing mass awareness about the urgency of, and benefits of, sustainable urban cooling. Cities can utilize multiple means and scale for such programmes, depending on their existing resources, and potentially expand the scope and reach of the programme in phases. ■ Assess capacities among city authorities and key actors to enforce and implement urban cooling initiatives (ongoing and planned), and accordingly take measures to develop the requisite workforce and technical capacities for appropriate delivery of sustainable cooling solutions.	**CITY INTERVENTIONS CATALYSED BY TRIGGER POINTS:** ■ Interventions in this category are generally supportive of other interventions and therefore may be triggered by those. The completion of the cooling landscape assessment or identification of recommended immediate actions to be undertaken may usually be the first triggers, where building awareness of their multiple benefits will help ensure support for moving forward and will enhance the leadership profile of elected officials. Other trigger points will generally be centred around building supply-side capability and capacity in support of the selected interventions. For instance, the need for capacity-building may be triggered by major policy- or infrastructure-related interventions such as adoption of building energy codes, or development of a district cooling project.
Funding and financing sustainable urban cooling interventions. (Chapter 12) → GO TO CHAPTER 12	**IMMEDIATE ACTIONS:** ■ Undertaking a funding landscape assessment to gain awareness of potential funding sources is a key first step. (Financing is not a revenue source but a debt obligation that will need to be serviced, with returns derived from the underlying investment or from future revenue sources.) Beyond this, with funding and financing being a facilitative intervention, the trigger points will be around the activation of the baseline assessment, cooling action plan or individual intervention strategies.	**CITY INTERVENTIONS CATALYSED BY TRIGGER POINTS:** ■ The starting point for evaluation of funding and financing options is the development of the benefits case for a single, or combination of, interventions – that is, what is the return for a city and its citizens. The return analysis should be undertaken on a whole-systems basis (as opposed to individual investor basis) to ensure that all benefits are captured; including inter-related benefits occurring in combination with other contemplated interventions. ■ Along with the build-out of the benefits of a specific intervention, or combination of interventions, cost should be optimized by leveraging other funded projects and trigger points in order to reduce the incremental first-cost of the planned intervention. ■ Once benefits and cost have been optimized, official development assistance, dedicated climate funds, and national- and state-level funding sources should be screened for fit. This is where the whole-system benefits analysis comes to the fore as, for example, an intervention to expand and restore green space proximate to a waterway may be eligible for funding intended to reduce stormwater run-off, mitigating flooding risk. ■ Review opportunities to leverage the city's tax-raising authority to capture new revenues to fund interventions that can demonstrably benefit, and gain the support of, the city's citizenry.

4.3 STRATEGIC ASSESSMENT OF RECOMMENDATIONS

Even when the interventions are appropriately leveraging the trigger points, there may be a range of possible interventions to choose from. It will be important for the city implementation team to carefully weigh the recommendations such that they best help the city in achieving its goals. This assessment will be influenced by the unique context in each city: for example, for some cities, where limited activity towards sustainable urban cooling has occurred, it may be important to garner some easy and visible wins first in order to build the momentum and catalyse concerted action; whereas for some cities, building on and leveraging the ongoing work will be most effective. That said, the following criteria – ease of implementation and expected benefits/impacts – generally offer a meaningful and widely applicable way to weigh and prioritize the interventions.

Figure 4.3 presents an assessment matrix mapping the various intervention categories discussed in this report along these two criteria:

- **Ease of implementation:** This refers to the level of effort anticipated to implement the recommendation – the lower the level of effort, the greater is the ease of implementation. In determining the level of effort, two underlying factors are considered in the matrix:
    - Requirements for human and financial resources: The matrix looks at the resource intensity in relation to absolute requirements for personnel and financial resources. However, the requirements relative to existing capacities are likely to be greater in cities in developing countries.
    - Complexity due to changes in policy, existing conditions or required pre-conditions: Factors such as policy and regulatory barriers or institutional barriers would pose challenges to implementation. On the other hand, a supportive regulatory environment, strong political will, or synergies with existing government schemes and programmes will support ease of implementation, and therefore reduce effort.

For certain intervention categories, the expected ease of implementation may differ for developing cities versus developed cities, particularly with respect to the complexity factor. Figure 4.2 therefore makes this distinction, presenting the "ease of implementation" assessment separately for developing and developed cities.

- **Expected benefits/impacts:** This criterion considers the extent to which the proposed recommendation will benefit the city in terms of:
    - attributable economic savings or revenue in relation to cost
    - public good / enhancing livability
    - urban heat island effect mitigation potential and
    - greenhouse gas reduction potential.

The expected benefits of interventions are not likely to differ in the case of developing or developed cities, and are presented as such in the matrix.

As mentioned, the actual sequencing of interventions will be influenced by each city's unique context, but the prioritization framework and the assessment matrix serve to support this process by providing a logical basis for organizing and prioritizing interventions.

Ideally, cities should implement interventions sequentially in a way that builds on past actions and paves the way for future measures towards sustainable urban cooling.

RESOURCE EXAMPLES

- **Urban Cooling Toolbox,** C40 Cities Climate Leadership Group and Ramboll, 2021. https://www.c40knowledgehub.org/s/article/Urban-Cooling-Toolbox
- **Urban Heat Planning Toolkit,** facilitated and published by the Western Sydney Regional Organisation of Councils (WSROC), Australia, 2021. https://wsroc.com.au/media-a-resources/reports/send/3-reports/306-wsroc-urban-heat-planning-toolkit
- **Urban Heat and Equity: Experiences from C40's Cool Cities Network,** C40 Cities Climate Leadership Group, 2021. https://www.c40knowledgehub.org/s/article/Urban-Heat-and-Equity-Experiences-from-C40s-Cool-Cities-Network?language=en_US

Figure 4.3 Matrix to support strategic assessment of city interventions for sustainable urban cooling

■ All Cities
■ Developed cities
■ Developing cites

	INTERVENTIONS LEVERAGING THE APPROPRIATE TRIGGER POINTS:		EASE OF IMPLEMENTATION: Requirements for human and/or financial resources	EASE OF IMPLEMENTATION: Complexity due to changes in policy, existing conditions, or required pre-conditions
CHAPTER 5	**City's cooling landscape assessment as the starting point for action**		Medium	NA
CHAPTER 6	**Heat-resilient urban design and infrastructure**	Heat-resilient urban planning	Medium	High
		Cool roofs	Low/Medium	Low/Medium Low
		Expanding green spaces (*e.g.,* parks)	Medium/High Medium	Medium/High Medium
		Street trees	Low/Medium	Low
		Green roofs and walls	Medium/High	Medium Low/Medium
		Reflective streets and pavements	Medium/High	Medium Low/Medium
		Public shading structures	Low	Low/Medium Low
CHAPTER 7	**District cooling**		High	High
CHAPTER 8	**Energy efficient and thermally efficient buildings**	Building energy codes	Medium	Medium High
		Mandatory energy disclosure policies	Low	Low/Medium
CHAPTER 9	**Cities leading by example**		Low/Medium	Low/Medium
CHAPTER 10	**Community-centric initiatives to advance heat-equity & access to cooling**		Medium	Low
CHAPTER 11	**Awareness and capacity building to Support Sustainable Urban Cooling**		Low/Medium Medium	Low Low/Medium
CHAPTER 12	**Funding and Financing Sustainable Urban Cooling Interventions**		Medium	Medium Medium/High

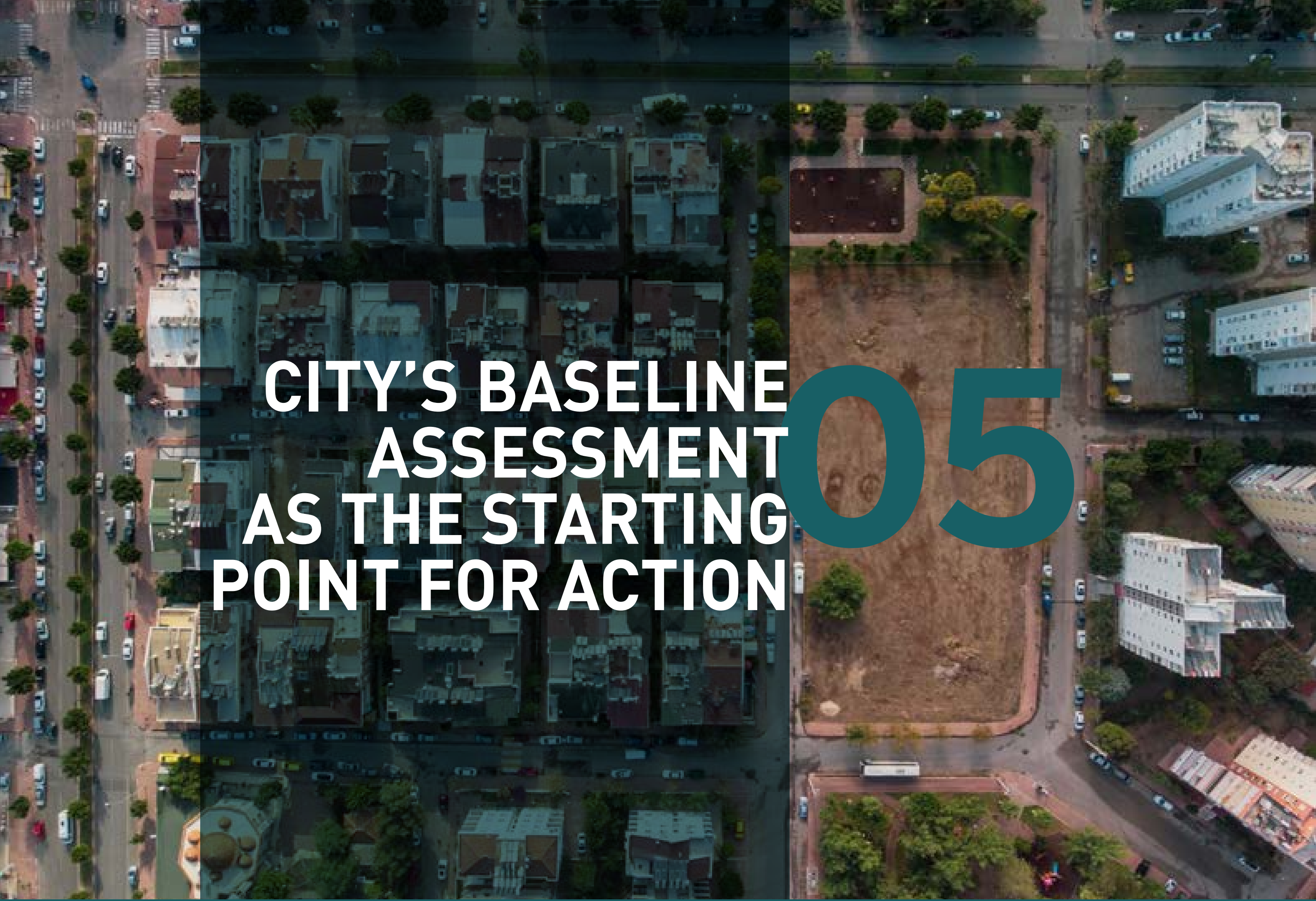
In the context of developing cities, there may be some variance in the ease-of-implementation, indicated in ■ BLUE, because:

- *Some interventions under "heat-resilient urban design and infrastructure" may be more readily deployed when integrated with new development or construction.*
- *Financing and availability of funding, as well as adequate capacities, are likely to be more constrained.*

BENEFITS/ IMPACTS

Attributable economic savings or revenue in relation to cost	Public good/ enhancing livability	UHIE mitigation potential	GHG reduction potential
NA	NA	NA	NA
Medium	High	High	NA
High	Medium	Medium/High	Low/Medium
Low/Medium	High	High	Low/Medium
Low/Medium	High	Medium/High	Low/Medium
Low	Medium	Medium/High	Low/Medium
Low	Medium	Low/Medium	Low
Low	Medium	Low/Medium	Low
High	Medium	High	High
High	Medium	Medium/High	High
Low	Medium	Low/Medium	Low/Medium
High	Medium	Medium/High	Medium/High
Low	High	Low	Low
NA	NA	NA	NA
NA	NA	NA	NA

Source: RMI



CITY'S BASELINE ASSESSMENT AS THE STARTING POINT FOR ACTION 05

While cities have several intervention pathways to advance sustainable urban cooling, conducting a city-wide baseline assessment is the foundational step for holistic planning for sustainable urban cooling and helps prioritize actions. The term "baseline assessment" here implies taking stock of the overall context around urban heat, the need for cooling, including current and future cooling demand and capacities, the impact of business-as-usual growth in cooling, and the key variables and stakeholders involved. A data-backed assessment can catalyse alignment among stakeholders on both a comprehensive plan and prioritized actions, effectively facilitating a pathway to sustainable urban cooling.

5.1 THE OBJECTIVES OF BASELINE ASSESSMENT

The baseline assessment should seek to understand the current and future impact of urban heat and business-as-usual cooling approaches on at-risk populations and the population at large, as well as the impact on energy systems, emissions and the city economy. The assessment should highlight the whole-system impacts of business-as-usual cooling growth and the benefits of addressing it proactively. The intended objectives of the baseline assessment broadly include:

- Establishing the city's current baseline. This includes:
  - Understanding the urban heat island effect currently impacting the city and its primary neighbourhoods.
  - Understanding existing equity issues and vulnerable communities.
  - Understanding the current levels of access to cooling.
  - Understanding the scale and impact of a lack of access to cooling on the city populace (such as on productivity and health) and how this in turn impacts the city's economy.
  - Understanding and quantifying the estimated impacts of cooling on power systems, emissions and the city's economy.
  - Understanding qualitative variables such as the socio-political landscape with respect to cooling, market factors and awareness levels.
- Quantification of projected cooling growth under business-as-usual scenarios and consequent impacts.
  - A starting point for the future outlook of cooling is an understanding of the trajectory of urban heat, which is based on a combination of global warming, growth in city population and city development projections. Cities should incorporate all growth drivers and local factors that will impact cooling demand to ensure that the assessment is forward-looking and comprehensive. The future projections may take the form of a range – such as a "moderate" growth scenario and an "aggressive" growth scenario. These baseline scenarios allow a city to proactively plan towards addressing the future cooling need, both equitably and sustainably.
- Having an informed basis for building the case for change.
  - The cooling demand estimation and future outlook together provide a view into the impacts of business-as-usual approaches to cooling – on energy systems, the environment, the economy and the population – and serve as a quantitative basis for cities to plan and prioritize actions towards sustainable cooling. The data gathered during the assessment help highlight the cost of inaction (business-as-usual approach) to the city and its citizens and help build a case for change.

5.2 KEY FACTORS FOR THE BASELINE ASSESSMENT

To achieve the intended objectives, the baseline assessment should incorporate the following (often inter-related) key factors as an important step towards charting a whole-system approach to sustainable urban cooling.

PHYSICAL AND GEOGRAPHICAL ATTRIBUTES

- **Physical attributes:** Understanding a city's physical attributes – including undeveloped land reserves, water bodies (rivers, oceans, lakes, etc.) and their seasonal temperature ranges, soil conductivity and wind patterns – is important so that cities can leverage these during the urban planning and development process to facilitate cooler urban environments. For example, planning building corridors in alignment with the natural wind direction will facilitate expulsion of heat and pollutants from urban cores – mitigating heat islands – and large water bodies can be evaluated for use as potential urban heat sinks.
- **Climate:** Understanding the climate – that is, the long-term pattern of weather in a particular area – will determine the extent of cooling needed by the population. In addition to common indicators such as temperature and humidity characteristics and seasonal variations, cooling degree days (CDD) are a particularly relevant proxy for the demand for cooling. CDD represents the number of degrees that a day's average temperature is above 18°C; annual CDD is a function of the number of days in a year where the temperature is above 18°C, and the number of degrees above 18°C. A city with an annual CDD of around 3,000 (such as New Delhi, India) will have a substantially greater energy demand for cooling the occupants in buildings as compared to a city with an annual CDD of around 1,000 (such as Milan, Italy).
- **Recent weather events:** In view of increasing global warming, it is important to assess the frequency and patterns of extreme heat events that the city has been experiencing in recent years.

URBAN CHARACTERISTICS

An assessment of various urban attributes will give cities a view into the current propensity for the urban heat island effect, and the opportunities and pathways for making the city cooler. These attributes, often closely inter-related, include (but are not limited to):

- **Heat maps:** Heat maps are key to assessing the urban heat island effect in the city and its primary neighbourhoods. The urban heat island effect is not uniform across a city environment and is generally linked to the population stratification. Many cities show a greater urban heat island effect in impoverished areas and among historically disadvantaged communities versus affluent communities – due mainly to the lack of public investment in green spaces and to the denser, low-quality building stock in these areas. An effective strategy is to leverage technology for identifying hotspots within the city – such as with a combination of satellite data and environment sensors – for enabling early action. To equitably protect its population from extreme heat in the urban environment, it is important for a city to understand both the urban heat island effect situation and the access to cooling across the entire population, and, in particular, to take stock of the heat-stressed vulnerable communities and populations and their challenges with respect to thermal comfort.
- **Percent green cover and distribution of green spaces:** These aspects in the city – inter-related to zoning – suggest the extent and opportunity of natural cooling benefits available to the city populace and will highlight possible equity issues in city neighbourhoods.
- **Urban form:** The shape, size, density and use of buildings – in conjunction with wind patterns and the availability of open green spaces – influence the intensity of the heat island effect in a given area and will highlight possible equity issues in city neighbourhoods.

- **Understanding the city's albedo:** Commonly used materials in urban surfaces – roads, pavements, roofs and walls – have low solar reflectance (albedo). Albedo is an important indicator for understanding urban heat islands. For example, an assessment of the percent of city area that is roof or road, along with the materials commonly in use, would highlight the extent of urban heat trapped within the city and would also help inform the analysis of possible equity issues in city neighbourhoods.
- **City zoning:** Zoning determines a city's make-up, such as the existence and location of heavy industry, whether the city has a growth boundary or not, any set-aside green spaces, and whether the commercial zones are located throughout or only at the core of the city. This gives a view into key aspects such as growth patterns and the propensity for anthropogenic heat.
- **Availability and extent of public transit:** This gives a view into the propensity for transport-related emissions and anthropogenic heat.
- **Energy maps:** Closely related to access to cooling is access to reliable power for the city's population. While typically not a concern in the developed world, this can be a significant concern in cities in developing countries where unreliable grids can cause hours of power outage, and/or the urban poor do not have access to power, and hence to cooling.

BUILDING CHARACTERISTICS

As a subset of the urban attributes, it is important to assess the characteristics of the built environment in order to understand the opportunities for advancing thermal efficiency of the building stock. Ideally this should be done by building typology so that the data are manageable. Key factors to assess are:

- average age of the building stock
- construction practices, such as typical design features and building materials in use
- drivers for energy-efficient buildings (such as policy push), and their market demand.

DEVELOPMENT TRENDS

Ongoing or imminent trends such as immigration into the city, and the natural increase in populations, are important indicators of the anticipated growth in cooling demand and its impacts. Population increase, whether through urbanization or natural growth, generally brings with it associated land-use changes within the city and is directly linked to – and in most cases the single largest driver of – a city's development plans. Other possible trends or triggers for development could include, for example, technology hubs and eco-towns being established within cities to attract new businesses and commerce, and advancement of transport and communication (which creates greater access to the city). A city's development trends – in particular its population growth trajectory – should be factored into any forward-looking plans and strategies for sustainably addressing urban cooling.

POLICY LANDSCAPE – NATIONAL/STATE

It is important to understand any national or state-wide commitments, regulations and policies that intersect with cooling as it relates to thermal comfort, as cities are subject to these. This may include state-wide and/or national mandates covering energy and climate, any policies to promote energy-efficient building practices and low-climate-impact cooling solutions – such as building energy codes, and minimum energy performance standards for cooling equipment. City actions will have to be planned within the framework of, and in alignment with, these broader commitments and mandates.

POLICY LANDSCAPE – LOCAL

- **Understanding the local policy landscape:** This includes policies and mandates that are within the control of the city, such as urban development policies and any relevant local by-laws. Comprehensively mapping the ongoing policies and programmes that intersect with cooling – and their effectiveness thus far – allows alignment of local action with broader regional or national priorities, identifying and leveraging synergies, and identification of policy gaps that should be bridged with city-level action. It is also important to review a broad range of city policies driving other goals, to identify any that may run counter to urban cooling ambitions, such as inadvertently worsening the urban heat island effect.
- **Understanding the city's institutional frameworks and capacities:** It is critical for cities to assess the depth and breadth of the institutional capacities available – and ultimately required – to support the drive for sustainable cooling. Even the best policy measures may not bring intended outcomes because of a lack of adequate capacities for enforcement.

MARKET CONDITIONS

This is a broad category that covers an understanding of both the supply and the demand for sustainable urban cooling solutions. The supply side includes taking stock of the availability of energy-efficient construction materials, appropriately skilled industry professionals and workforce, and low-climate-impact cooling solutions. The demand side includes an understanding of the level of adoption of efficient cooling practices and procurement behaviours (both public and private), as well as an assessment of the underlying factors for the same – such as the level of awareness among stakeholders, and financial or other barriers. The assessment should also take stock of any private sector or civil society-led initiatives towards sustainable cooling, and the opportunities for collaboration between the public and private sectors to facilitate new and innovative business models and solutions. This market understanding is foundational to targeted solutions and interventions that a city can adopt to accelerate the transition to sustainable urban cooling practices.

While the above are a widely applicable set of key factors, the cooling landscape assessment will be specific to each city, tailored to its specific context and focus areas. Even where cities are taking active steps towards sustainable cooling, such an assessment can help identify priorities, align stakeholders for synergistic actions and serve as a planning tool for holistic city-wide action, such that the whole is greater than the sum of the parts. The outcomes of city-wide assessment can also help highlight the expected positive impacts of a city's interventions – as they correlate to any national targets or regional targets – and help catalyse funding and support.

FURTHER RESOURCES

- **Turn Down the Heat project** (ongoing) and **Turn Down the Heat Strategy and Action Plan** (2018), Western Sydney Regional Organisation of Councils (WSROC), Australia. https://wsroc.com.au/projects/project-turn-down-the-heat
- **Climate Action Planning Resource Center,** C40 Cities. https://resourcecentre.c40.org/climate-action-planning-framework-home

RECOMMENDED CITY ACTIONS

05

A macro-level cooling baseline assessment is foundational for any city as a starting point for holistic city-wide action towards sustainable urban cooling. A city can still move ahead immediately with a limited number of "no-regrets" interventions, but to ensure a holistic and integrated response to the urban cooling challenge, this assessment is the first step towards creating awareness, garnering support, catalysing alignment among multiple stakeholders, and highlighting priorities and opportunities for synergistic interventions.

NO-REGRETS ACTIONS

- Establish an understanding of the linkage of urban cooling with existing national or state initiatives such as climate action plans and cooling action plans.
- Identify city departments that will have a role to play in the baseline assessment and subsequent actions, and engage their support.
- Identify equity gaps within the city environment such that the cooling action plan (or other city planning initiatives), when developed, is aligned to the different levels of need.

The above actions are immediate priorities and will serve as building blocks for the cooling baseline assessment. While a baseline assessment can be undertaken by cities at any time as an important foundational step to developing a cohesive cooling action plan, some key trigger points that are a logical point to initiate such assessment are noted below.

CITY INTERVENTIONS CATALYSED BY TRIGGER POINTS

Trigger points		Interventions
1 Planned new development and/or major re-development	2 Introducing or initiating city planning processes	
✓		Ensure that mapping of future cooling demand is undertaken in conjunction with mapping of energy demand.
	✓	Conduct a baseline assessment as a foundational step to developing a cohesive and coordinated response to the challenges of urban heat.
	✓	Identify urban cooling's linkage to, and opportunities for synergies with, ongoing/planned city initiatives and agendas.
	✓	Embed strategies (in city planning initiatives) that are designed with urban heat mitigation, equitable access to cooling and emissions reduction in mind.

CASE STUDY 5.1 | TURN DOWN THE HEAT STRATEGY AND ACTION PLAN – WESTERN SYDNEY, AUSTRALIA

HIGHLIGHTS:

- **Aspects of cooling landscape assessment**
- **Development of a holistic cooling action plan**
- **Collaborative multi-sectoral approach to urban planning**

ADDITIONAL CHARACTERISTICS:

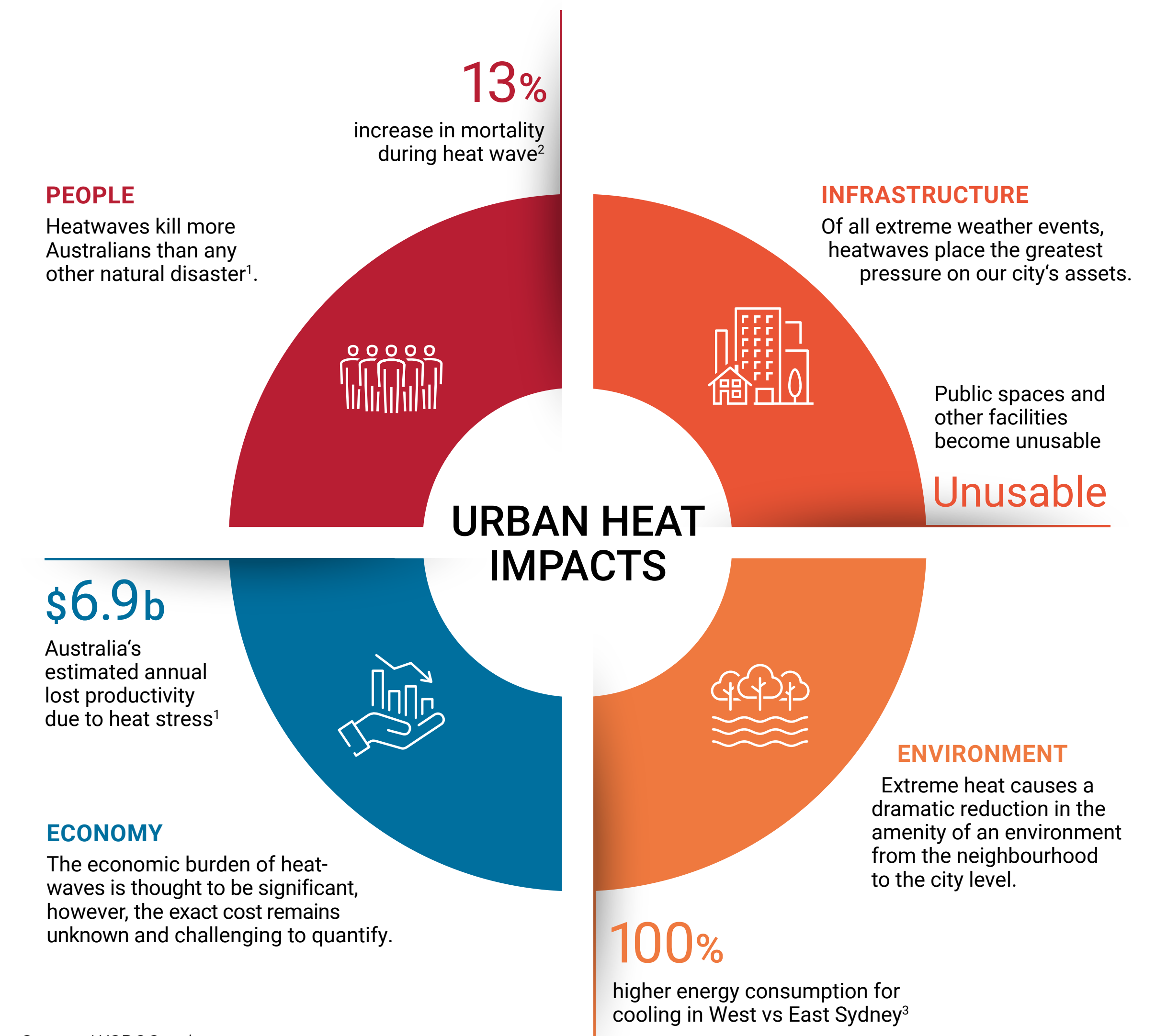
- **City cohorts**
- **Heat-resilient urban design and planning**
- **Thermally efficient built environment**
- **Community engagement**

Western Sydney is a region of the metropolitan area of Greater Sydney, New South Wales, Australia, characterized by a hot climate. This region is getting hotter due to a combination of climate change and rapid urbanization. Rising urban heat is a significant concern and is driven primarily by projected urbanization and by planned changes in land use from grassland and forest to urban infrastructure to accommodate population growth. In response to this, the Western Sydney Regional Organisation of Councils (WSROC) – which represents seven local city councils in the Greater Western Sydney region – undertook the initiative to develop a holistic action plan (Turn Down the Heat Strategy and Action Plan) that aims to increase awareness and facilitate a broader and more coordinated response to the urgent challenges of urban heat in Western Sydney (WSROC n.d.).

The WSROC exemplifies a city's cohort approach where common challenges and objectives are addressed, leveraging the collective resources and strengths of its member cities. One such endeavour, the Action Plan, is a highly collaborative initiative that reflects insight and inputs from stakeholders including local councils, state government, businesses, researchers, developers, infrastructure and critical service providers, as well as health and community service providers. These stakeholders participated in a series of workshops, forums and interviews in 2017, informing the assessment and strategy development. With the support of a multi-stakeholder steering committee, and in partnership with a private consulting organization, WSROC published a comprehensive Turn Down the Heat Strategy and Action Plan in 2018. An in-depth assessment of the cooling landscape was foundational to the development of this comprehensive Strategy and Action Plan and included aspects such as:

- assessment of the current state of urban heat in Western Sydney today;
- the future of urban heat in Western Sydney, highlighting the increasing severity and frequency of heat waves;
- impacts of urban heat on people, infrastructure, the economy and the environment; and
- taking stock of the existing work across Western Sydney to address heat.

Diagram of key urban heat impacts: People, economy, environment and infrastructure



Source: WSROC n.d.

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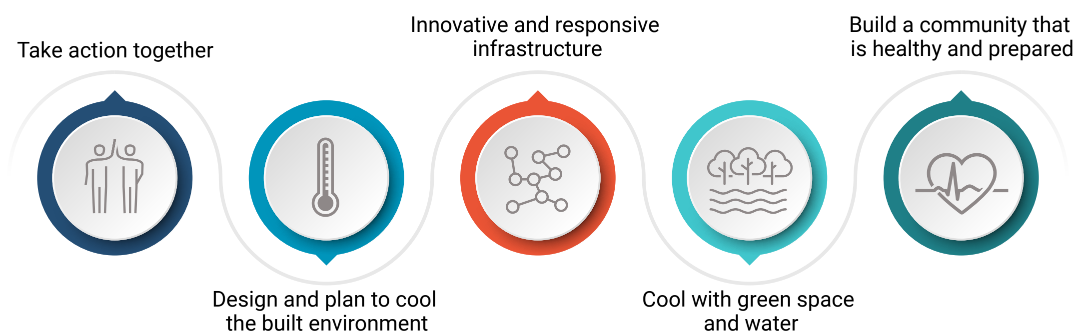
CASE STUDY 5.1
TURN DOWN THE HEAT STRATEGY AND ACTION PLAN – WESTERN SYDNEY, AUSTRALIA

The action plan is organized around the following five strategic drivers that represent the resilience outcomes that can be achieved through implementation of this strategy (WSROC 2018):

- Take action together: Leaders across diverse organizations and institutions at the local, state and federal levels to collaborate to raise awareness and promote action around the issue of urban heat.
- Design and plan to cool the built environment: Changes to regulatory policies and other opportunities to reduce the built environment's contribution to urban heat and influence the planning and design outcomes of hundreds of development projects under way in Western Sydney.
- Innovative and responsive infrastructure: Working towards reliable critical infrastructure that can withstand heatwaves to provide essential services (such as day-to-day transport needs) to all residents and businesses in Western Sydney.
- Cool with green space and water: Leverage Western Sydney's parks, waterways and green spaces to cool existing public and private spaces, expand collective understanding and practice of urban greening and water sensitive urban design, and ensure that future spaces are designed with urban heat in mind.
- Build a community that is healthy and prepared: Support community engagement, education and preparedness, especially for those vulnerable to urban heat.

Five key areas of action identified to address urban heat in Western Sydney, Australia



Source: WSROC 2018

CASE STUDY 5.2 | HANOI CITY MASTER PLAN 2030 – HANOI, VIET NAM

HIGHLIGHTS:

- Planning to protect green space amid growth
- Collaborative multi-sectoral approach to urban planning

ADDITIONAL CHARACTERISTICS:

- Heat-resilient urban design and planning
- Community engagement

Like most cities, Hanoi City, Viet Nam is anticipating rapid population growth and is expected to grow to over 9 million people by 2030. Recognizing that this population growth and resulting city expansion would result in dramatic land-use changes and increased urban temperatures, in 2011 Hanoi City collaborated with leading global architecture and planning firms and involved many agencies, ministries and the public to create the Hanoi City Master Plan 2030. For developed areas, the plan created a defined urban core, an expanded core, five satellite urban areas and three eco-townships/villages. The plan also addressed issues of transport, population distribution, education and health care, a green network of water surfaces, flood plains, mountains, and a green corridor, as well as the preservation of natural space.

The plan established that most of Hanoi – including its remaining natural areas and agricultural land – would be permanently protected from further urban expansion and development (Perkins Eastman n.d.). Additionally, tree-lined streets, river banks and lakes would be preserved, and the density of green trees and water surfaces in the downtown centre would be expanded from the current density of 1-2 square metres per person to 7-15 square metres per person by 2030 (Liou, Nguyen and Ho 2021). These measures are key to protecting the city's green spaces – and their cooling benefits – amid the anticipated rapid growth.

The master plan included an assessment that considered various environmental issues such as soil pollution and water and ecosystem quality. Although it did not assess the effects of development on the urban climate, a later analysis compared the proposed strategies in the master plan for the year 2030 to existing summer conditions (in June 2010) and found that daytime peak air temperature in the master plan condition would remain at about the same level as the current condition for most of the city, despite anticipated population growth from 6.7 million to 9.2 million by 2030. The study did find that some areas with the most planned development would see an increase in peak air temperatures (Kubota, Rijal and Takaguchi 2017). Planned green strategies were projected to cool air temperatures within the green spaces at night.

The Hanoi City Master Plan planning process created a strong relationship between regulatory agencies, and the plan is intended to be flexible to accommodate necessary changes over time.

06 HEAT-RESILIENT URBAN DESIGN AND INFRA-STRUCTURE

Cities have a wide range of physical interventions they can use to promote cooling, ranging from optimizing the shape of the built environment, to changing the composition and colours of streets, sidewalks and other surfaces, to increasing the quantity and quality of green space. While some of these may require policy or regulatory changes (*e.g.*, land use and zoning), significant planning (*e.g.*, new green spaces) or cost premiums (*e.g.*, reflective or permeable surface materials), many are “quick wins” for cities in most climate zones looking to improve heat resilience (*e.g.*, cool roofs or ensuring adequate vegetation).

At the same time, many interventions require trade-offs between cost, speed, indoor and outdoor thermal comfort, and equity (these trade-offs are explored more at the end of this chapter). Understanding the priorities and constraints of communities will help as city planners, developers and local government departments (*e.g.*, public works, parks and recreation) consider their options for urban cooling solutions.

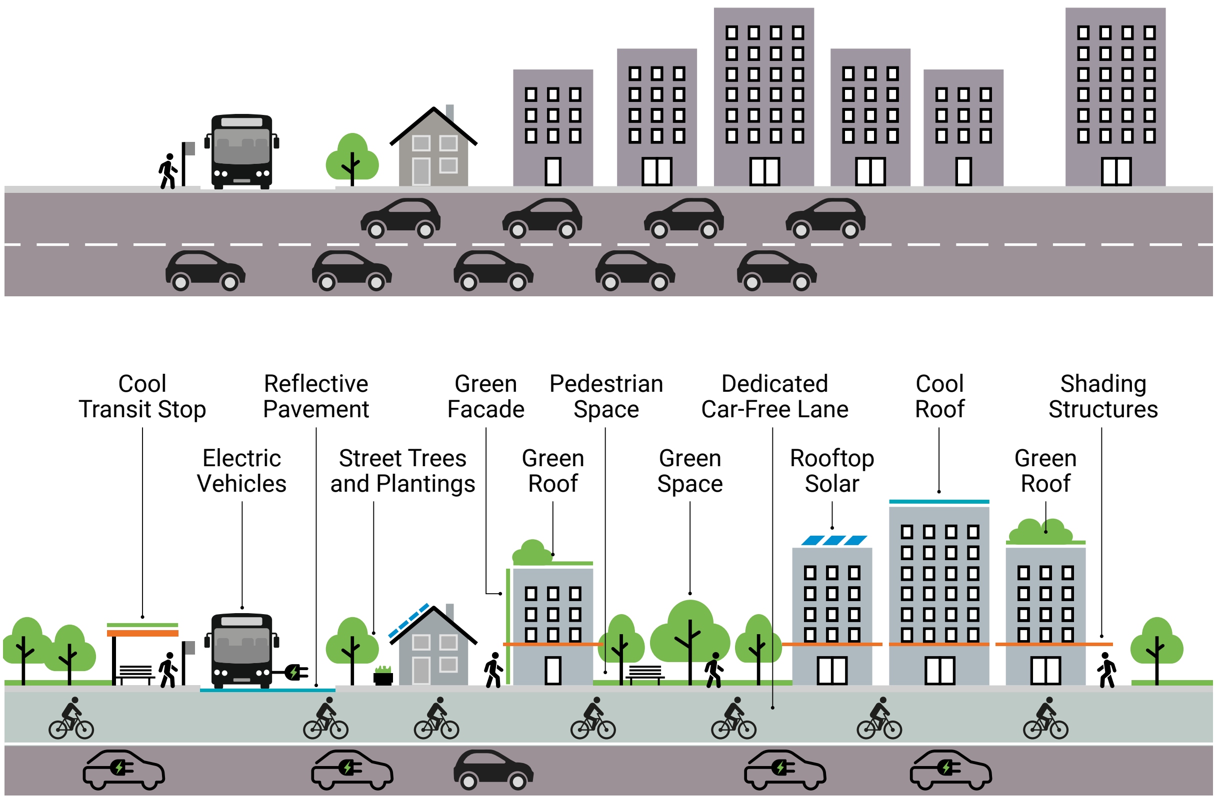
Before exploring interventions, it is important to understand why urban heat islands form and how to prevent and mitigate them. Cities are hotter than surrounding areas because:

- They have a high share of roofs and paved surfaces compared to natural surfaces such as water, grass and trees. The human-made surfaces are usually darker than natural surfaces, so they absorb more sunlight and convert it to heat.
- Anthropogenic sources such as factories, cars and air conditioning produce heat.
- The shape of the built environment (*e.g.*, "urban canyons" of tall buildings) traps heat by reducing air circulation.

To counter these forces and promote cooling, cities can use three main principles (figure 6.1):

- Reduce solar gain, or the amount of sunlight that built surfaces absorb (*e.g.*, with cool roofs that reflect light, green roofs and walls, trees and human-made structures that shade these surfaces).
- Reduce the amount of heat produced in the city (*e.g.*, by shifting transport away from single-occupancy vehicles, making remaining vehicles electric and reducing use of mechanical cooling).
- Dissipate heat (*e.g.*, plan streets and buildings to increase ventilation, ensure sufficient green spaces and plan green spaces to create cool corridors).

Figure 6.1 Conventional (top) versus heat-resilient (bottom) urban areas



Source: RMI

Note: In the figure, the conventional urban area has a high proportion of impervious surfaces and single-occupancy vehicles. By comparison, the heat-resilient urban area has a higher proportion of green space, cool surfaces, alternative modes of transport and electric vehicles.

With these principles in mind, this chapter looks at interventions at the urban scale that contribute significantly to keeping urban areas cooler while inherently reducing the mechanical cooling needs of buildings. (Interventions that apply specifically to buildings are discussed in chapter 8 of this report.) These interventions to keep urban areas cooler are grouped into three categories: urban form and planning, nature-based solutions and cool surfaces.

The interventions described here are highly context-specific. Several recent literature reviews have pointed to the variability in modelled and observed results and remaining knowledge gaps (Wang, Wang and Kaloush 2020). One recent review of modelling showed that increasing the reflectivity of coatings or materials offers approximately the same amount of cooling as increasing tree canopy cover by the same proportion, with much of the variability between studies resulting from modelling choices (Krayenhoff *et al.* 2021). However, different interventions have different co-benefits beyond temperature reduction.

Further work is also needed on reflective pavements and coatings to better understand their life-cycle greenhouse gas emissions, minimize their toxicity and make them more durable (Wang, Wang and Kaloush 2020). What remains clear, however, is that all these interventions do mitigate the urban heat island effect, and many of them increase indoor and outdoor thermal comfort. Details on the magnitude of impact will have to be modelled and tested on a case-by-case basis.

For each intervention, the analysis describes how the intervention is best used and at what points in the urban planning or development process.

Following this discussion of interventions at the planning and infrastructure scales, case studies are presented showing how cities have implemented the interventions.

6.1 URBAN FORM AND PLANNING

Many cities are already dense and highly developed, but urban areas are expected to grow from 4.2 billion people in 2018 to around 6.7 billion people by 2050, forcing the expansion of existing cities and the creation of new ones (United Nations 2018). China alone is planning 3,500 new urban development zones (Li *et al.* 2021). Smart urban density can reduce sprawl-induced land-use change, reduce per capita greenhouse gas emissions and increase opportunities for vulnerable populations – all important for a sustainable future. But when dense cities pack lots of impervious surfaces close together, they increase local temperatures by trapping heat and reducing ventilation (interventions to reduce impervious surfaces are discussed later in this chapter) (Raven *et al.* 2018). In addition to avoiding the production of heat altogether, cities can reduce the effects of the built environment by siting different land uses in ways that avoid creating heat islands, harnessing prevailing winds, and planning neighbourhoods to reduce the need for driving.

The interventions discussed in this section are most relevant for city planners and transport planners, and they are best codified in a city's comprehensive land-use plan (also called a master plan or general plan). Some, such as street orientation, can only be accomplished during new development or major re-development. As a result, much of this section is more relevant to rapidly growing cities. But principles such as building height and setback, transit siting and percentage of natural space can be addressed at critical growth, repair and re-development junctures. Another large-scale intervention that will be useful in many cities is district cooling, which is explored in chapter 7.

DISTRIBUTION OF LAND USES FOR HEAT MITIGATION

The conversion of vegetated landscapes (*e.g.*, forests, scrubland, agricultural fields) to built landscapes will increase heat because of the addition of impervious surfaces, the reduction of transpiration from plants, the reduction of evaporation from the soil, and the production and trapping of waste heat. The shape, size, density and use of buildings influence the intensity of the heat island in a given area. For example, areas with mid-rise buildings with space between them generally have a greater diurnal range (*i.e.*, cool down more at night) than areas with mid-rise buildings close together, because of the difference in building density and land cover. Areas with buildings close together are often hotter than areas with buildings spaced farther apart, and the coolest areas are nearly always those with significant vegetation or bodies of water (Stewart, Oke and Krayenhoff 2014; Geletič, Lehnert and Dobrovolný 2016; Shih 2017).

Areas of heavy industry are often particularly hot, both because they often lack vegetation and because they produce significant waste heat. All energy-consuming activities that take place in a city – driving, air conditioning, industry, data centres and even human metabolism – produce anthropogenic heat emissions, or waste heat. Industrial facilities are a particular contributor because they lose 20-50 per cent of their energy input as waste heat. To improve energy efficiency and reduce urban heat, industrial waste heat can be recovered to fuel additional work or provide hot water resources. The US Department of Energy has technical resources to help manufacturers with waste heat reduction (US DOE 2017). In mixed-use areas, district heating and cooling systems can connect industrial, commercial and residential buildings that have energy, heating and cooling needs at different times (Pless *et al.* 2020; Stone and Jungclaus 2020). This process is sometimes called industrial symbiosis (European Commission 2018). These mixed-use areas can also reduce the impact of waste heat by allowing heat to dissipate. More information about mixed-use areas is below.

Beyond generalizations about some land-use types, conditions in each local climate zone vary based on local factors. How then can cities reduce heat when its sources – impervious surfaces, density – are necessary, and in some cases beneficial? No magic land-use or zoning pattern will always keep cities cool, especially when they are tall and dense – important elements of sustainable urban development in many cities. Instead, heat mitigation measures need to be built into urban planning. These measures go back to the core principles of preventing heat production and dissipating heat (and, to some extent, preventing solar gain).

- **Harness prevailing winds:** Wind speeds in cities are often slower because the urban landscape is "rough" – that is, buildings extend high above the ground and to varying heights. The "building height and street orientation" section below discusses how cities can increase wind speeds by creating ventilation corridors.
- **Maintain or increase the share of green space:** Having relatively more pervious ground surface, vegetation and water (especially in hotter areas, like industrial zones) compared to impervious surfaces reduces temperature locally and throughout the city. Nature-based solutions are discussed later in this chapter.
- **Increase solar reflectance:** Increasing the reflectance of urban surfaces reduces the amount of heat these surfaces emit. Reflective surfaces are discussed later in this chapter.
- **Reduce waste heat:** As discussed above, cities can increase building and industrial efficiency, increase waste heat recovery and reuse, and decrease vehicle miles traveled.
- **Reduce reliance on cars:** Providing opportunities for residents to live, work and play in the same areas can reduce the need for driving. This is discussed more below.

SMART DENSITY, MIXED-USE DEVELOPMENT AND TRANSIT

Internal combustion engine vehicles have transformed humanity – and our cities. Widespread car ownership has led to cities where living, working and recreation spaces are separated from each other. While cars have created many opportunities, they have also created an array of environmental and social problems. From an urban cooling perspective, cities that require residents to drive from one part of the city to another to meet daily needs are creating significant waste heat, from vehicles themselves and from the roads and parking lots they require. Likewise, zoning that restricts certain land uses or limits density misses the opportunities for cooling. (Car-centric cities and exclusionary zoning also contribute to inequity, air pollution and climate change.)

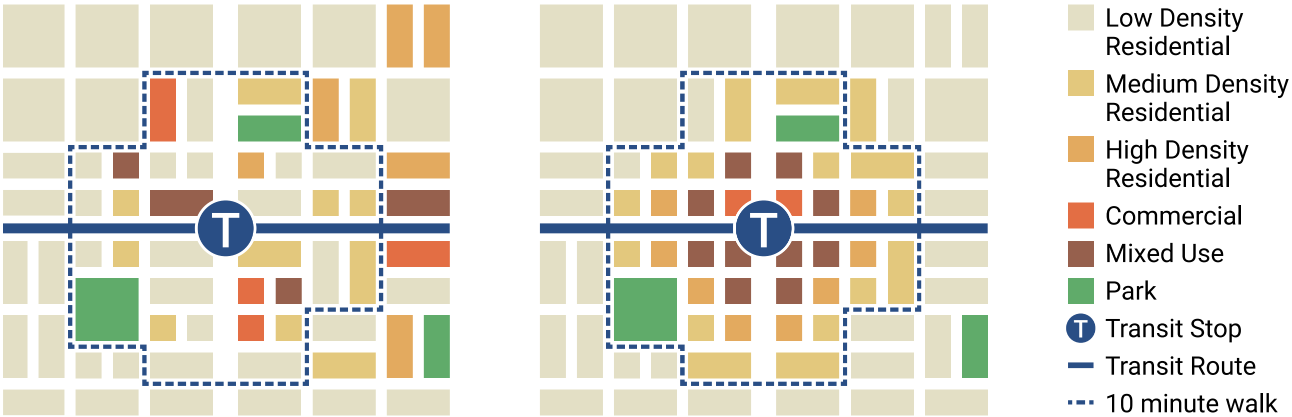
Transport is a major contributor to urban anthropogenic heat emissions – on average, transport accounts for around 30-45 per cent of anthropogenic heat in major US cities, depending on the time of year (Sailor *et al.* 2015). Gasoline-powered cars lose over 70 per cent of their energy as waste heat, and even electric vehicles lose up to 30 per cent. A study in Singapore showed that morning rush hour traffic can increase local air temperature up to 1.1°C. While replacing all vehicles with electric vehicles could reduce this impact by 0.5-0.9°C in a few small areas, in most of the city the reduction would only be up to 0.2°C (Singh, Acero and Martilli 2020).

While vehicle electrification is important, simply replacing conventional personal vehicles with electric ones will not solve all the challenges of car-centric design. We have built our cities around vehicles in ways that make us sicker and hotter and force us to travel longer and farther for everyday needs. Instead, we can remake our cities as places where 1) all residents can easily meet their needs instead of being forced to rely on motorized travel, and 2) alternative modes of transport (*e.g.*, walking, biking, micro-mobility, using wheelchairs or other mobility aids and public transit) can easily replace driving.

In the "fifteen-minute city", everyday needs are clustered throughout the city, within a 15-minute walk (about 1.2 kilometres) for all residents, with nearly all needs within a 15-minute bike ride (about 4.8 kilometres) (Duany and Steuteville 2021). (Walking and biking are often the focus of the fifteen-minute city, and the approach is more equitable than one reliant on motor vehicle ownership. However, it is important to recognize that neighbourhood services also need to be accessible to those with limited mobility and/or those using alternative modes of transport.) But even in a fifteen-minute city, with less need for personal vehicles, transport services are critical to enable movement into and out of the city and between neighbourhoods, and to support residents with limited mobility.

Transit-oriented development is likewise focused on creating mixed-use communities that reduce the need for driving and facilitate alternative modes of transport. In transit-oriented development, each community is built around a high-speed transit station, such as a train, subway or light rail (figure 6.2) (Transit Oriented Development Institute n.d.). Further, in order for these communities to be successful, their land-use policies must allow for critical destinations (*e.g.*, grocery stores, health care, education and employment) in close proximity to homes.

Figure 6.2 In transit-oriented development, the areas around transit stops are dense and mixed-use



Non-Transit Oriented Development
Land uses not organized around transit

Transit Oriented Development
Land uses organized around transit

Source: Seattle Planning Commission 2013

Paris' take on the "quarter-hour city" reimagines schoolyards as the "capital of the district", providing recreational, sports and cultural opportunities for the whole community, not just schoolchildren. The city plans to increase the number of participating schools from 12 to 51 by the end of 2021. At the same time, the city is undertaking a complementary effort to renovate schoolyards to act as cool oases, with more vegetation, water retention and shading (City of Paris 2020; City of Paris 2021a; City of Paris 2021b). Together, these efforts show how cities can leverage small but common spaces to reduce the need for travel and promote heat resilience.

An "oasis" schoolyard in Paris, France

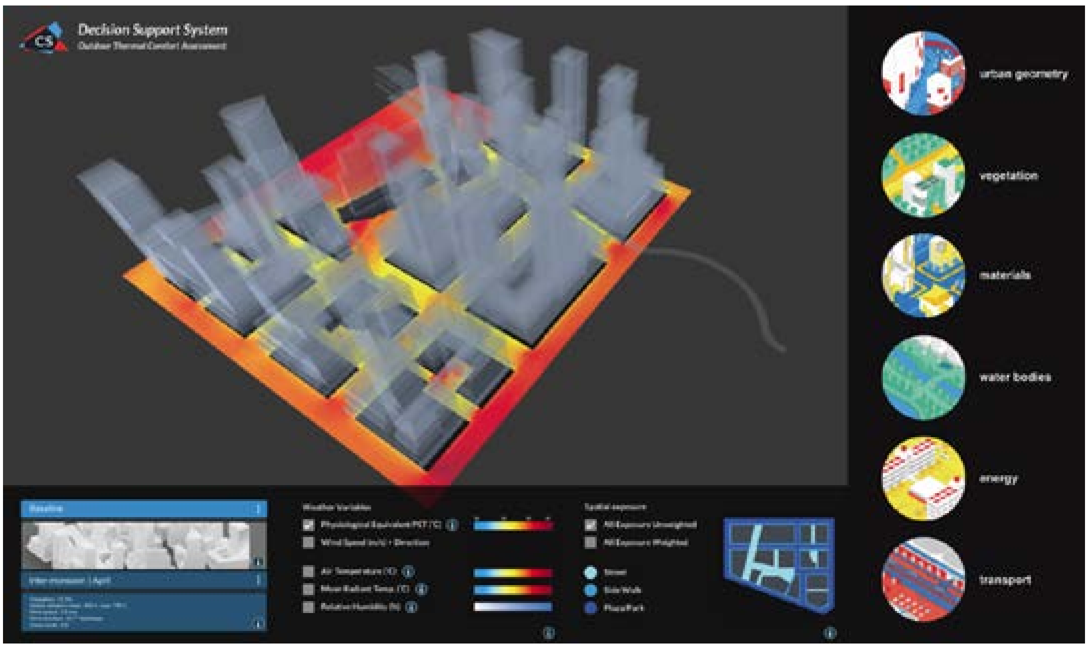
Ultimately, cities will need to prioritize alternative modes of transport. In addition to prioritizing the infrastructure needed for alternatives (bus lanes, light-rail lines, subway tunnels, sidewalks, bike lanes, micro-mobility lanes), cities will need to deprioritize and disincentivize car use. This could include no new lanes for cars, closing certain areas to vehicular traffic on weekends, removing parking lots and lanes, and supporting or incentivizing carpooling.

BUILDING HEIGHT AND STREET ORIENTATION

Large, uniform blocks of tall buildings create “urban canyons” that interfere with ventilation and trap heat and pollutants. Improved ventilation is important to allow heat and pollutants to dissipate and to increase thermal comfort (even when ventilation does not reduce the absolute air temperature, higher wind speed can increase thermal comfort). Overcoming these built environment features can be complex. For example, reducing density and building height may help heat dissipate higher up (which could reduce space cooling loads because intake air is cooler), but it does not improve wind flow at the street level (Rajagopalan, Lim and Jamei 2014; Gu *et al.* 2020). And the interactions between elements is significant. For example, a skyscraper among mid-rise buildings increases windspeed on its windward side but creates a “wind shadow” on its downwind side and decreases windspeed at street level (Rajagopalan, Lim and Jamei 2014). Because of the complexity of fluid dynamics, modelling is often an important tool to help planners understand hyperlocal conditions and interactions.

For example, the Cooling Singapore initiative is a major research effort to build a decision support system to reduce urban heat islands based on past and ongoing region- and micro-scale modelling. Since 2017, researchers have been integrating environmental, land surface, industrial, traffic and building energy computational models and adapting them to local conditions (figure 6.3). All research and publications are available on the project website, allowing other cities to learn both from their findings and from their modelling experience. The project is expected to conclude in 2023 (Cooling Singapore n.d.).

Figure 6.3 Micro-scale modelling for outdoor thermal comfort in Singapore



Source: Cooling Singapore 2020

Planners can turn urban canyons into "ventilation corridors" that carry wind throughout the city by orienting major streets parallel to prevailing winds (figure 6.4). For example, in the Philippines, where the government is converting a military base into a new planned community, New Clark City, planners are taking into account sun and wind patterns in different seasons to make outdoor spaces more comfortable and usable in the hot and humid climate. Another example is coastal cities with major streets running perpendicular to the coast and extending to the coastline to take advantage of sea breezes. Conversely, a row of skyscrapers parallel to the coast (perpendicular to the prevailing wind) will block ventilation.

In a gridded layout, orienting major streets parallel to the prevailing wind means some streets will be perpendicular. Here the urban canyon's aspect ratio, or the ratio of its height to its width, determines the characteristics of the wind flowing perpendicular to the street. When the aspect ratio is greater than 0.7 (meaning the height of the buildings is almost as wide as the street, equal to, or taller than the street), the canyon is most likely to trap air (Oke 1987). Wider streets also admit more natural light, but they reduce how much buildings shade each other and pavement (more on this below). Where wider streets are due to additional lanes for cars (as opposed to space for pedestrians, sidewalk cafes, cyclists, etc.), they could also mean less density (more sprawl) and more waste heat from cars.

The "shape" of the urban canyon also plays a role in ventilation (individual building shape is discussed in chapter 8). Relatively uniform urban canyon walls (*i.e.*, building façades) slow wind speeds (Gu *et al.* 2020). In a "step-up configuration", the height of the upwind building is less than the height of the downwind building (by one or two stories), allowing the wind to reach the leeward side of each building and increasing wind speeds at pedestrian height across a series of buildings (figure 6.5).

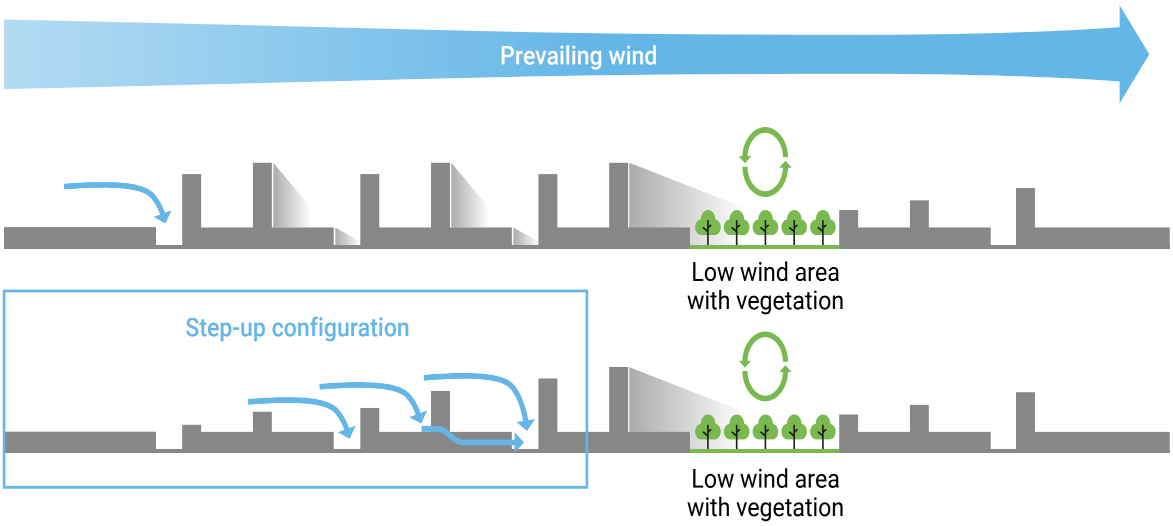
If the buildings are low, adding towers on the windward side allows maximum ventilation (compared to the towers being at the middle or downwind side of the building) (Rajagopalan, Lim and Jamei 2014).

Figure 6.4 Proposed ventilation corridors, Hong Kong and Thanh Hoa City, Viet Nam

Green and blue fingers in the city, planned for 2020: Contiguous green corridors and canal circulation networks aligned with prevailing summer breezes, punctuated by stormwater retention bodies as urban design amenities

Source: Raven et al. 2018

Figure 6.5 How the shape of the urban canyon plays a role in ventilation



Note: In the figure, taller buildings of relatively uniform height produce wind shadows and reduce ventilation in urban canyons (top). A step-up configuration, in which downwind buildings become progressively taller, increases pedestrian-level ventilation (bottom). Where wind shadows are unavoidable, green spaces provide cooling convection.

Source: Adapted from Rajagopalan, Lim and Jamei 2014

While different layouts and spacing of trees affect wind and microclimates differently (this is discussed later in this chapter), adding trees in areas with low wind speed could improve thermal comfort and could even increase ventilation (Rajagopalan, Lim and Jamei 2014). More generally, one way to create wind corridors is to create "cool corridors" of nearby green spaces and bodies of water. The green and blue spaces have lower temperatures than their surroundings, driving circulation and drawing cool air through the city. Cool corridors are discussed more in the next section.

Another strategy to improve ventilation is to create a void deck, or cutout, instead of the ground level of a building (this feature is common in Singapore). Wind flows through the voids, increasing pedestrian-level wind flow in urban canyons. The effects are greater with greater void deck height (Chew and Norford 2019). Potential drawbacks of void decks include reduced sidewalk shading and loss of enclosed ground-level retail space.

A building in Singapore with a void deck

The discussion above pertains mostly to mid- to high-rise downtown areas, which have natural height variability. Blocks of uniform-height, low- to mid-rise buildings (*e.g.*, planned residential areas) often have even less ventilation because of the absence of tall buildings to create turbulence. Scattering tall buildings throughout such areas to increase surface roughness increases turbulence (although it also creates wind shadows downwind from the tall buildings) (Gago *et al.* 2013; Rajagopalan, Lim and Jamei 2014). High-rise buildings are also more able to provide shade to other buildings, streets and sidewalks (Qaid *et al.* 2016).

SKY VIEW FACTOR AND SHADING

Balancing shade and sun is an important decision in designing for thermal comfort. Sun provides indoor daylighting, a sense of well-being, and passive heating in cold weather, supporting thermal comfort. Shade prevents overheating in hot weather and reduces the urban heat island effect. But too much sun (or sun at the wrong time) can greatly degrade thermal comfort, and too much shade from tall buildings can create the feeling of being trapped in a concrete jungle. In technical terms, the balance is between the sky view factor (from any point, the ratio of visible sky to the hemisphere centred over the given point) and the aspect ratio.

While high aspect ratios can reduce ventilation, they provide more shade, which can be particularly helpful in hot environments. Planners can help shape buildings that are acceptable for their climates and provide both shade and sky view and solar access to surrounding buildings (see chapter 8 for more on building elements that provide shade) (Jamei *et al.* 2020). Shade can also come from nature-based solutions such as trees, or from fixed or dynamic exterior shading devices. These devices can control glare and provide thermal comfort, do not block building daylight as completely, and reduce

the sky view factor in a qualitatively different way than buildings do (*i.e.*, a tree blocking the sun might feel subjectively more pleasant than a building blocking the sun). However, the desirable sky view factor will vary with the context – an open grassy field or a pond will reduce the urban heat island effect, whereas an asphalt parking lot will increase it (Yin *et al.* 2018).

Designing for shade can also reduce the need for other interventions. For example, well-shaded sidewalks and walls reduce the need for reflective pavements, and they encourage walking and alternative modes of transport, reducing waste heat. Strategically placed trees on sidewalks and on the perimeter of private properties are important for shade and provide the benefits of nature-based solutions described below, but they take years to mature and require care. In addition to trees and other vegetative solutions (*e.g.*, trellises), shade can come from fabric, metal, or wood canopies or awnings, solar canopies, vertical panels, large sculptures and buildings themselves. Shade can improve thermal comfort for sidewalk walking and dining, recreation in playgrounds and parks, and at bus stops. In some cases, this shade can extend to micro-mobility and bike lanes.

Community members in Phoenix, United States re-imagined bus stops as "micro parks" or "rest stops". Using vertical and horizontal shading and vegetation, the stops would provide comfort both waiting for the bus and as places for pedestrians to take a break. Based on community input, the project implementers created design principles for shade in Phoenix, including:

- Thermally comfortable pedestrian routes:
  - To achieve a walking route that is safe during the entire summer, target shade coverage on walking corridors (as measured during the hottest times of the day) should be greater than or equal to 62 per cent.[15]
  - To achieve a walking route that is safe for 95 per cent of summer afternoon hours, target shade coverage should be greater than or equal to 30 per cent.
  - To achieve a walking route that is safe for 90 per cent of summer afternoon hours, target shade coverage should be greater than or equal to 20 per cent.
- Model for all relevant conditions, not just solar noon in the hottest month (in most cases, this is the afternoon hours during summer months).
- East-west oriented streets are likely to need additional shade structures:
  - Vertical structures can provide shade early and late in the day.
  - Buildings on the south side of the street (in the northern hemisphere; north side of the street in the southern hemisphere) may provide some shade.
  - Galleries on the ground floor of buildings can provide additional shade (Ali-Toudert and Mayer 2007).
- On north-south oriented streets, taller buildings provide shade, and horizontal structures can supplement.
- Locate sidewalks close to buildings to maximize building shade and minimize walking distance.
- Prioritize shade on critical and high-traffic pathways (*e.g.*, for commuting, to schools, to grocery stores).
- Mitigate sources that reflect light onto pedestrians (*e.g.*, vehicles, buildings).

15 All percentages are specific to Phoenix's climate and location and should be adjusted to local conditions if used in other cities.

Concepts for a shaded bus stop (left) and walking route (right) in Phoenix, Arizona

Given the role that buildings can play in facilitating shade, enabling policies are important. Cities should ensure that there are no barriers (*e.g.*, ordinances) preventing businesses and residences from using shade structures such as awnings, canopies and trellises (The Nature Conservancy 2019). For example, the City of Seattle's building code requirement to improve the quality of new development deems landscaping in the public right-of-way to be part of the site itself (Urban Land Institute n.d.).

Solar photovoltaic (PV) panels can also provide shade. PV canopies are becoming a popular option over parking lots to keep cars cool and provide electric vehicle charging. Smaller installations such as solar "trees", bus shelters and covered picnic tables can also provide shade for people in gathering and resting places. One application that would fit well with the shade design principles above would be PV awnings on buildings that frequently receive sun. These awnings would also be easy to connect to the grid compared to some stand-alone options. An important caution is that PV shade structures need to be designed for this use case, or the bottom of the panels could radiate heat and increase air temperature below.

Many shading elements can improve indoor thermal comfort as well, as described in chapter 8.

6.2 NATURE-BASED SOLUTIONS: GREEN AND BLUE SPACES

Nature-based solutions are some of cities' most powerful tools to both reduce cooling demand and improve outdoor thermal comfort. Nature-based solutions such as bodies of water and trees also provide a range of physical and mental health benefits, are cost-effective, and have few trade-offs or downsides compared to other cooling interventions. This category of solutions encompasses interventions from a single tree to an entire urban forest. In this section, we focus on larger interventions such as bodies of water, urban forests, parks and cool corridors – "green and blue spaces" for short. Generally, parks departments will have oversight over these interventions.

Nature-based solutions are "actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits" (IUCN n.d.). In an urban setting, nature-based solutions include trees (in the form of urban forests, parks, street trees or shade trees), other vegetation, rain gardens, bioswales, wetlands, mangroves and bodies of water (lakes, ponds, reservoirs, rivers, streams, canals). Many of these interventions cross scales and planning stages.

In greenfield developments, planners can retain and leverage existing green and blue spaces and plan new large green spaces. More dispersed trees and vegetation can be added in already developed areas. An analysis of the cooling effect of multiple impervious, mixed, pervious and aquatic site configurations showed that certain configurations offer more cooling potential, although these effects may be site-specific. Approaches should be taken at a local scale to respond to specific design requirements, site characteristics, microclimate targets and goals (Bartesaghi-Koc, Osmond and Peters 2020).

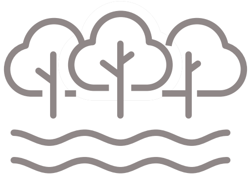
Trees provide cooling in their immediate area through shade, but they have additional benefits. Vegetation cools its surroundings through transpiration, taking up heat from the air to turn water into water vapour. Water also evaporates from the soil and from bodies of water. Evaporation and transpiration can be particularly beneficial for nighttime cooling, which allows urban temperatures to fall overnight and provide a period of lower heat stress (in comparison, surfaces like concrete release heat overnight, contributing to warming even in the absence of sun) (ESMAP 2020a). Heat reduction services from urban tree cover in the United States are estimated to be worth $5.3 billion to $12.1 billion annually. Globally, investing $100 million annually in street trees would give 77 million people a 1°C reduction in maximum temperatures on hot days (McDonald *et al.* 2016; McDonald *et al.* 2020).

Nature-based solutions are particularly powerful for their many co-benefits in the cooling context. Trees and vegetation reduce stormwater run-off, improve water quality and air quality, encourage physical activity, reduce physical and mental stress, improve physical recovery from illness, and increase property values and business income (Trust for Public Land 2016). (Nature-based solutions are also critical for other reasons less relevant to cooling, such as biodiversity and habitat connectivity.) While the cumulative benefits usually outweigh costs, other considerations when adding trees and vegetation include:

- Dense tree canopies can trap heat and air pollution.
- Vegetation and water increase humidity in the air.
- Vegetation requires irrigation in arid climates, where water may be scarce.
- Species need to be climate-resilient and non-invasive to be effective.
- Vegetation produces air pollutants in the form of volatile organic compounds and pollen.
- Vegetation (especially trees) has planting and maintenance costs, and urban trees have lower life expectancies than rural ones (Trust for Public Land 2016; ESMAP 2020a).

Numerous studies have shown the relationship between land use and temperature (land surface temperature and canopy temperature) (Su, Gu and Yang 2020). In general, the temperature increases as impervious surfaces and buildings increase and as the area of vegetated land and bodies of water decreases. In simplest terms, then, increasing the proportion of green and blue space (urban forests, street trees, parks, gardens, fields, streams, rivers, canals, lakes and ponds) in a city can reduce the urban heat island effect.

In general, cities should seek to maximize green spaces, especially native species, to reduce heat – and also to improve air quality, mental health, social cohesion, and soil health and stability, and to reduce stormwater run-off. (While the number and area of bodies of water is more fixed, ensuring healthy aquatic ecosystems provides many of the same benefits as green spaces.) But cities are necessarily built environments, and climate, terrain and geography can further constrain available green and blue spaces. Additionally, the effects of urban surfaces on trees and vegetation should be assessed and considered in the planning process (Bartesaghi-Koc, Osmond and Peters 2020). The way city planners site natural spaces within these constraints is therefore an important tool to reduce the urban heat island effect.



The discussion below first looks at best practices for parks and bodies of water before exploring how to use nature-based solutions together to create cool corridors.

PARKS AND URBAN FORESTS

Urbanization and urban growth often mean converting permeable land such as fields, wetlands and forests into impermeable surfaces such as roads and buildings. These changes increase urban temperatures and decrease the space available to provide shade and outdoor cooling. C40 recommends that cities aim for 30 per cent of their area to be green space.[16]

Land-use change also increases run off, as there is little permeable ground available to absorb precipitation. As a result, cities have to build additional stormwater infrastructure. Instead of responding to land-use change with carbon-intensive measures, cities can provide additional green spaces for cooling and shade, as well as to act as "green infrastructure" for stormwater management.

Large green spaces such as urban forests and parks can provide significant benefits within and beyond their bounds. Vegetation cools its immediate vicinity through transpiration, and the resulting air temperature differential creates convection currents that lift warm air above ground level and disperse cool air. The cooling effect of parks and urban forests can extend about 800 metres outside the park, although the effect drops off steeply with distance. Cooling also extends farther on the downwind side of the park and when the park is at a higher elevation than its surroundings. An undeveloped buffer around green spaces also allows cooling to extend farther. Individual green spaces cool their immediate surroundings, and the collective impact of green spaces throughout a city can reduce air temperature overall.

Not all green spaces are created equal. City parks are designed for different purposes (*e.g.*, enjoying nature, active recreation, varied ages and ability levels) and from different available land (*e.g.*, preserved forests, private estates, vacant lots, parking spaces). As a result, a city park may or may not be a green space – it could be an urban forest, a grassy field, a paved playground or any combination of these and other elements. For example, in a five-year effort to add green infrastructure, Seoul, Republic of Korea, added nearly 2,000 urban forests and gardens in sizes ranging from sidewalk gardens to small forests (Rim 2018).

The distribution of green space in a city is not always equal. Research by the Trust for Public Land showed income and race disparities in parks in the United States. Parks in majority non-white neighbourhoods are half as large and serve nearly five times more people than parks in majority white neighbourhoods. Parks serving majority low-income households are, on average, four times smaller and serve nearly four times more people than parks that serve majority high-income households.[17] In Santiago, Chile, it was found that the five wealthiest municipalities had, on average, access to more than five times the amount of public green space than the five poorest municipalities. In China, a national study also found that wealthier cities have more green space than less affluent cities. Even if these trends are different in other countries, they still show how park design can fail some residents by leaving neighbourhoods without amenities and with higher heat burdens (Chen *et al.* 2017; Contessa, van Vliet and Lenhart 2018; Trust for Public Land 2020a).

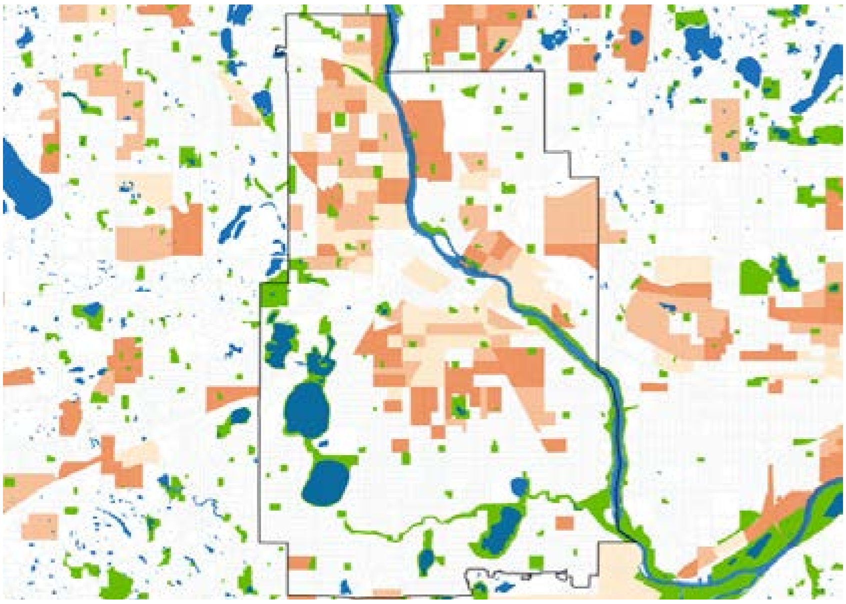
The Trust for Public Land's ParkScore index rates the park systems of major US cities based on four characteristics: acreage, investment, amenities and access. While ParkScore rates entire park systems on a range of benefits, the approach is still relevant to cooling (Trust for Public Land n.d.). Policymakers wishing to harness green spaces for cooling can think about the following elements:

- **Acreage:** Larger parks have greater cooling potential than smaller ones, and a higher percentage of city area devoted to parks has more widespread cooling benefits. But small green areas should still be used where space is limited. Small parks provide local cooling and can still provide many co-benefits (Trust for Public Land 2016). Figure 6.6 shows small and large green spaces distributed throughout Minneapolis, United States, and figure 6.7 shows plans in Madrid, Spain to focus tree planting in five areas throughout the city.

16 Personal correspondence with C40.

17 Low-income neighbourhoods are often denser and have smaller lot sizes than high-income neighbourhoods, but the fact that parks in low-income neighbourhoods are both smaller and serve more people points to inequitable distribution.

Figure 6.6 Access to green spaces In Minneapolis, Minnesota

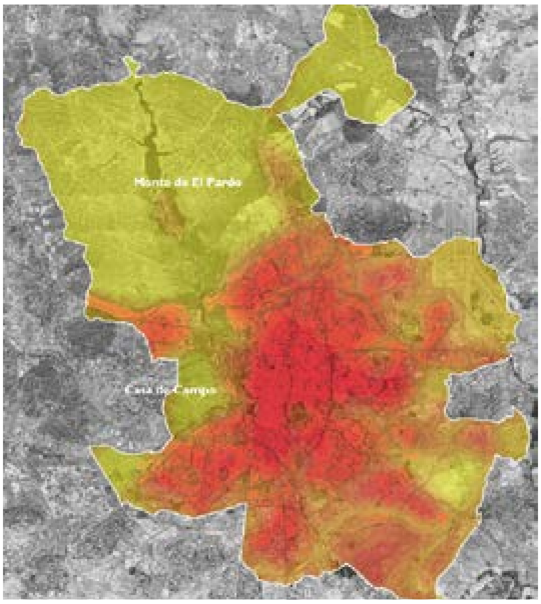


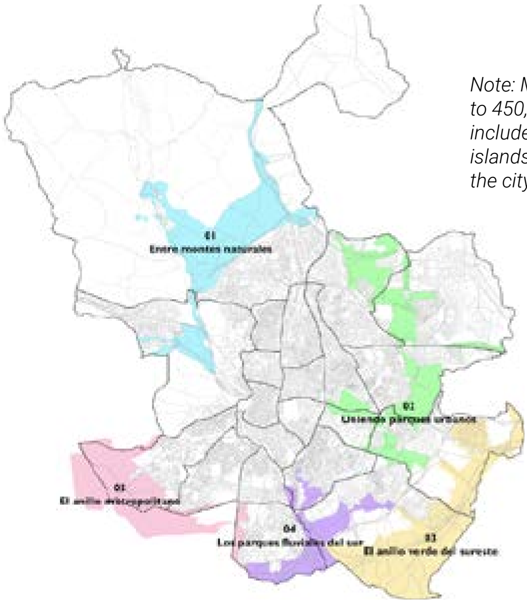
Source: UrbanFootprint, RMI and Trust for Public Land

Note: In Minneapolis, 98 per cent of residents live within a 10-minute walk of one of the city's 271 parks (the smallest parks are not visible in the image). Minneapolis has a variety of public green spaces throughout the city, including large parks, lakes, greenways along the river and across town, and small neighbourhood parks. However, the largest green spaces are more accessible to higher-income and white populations. The red circles show approximate locations of where new parks are most needed to improve access, according to the Trust for Public Land.

- **Investment:** Cities need funds to create new parks, maintain and operate existing ones, and provide programming. This money comes from city budgets, taxes, government grants, non-profits and foundations, and volunteer time. Some cities have patterns of inequitable investment, for example putting more money towards parks in wealthier neighbourhoods or where conservancy groups are most active. To counter this trend, some cities have adopted equity frameworks to guide their investment (Eldridge *et al.* 2019). More information on leveraging funding sources is in chapter 12.
- **Amenities:** From a cooling perspective, the most important park amenities are trees and vegetation (and water bodies where they exist). Ample shade, vegetation and minimal paved surfaces make for cool residents, clean air, natural beauty and less run-off. However, it is also important to take into account community needs, ideally through planning in which the surrounding community participates. Parks should offer opportunities for residents of all ages and abilities and provide the amenities that the surrounding community wants (*e.g.*, playgrounds, sports facilities, dog runs, spray parks and shaded gathering areas). New parks should also be located in an area that the community will use and that can provide the desired amenities (see also access, below).
- **Access:** An accessible park is one that is available to all (*i.e.*, public), reachable (*i.e.*, accessible by foot and public transport) and welcome to all (*i.e.*, offers value to people of all abilities, races, income levels, etc.).
  - Available: Private green spaces can play the same role in cooling as public ones, and from this perspective should be encouraged. But for all residents to be able to enjoy the full range of benefits, cities need varied and distributed public parks.
  - Reachable: Cities need high-quality parks in all neighbourhoods, especially low-income or minority neighbourhoods that are often hotter (partly because of a lack of green space and tree canopy). These neighbourhoods are often physically cut off from their surroundings by highways and railroad tracks, or roads may lack sidewalks. Planners should ensure that residents can reach the park by foot

Figure 6.7 Ambitious tree-planting plan and urban heat islands in Madrid, Spain





Note: Madrid's plan to plant up to 450,000 native trees by 2030 includes attention to urban heat islands in the south and east of the city.

Images courtesy of the City of Madrid

easily and safely. The Trust for Public Land's goal is for everyone to be within a 10-minute walk (about 800 metres) of a public park. In highly developed areas where new parks are not possible, public transport connecting neighbourhoods without parks to existing parks is important.

- Welcoming for all: Racial and ethnic minorities, low-income populations and other marginalized groups may feel less welcome in parks, especially if parks were not designed for them. Cities can involve these groups when planning, maintaining and programming parks to ensure that the parks meet their needs. Genuine community engagement also can make residents more comfortable using parks (Trust for Public Land 2020a).

- **Longevity:** As with all investments, parks need to be planned for the future, as well as the present. Cities can use climate projections to understand how temperature, drought, precipitation, flooding and extreme weather events might affect parks in the future. Planning for future risks should also include selecting species that are resilient to pests and diseases. This information can help cities choose appropriate park locations (*e.g.*, to connect habitats and avoid flooding) and species (*e.g.*, to increase genetic diversity and resist droughts).

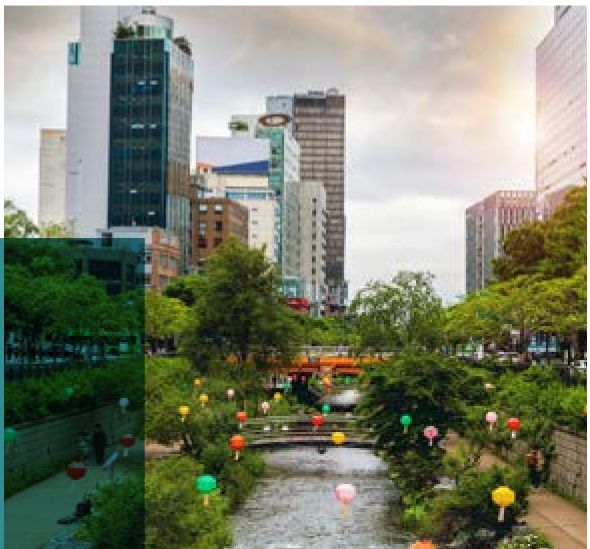
The considerations above are easiest to implement in undeveloped areas or in areas with existing open spaces that can be re-developed; they may feel out of reach in very dense urban environments and informal settlements.

These elements also highlight some trade-offs. Large green spaces provide more cooling (and some other benefits, like wildlife habitat) than small green spaces, but cities may not have space to put large parks in all neighbourhoods. Cities should do the best they can with available opportunities. Converting a small vacant lot into a pocket park that neighbours use daily provides more total community benefits than a larger, cooler park several kilometres away that the same community rarely uses.

WATER

Like vegetation, bodies of water – natural or constructed lakes or ponds, wetlands, rivers, streams, canals and reservoirs – provide many benefits, including evaporative cooling. The cooling effect increases as the area of water increases, allowing cooling up to one kilometre away. Cooling is more effective when there is a buffer between the water and surrounding buildings or dense vegetation (although riparian and shoreline vegetation can provide additional cooling as well as ecosystem benefits) (Trust for Public Land 2016). Cities can maximize the benefits of blue spaces through preservation, restoration and careful waterfront development.

In Seoul, an effort to restore the Cheonggyecheon stream that runs through the city replaced 5.8 kilometres of elevated expressway that covered the stream with a mixed-use waterfront corridor. The waterfront area now allows pedestrian and cycle traffic and has several recreation areas. The project increased green space (and made existing blue space usable), wind speed, biodiversity, pedestrian use, public transit use, tourism, property values and business growth. It decreased temperature 3.3°C to 5.9°C compared to a parallel road a few blocks away, as well as reducing air pollution, noise and car traffic (Wicht, Wicht and Osińska-Skotak 2017; Landscape Performance Series n.d.).



While natural water bodies often provide more holistic benefits such as ecosystem resilience, constructed elements can increase cooling opportunities. In India, step wells provide cooling at different levels plus shaded spaces for recreation. A descending staircase from ground level allows access to the well, even as the water level fluctuates (Zagyi 2013).

An important caution about water is that standing water can increase vector-borne diseases by providing breeding grounds for vectors like mosquitoes. Holistic measures such as integrated vector management are critical, and they are largely compatible with cooling goals. Flowing water is less hospitable for breeding, so restoring natural bodies of water and adding aeration in constructed ones can mitigate disease risk (Eder *et al.* 2018; WHO n.d.b).

COOL CORRIDORS

Cities can further leverage the benefits of green and blue spaces by siting them to create "cool corridors". A series of green and blue spaces parallel to the prevailing wind can channel cool air through the city and extend the cooling of individual sites farther. Adding street trees between green spaces and employing the design strategies discussed above further extend the effect. At a practical level, cool corridors also create safe routes for residents to access a green space or cooling centre. Street trees and vegetation makes these routes cooler and more usable for pedestrians, cyclists, and micro-mobility users, as well as those waiting for buses or light rail. (Other ways to make streets cooler for people are discussed in the following chapters.)

More information about cool corridors is in the case studies on Ljubljana and Medellín at the end of this chapter.

6.3 COOL SURFACES

In an urban environment, the surfaces that contribute to the urban heat island effect (roads, sidewalks, parking lots, building walls and roofs, even car exteriors) far outnumber the surfaces that reduce the effect (parks, lawns, trees, gardens, water) – over 60 per cent of all surfaces in urban areas are pavements and roofs (Akbari, Menon and Rosenfeld 2009). Many of these built surfaces, can, however, be replaced with or modified to be "cool surfaces" – surfaces that reflect heat instead of absorbing it. In this chapter, we look at how public works departments can implement cool pavements and how cities can encourage cool and green roof and wall adoption. In chapter 8, we look at how building codes can also drive cool and green roofs and walls.

Commonly used materials in urban surfaces – roads, pavements, roofs and walls – have low solar reflectance (albedo). These materials heat up and warm not only the nearby air but also the atmosphere. In particular, the prevalence of dark roofs and impervious, dark-coloured pavements, coupled with declining vegetative cover, are significant contributors to the temperature differential between urban hubs and the surrounding areas.

All built urban surfaces (roofs, walls, pavements) reflect some sunlight and absorb the rest, which they then lose as heat. Replacing or retrofitting existing low solar-reflectivity surfaces (*i.e.*, those that absorb most sunlight and stay hot for a long time) with high solar-reflectivity surfaces (*i.e.*, those that reflect most sunlight and emit heat quickly) can drastically reduce the urban heat island effect. Figure 6.8 shows how replacing a traditional roof with a cool roof reduces the roof's surface temperature, the amount of heat transferred to the building and the warming of nearby air (although not the air at street-level).

When deployed throughout an urban area, cool and reflective surfaces can significantly reduce the intensity of the urban heat island effect. And by reducing the need for mechanical cooling, they can help break the cycle of waste heat and urban heat islands. Widespread deployment of cool surfaces can even help offset global warming by reducing the amount of heat trapped in the earth's atmosphere (more on passive radiative cooling is below).

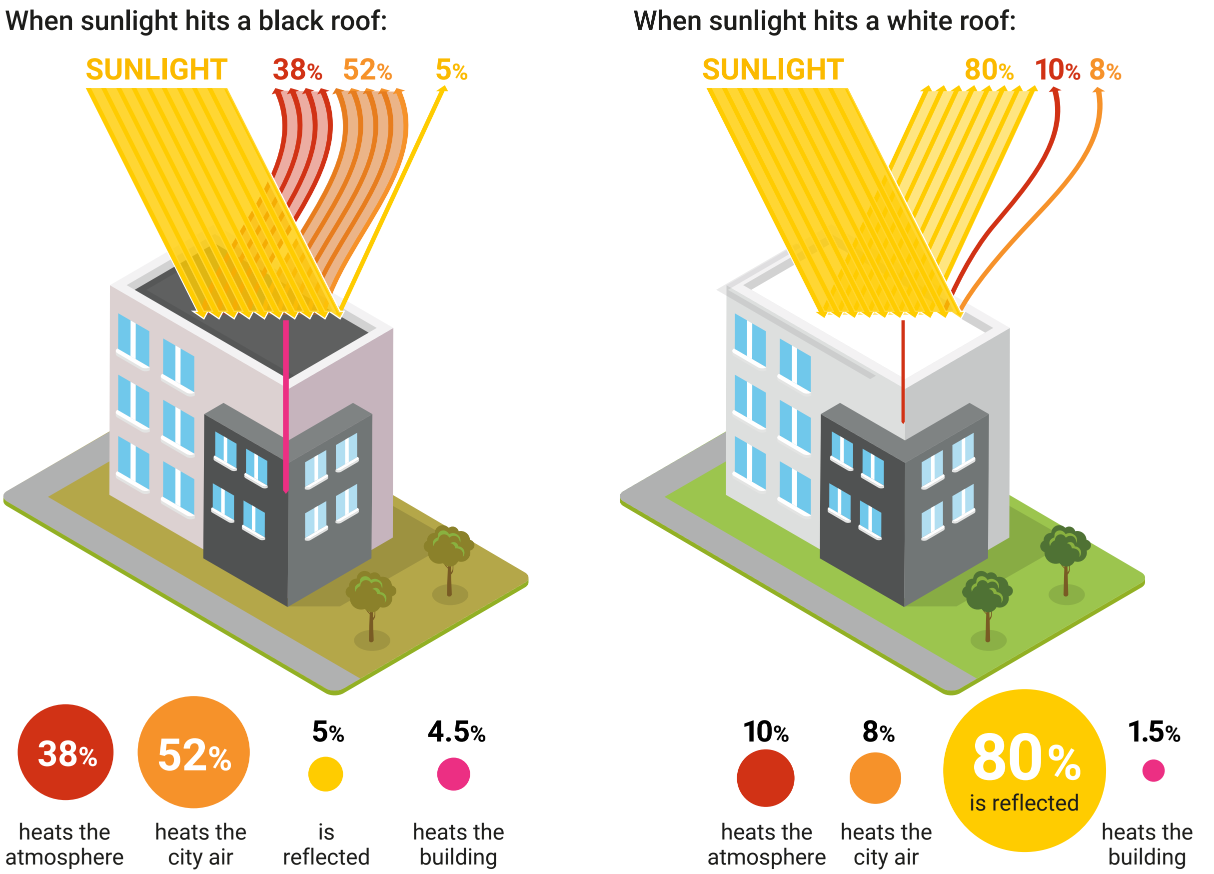
Cool surfaces are commonly created by making the roof, wall or paved surface colour lighter to reflect more solar energy in the visible spectrum (*e.g.*, a white roof rather than a dark roof). Much solar energy is in the near-infrared spectrum, so certain pigment technologies known as cool colours reflect infrared solar energy as well. Cool colours are also useful where aesthetics are important, for example for walls and steep roofs. Another application of light colours and cool pigments is car exteriors (ESMAP 2020a). Light-coloured cars heat up less than dark-coloured ones, requiring less energy for cooling and producing less waste heat (Levinson *et al.* 2011).

Cool surfaces present some costs compared to traditional surfaces: most (but not all) materials are more expensive, installation and maintenance are required (as they are for traditional materials), and winter heating needs may increase (for cool roofs and walls). Upfront premium costs vary widely in different markets and can represent a challenge in markets where fewer options are available; first-costs may decline as markets continue to develop. The other critical cost for cities to consider, for cool surfaces and all cooling interventions, is the cost of inaction.

A study of 1,700 cities found that, under the Intergovernmental Panel on Climate Change's high-emissions pathway (RCP8.5), the median city could expect to lose 3.9 per cent of GDP by 2021 due to global climate change, but that number jumps to 5.6 per cent of GDP when taking into account local urban heat. The worst-off city could see combined losses of 10.9 per cent of GDP. (In RCP4.5, one of the moderate stabilization pathways, the median city would see 1.2 per cent GDP loss from climate change in 2100 and 2.3 per cent for climate change and urban heat combined (Estrada, Wouter Botzen and Tol 2017).) In other words, urban heat and its local causes (not just global climate change) could play a significant role in cities' financial losses.

Given the cost of interventions and the cost of inaction, are these interventions cost-effective? In the following discussion, this chapter cites several figures for the payback period and net present value of interventions,

Figure 6.8 The albedo effect: comparison of a black and a white flat roof on a summer afternoon with an air temperature of 37°C



Note: Numbers do not sum to 100 per cent due to rounding.
Source: Adapted from Global Cool Cities Alliance 2012, and data from LBNL Heat Island Group.

but all are based on an incomplete accounting of benefits and costs of each intervention. Figure 6.9 shows many of the benefits and costs of cool and green roofs (although not the business-as-usual benefits or costs of not using these interventions). Many of these are difficult to quantify, and as a result, most analyses only include a few of the more easily quantified benefits and costs. And, of course, the relevant importance of each factor varies with each city's climate, energy costs, etc.

In addition, the relative costs and benefits change with market maturity and scale. Green roofs often have high costs on a per-metre basis, but research suggests that the building-level and city-level benefits of widespread green roof implementation would outweigh the costs (Rosenzweig, Gaffi and Parshall 2006; Kats and Glassbrook 2018). All exact figures in this chapter should therefore be considered indicative. Figure 4.2 provides a qualitative and relative overview of interventions.

Figure 6.9 Selected benefits and costs of cool roofs and green roofs (most apply to both interventions, unless specified with cool roofs or green roofs)

BENEFITS	COSTS
Direct cooling energy reduction	Installation
Indirect cooling energy reduction	Maintenance
Building HVAC intake air temperature reduction	Direct heating energy penalty
Peak energy load reduction	Indirect heating energy penalty
Greenhouse gas emissions reduction	Increased pollen (GR)
Global cooling	
Carbon sequestration (GR)	
Ozone concentration reduction	
PM2.5 concentration reduction	
Heat-related mortality reduction	
Mental health improvement (GR)	
Increased roof life (CR)	
Downstream cooling	
Reduced stormwater run-off temperature	
Reduced stormwater run-off quantity (GR)	
Amenity value	
Aesthetic value (GR)	
Biodiversity (GR)	
Food production (GR)	
Increased PV efficiency	

Note: This table only shows the benefits and costs of implementing these interventions, not the business-as-usual scenario without action.
Source: Adapted from Rosenzweig, Gaffi and Parshall 2006; Kats and Glassbrook 2018

Cool surfaces present a wide array of benefits as well. For cool roofs and walls, these include direct and indirect cooling energy reduction, peak energy load reduction and lower energy bills. For all cool surfaces, in some cases a benefit is the longer surface life, plus all the air quality and human health benefits of reduced urban heat. And while manufacturing some cool surfaces produces more greenhouse gas emissions than traditional surfaces, the reduction in global warming potential from using a more reflective surface is far greater (Gilbert *et al.* 2017). Data indicate that widespread adoption of cool surfaces can also have significant cooling benefits downwind from the city. This finding points to the potential value of cooperation between cities and between jurisdictions of large metropolises. Cooling measures on the downwind end of a metropolis will not be as effective if no action is taken upwind. Conversely, action taken upwind can amplify the benefits of action downwind (Kats and Glassbrook 2018).

REFLECTIVE PAVEMENTS

Pavements (roads, parking lots, sidewalks and other paved areas) cover around 20-65 per cent of a city's surfaces, providing a significant opportunity to cool these hot surfaces (ESMAP 2020a). Traditional asphalt pavement starts its life with an albedo (solar reflectivity) as low as 0.05, which increases up to 0.20 as it lightens with use; traditional concrete starts around 0.40 and darkens with use to 0.25. Red brick has similarly low reflectivity, around 0.20-0.30. Several studies show that increasing surface albedo by 0.1 can decrease concrete or asphalt surface temperature 3-5°C (air temperature reductions are much smaller, usually less than 1°C) (Kats and Glassbrook 2018). And decreasing pavement temperature, in addition to helping with cooling, can significantly extend pavement lifetime.

There are two main strategies to make pavements more reflective:[18]

- Use lighter-coloured materials:
  - Asphalt: Conventional asphalt is made of aggregate rock and dark bitumen binder, which wears down over time and reveals more of the aggregate colour. Use a lighter fine aggregate like crushed limestone or light-coloured fly-ash, or, on low-traffic pavements, use clear resin, for example tree resin, for the binder. Applying surface applications, such as hydrated lime, to fresh asphalt concrete can also increase albedo (Emery *et al.* 2014).
  - Concrete: Adding slag to conventional concrete increases its reflectivity to 0.60 (this method is already used to reduce embodied carbon), or use a lighter fine aggregate like crushed limestone or quartzite sands.
- Apply a coating or overlay:
  - Reflective coating: Apply a light-coloured topical surface treatment on new or existing pavements (asphalt or concrete).
  - Whitetopping: Apply 2-4 inches of concrete overlay during resurfacing (without replacing the existing pavement system).

Reflective pavement use is nascent compared to other interventions discussed, and many questions remain. Several reflective coatings and other products are available, but more research and demonstration is needed to understand their economics, life cycle, ageing, environmental safety and embodied carbon. Some available products are similar in price and longevity to conventional asphalt seal coats, while others are more expensive but last longer (some as long as asphalt overlays). However, service life depends on local conditions and use, potentially changing the economics (ESMAP 2020a).

Cities considering these products will want to take into account local product and technology availability to help them assess costs and environmental and climate impacts. Research in three US cities found the net present value of reflective pavement ranges from $0.17 to $0.57 per square foot for roads and from -$0.39 to

18 A third strategy is using concrete instead of asphalt, but because the albedos of the two materials converge over time, this approach does not solve the problem.

$0.54 per square foot for parking lots and sidewalks. Where the net present value is negative, it is due largely to the cost of replacing parking lots and sidewalks that might not otherwise be replaced in the near term.[19]

Efforts are under way to push the market forward. Several cities, including Los Angeles (over 45 city blocks, or approximately 9 kilometres), Phoenix (72 kilometres) and Tokyo (64 kilometres), have piloted cool pavements on roads. In 2020, the Global Cool Cities Alliance launched the Cool Roadways Partnership, a group of over 20 US cities interested in implementing cool pavements, plus industry representatives and non-profit partners. The Partnership seeks to demonstrate demand for cool pavements to accelerate the availability and cost-effectiveness of these solutions, with a long-term goal of establishing procurement specification standards that cities can use. The Partnership issued a request for information, asking industry to provide information on its products to inform the Partnership's activities (Global Cool Cities Alliance n.d.).

When considering where to deploy reflective pavements, cities should think about who uses the pavements and how, and what surrounds the pavement (figure 6.10). The reflected light from roads and sidewalks can decrease thermal comfort for pedestrians, and it can increase thermal gain on adjacent buildings. These effects are reduced if the sidewalk is shaded (although a well-shaded sidewalk will not provide much cooling) and there is vegetation between the street or sidewalk and adjacent buildings.

Figure 6.10 Comparison of uses for reflective pavements

USE	PRO	CONTRA
Expressways, other high-speed, high-traffic roads	Less concern about reflecting on buildings or pedestrians	• High-wear, frequent reapplication • Potential decreased visibility of road markings
Local roads	Mixed depending on location, use and shading	
Parking lots	• Low-wear, infrequent reapplication • Keeps cars cooler	First-use cost if paving not otherwise necessary
Sidewalks – shaded	• Low-wear, infrequent reapplication • Potential increased thermal comfort in cold, sunny weather	Less cooling benefit when already shaded
Sidewalks – unshaded	• Low-wear, infrequent reapplication • Possible improved daylight in nearby buildings	• Potential decreased pedestrian thermal comfort from reflected light • Possible increased solar gain on nearby buildings

Note: This comparison does not take into account any cost premium between conventional and reflective materials; it does take into account frequency of reapplication.

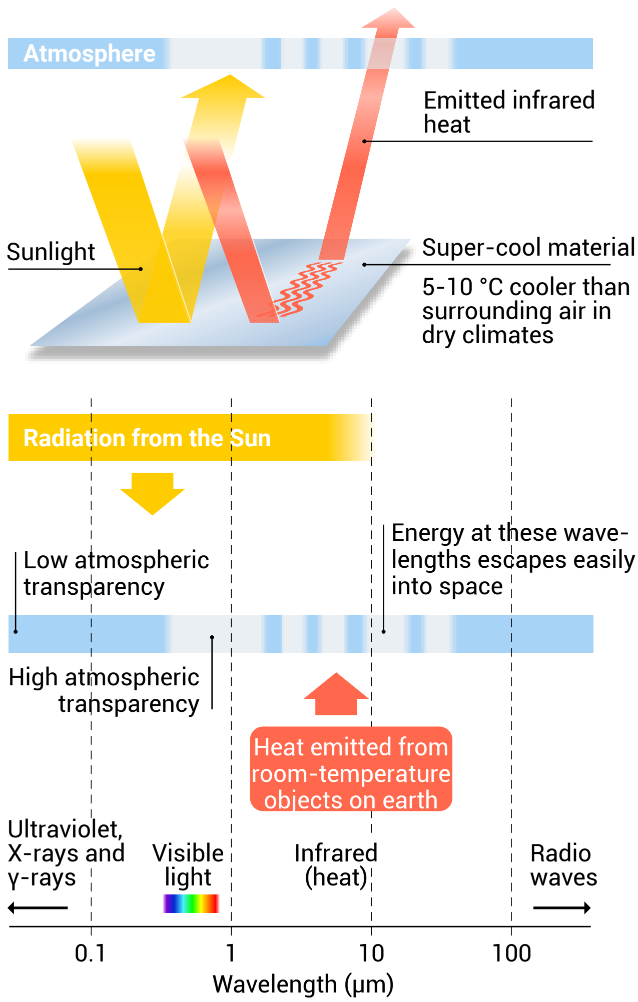
Another type of reflective surface is a super-cool surface, which uses passive radiative cooling. When surfaces emit heat as infrared radiation, the atmosphere absorbs most of the heat. However, wavelengths between 8 and 13 micrometres can pass through the atmosphere into outer space, effectively using space as an enormous heat sink (figure 6.11). This process of passive radiative cooling occurs naturally, but during the day insolation dwarfs radiative cooling. Recently, real-world experiments have shown that special super-cool materials can emit enough radiation at the critical range to become several degrees cooler than surrounding air. Much work remains to develop and commercialize viable materials (Lim 2019; Yin *et al.* 2020).

Figure 6.11 Super-cool surfaces use passive radiative cooling to emit infrared radiation to outer space

'Super-cool' materials stay colder than their surroundings even in direct sunlight by emitting heat that can pass through the atmosphere and into space.

Reflect and emit
Super-cool materials are extremely reflective (even more so than white paint), so they are relatively unaffected by sunlight. They also absorb wavelengths between 8 and 13 µm, then emit them into space.

Transparent atmosphere
Earth's blanket-like atmosphere absorbs most infrared wavelengths but is transparent to those between 8 and 13 micrometres.



Source: Adapted from Lim 2019

PERMEABLE PAVEMENTS

When permeable pavements are used instead of conventional materials, run-off and stormwater pass through the pavement and its bed, allowing evaporative cooling and stormwater management. After the water passes through the permeable surface, it enters a recharge bed made of crushed rock and is slowly released into the soil. While permeable pavements have been used for stormwater management, they also contribute to cooling as the moisture they contain evaporates and reduces air temperature. Common technologies include porous asphalt and pervious concrete (similar to their conventional counterparts but mixed without fine particles), brick or stone pavers, and grass or gravel grid pavers (ESMAP 2020a).

Permeable pavements work in low-traffic areas where stormwater management would be helpful. It is important to make sure permeable pavements are sited so they do not pick up high pollutant loads or release the water they collect directly into natural water bodies. Permeable pavements do not provide cooling benefits when they are dry.

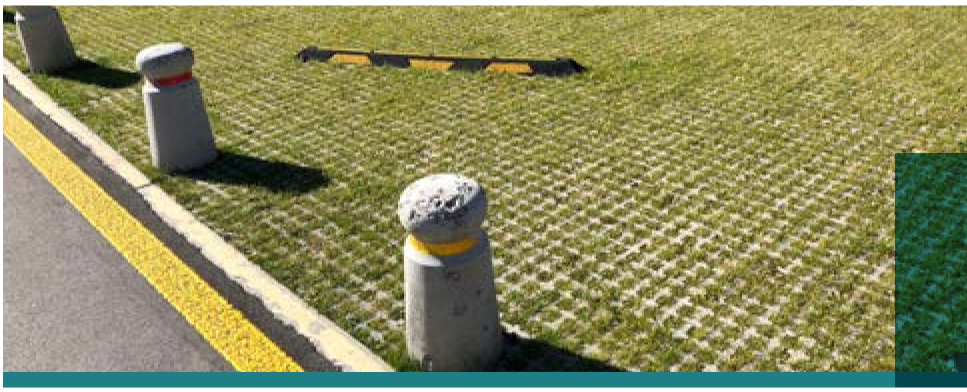
Permeable pavements have a cost premium and require regular maintenance. The Energy Sector Management Assistance Program recommends that "cities...work with the private sector and others to demonstrate the local performance and capacity of permeable pavements and to send a signal to the market" (ESMAP 2020a). It seems that these technologies have a role to play in stormwater management, but their cooling applications may be more limited, *e.g.*, flood-prone parking lots or off-street walking paths. Otherwise, green infrastructure and shading structures can provide desired cooling benefits.

COOL ROOFS AND WALLS

Roofs typically make up 25-30 per cent of an average city's surfaces, providing a significant opportunity for cities to reduce the heat they absorb. Although many modern roofs are dark-coloured, some areas have traditionally applied materials such as lime wash to roofs, walls and pavements to decrease their solar gain and improve comfort (Kubota, Rijal and Takaguchi 2018). Cool roofs are globally applicable to nearly all building types, there are a wide variety of highly reflective roofing products available in nearly every roof surface type used worldwide, and they are generally cost-effective. In most cases, cool roofs are a no-regrets measure .

Estimates in the United States and Mexico show that the payback time for a cool roof is 0 to 8 years based only on building energy cost savings, with warmer climates showing shorter payback periods than temperate regions (Hernández-Pérez *et al.* 2017). Other analysis in three US cities shows cost-benefit ratios ranging from 4.23 to 8.29 for cool roofs and from 2.50 to 3.03 for reflective pavements. The same analysis shows net present value ranging from $3.08 to $5.45 per square foot for low-slope roofs and -$0.07 to $0.30 for steep-slope roofs (Kats and Glassbrook 2018).

All cool roofs reduce the urban heat island effect, but they provide the most indoor thermal comfort benefits in single-storey structures with a high roof-to-wall-area ratio. Research is mixed as to the significance of reflective roofs for outdoor ground-level temperature reduction, especially for tall buildings. It is clear that cool roofs reduce the surface temperature of the roof and the air temperature above the roof and inside the top storey of the building (Santamouris *et al.* 2016; ESMAP 2020a).



Inexpensive cool roofs (*e.g.*, coating corrugated metal with lime wash) are highly applicable where building efficiency measures are difficult, such as informal settlements or areas where building codes are ignored. Several cool roof and cool wall pilots in low-income housing in India and South Africa have shown increased indoor thermal comfort and resident satisfaction (ESMAP 2020a). Additional pilots are under way in Bangladesh, Côte d'Ivoire, Indonesia, Kenya, Mexico, Niger, the Philippines, Rwanda, Senegal and South Africa via the Million Cool Roofs Challenge, with the goal of each project deploying 1 million square metres of cool roofs by August 2021 . Other benefits of cool roofs include energy savings potential, cost savings potential, improved roof and equipment life, and short payback period. (In some buildings, cool roofs can require more winter-time heating, but energy savings in the summer are usually greater than energy increases in the winter.)

It is easiest to design for and choose a cool option when a new roof or a replacement roof is installed, but there are also options to use coatings to increase the solar reflectance of an existing, functional roof. Currently, materials for cool low-slope roofs are more reflective and cheaper per square metre than materials for cool steep-slope roofs, but technology for both continues to improve.

Another technology that could be considered a "cool roof" is rooftop solar PV technology. While solar panels absorb, instead of reflecting, light, they produce the same outcome as reflective surfaces by preventing solar gain on the roof. While solar panels usually do not cover an entire rooftop, they can be used in combination with cool surfaces and/or green roofs.

Cool walls use the same principles as cool roofs and provide the same benefits. Cool walls need special consideration when used on buildings that are close together and receive significant sunlight. In these cases, cool walls may reflect sunlight onto neighbouring buildings, leading to heat gain if the neighbouring building has absorptive surfaces. Cool walls also increase the solar radiation directed at pedestrians, which could decrease thermal comfort, but at the same time cool walls also decrease thermal infrared radiation directed at pedestrians and lower the outdoor air temperature. As a result, pedestrians experience little change in thermal comfort (ESMAP 2020a).

Cool surfaces present some costs compared to traditional surfaces. Most (but not all) materials are more expensive, installation and maintenance are required (as they are for traditional materials), and winter heating needs may increase. Upfront premium costs vary widely in different markets and can represent a challenge in markets where fewer options are available. But cool surfaces present a wide array of benefits as well. These include direct and indirect cooling energy reduction, peak energy load reduction, lower energy bills, in some cases longer surface life, plus all the air quality and human health benefits of reduced urban heat. And while manufacturing some cool surfaces produces more greenhouse gas emissions than traditional surfaces, the reduction in global warming potential from using a more reflective surface is far greater (Gilbert *et al.* 2017).

Data indicate that widespread adoption of cool surfaces can have significant cooling benefits downwind from the city. This finding points to the potential value of cooperation between cities and between jurisdictions of large metropolises.

Cooling measures on the downwind end of a metropolis will not be as effective if no action is taken upwind. Conversely, action taken upwind can amplify the benefits of action downwind (Kats and Glassbrook 2018).

Ultimately, cool roofs are one of the most important building-level levers cities have to reduce heat locally. Local materials can be used, and there are few drawbacks. Cool walls require more careful deployment. While most roofs receive significant sunlight, some walls (*e.g.*, in dense areas) may not receive sufficient light to benefit from a reflective surface. Where there is sufficient light, care needs to be taken that the reflected light does not inadvertently heat other buildings or pedestrians. Chapter 8 on building shading presents other approaches for shading walls.

GREEN ROOFS AND WALLS

Green roofs and walls combine the benefits of vegetation discussed in the previous section with the benefits of cool roofs and walls: they prevent solar gain on buildings, cool the surrounding air through evapotranspiration and reduce run-off. Green roofs range from a thin layer of vegetation (extensive green roofs) to trees and shrubs (intensive green roofs); they are most appropriate in cities with sufficient precipitation and require buildings that can support their weight (Kats and Glassbrook 2018; ESMAP 2020a). Indicative properties of green roofs are shown in figure 6.12.

Green roofs are more expensive than abiotic cool surfaces and require ongoing maintenance. Analysis in three US cities found roof net present values per square foot of -$18 to $24.82 for commercial low-slope and -$17.16 to $24.53 for residential low-slope (as with other analysis from this study, only currently quantifiable costs and benefits were included). Some of the wide range here is due to climate (net present value is negative in the arid city) and possible incentives (one city has stormwater mitigation incentives that make green roofs more viable) (Kats and Glassbrook 2018). Separate analysis found that initial green roof costs decreased by 33-50 per cent when local markets matured (Feng and Hewage 2017).

Figure 6.12 Indicative properties of green roofs

	EXTENSIVE GREEN ROOF	SEMI-INTENSIVE GREEN ROOF	INTENSIVE GREEN ROOF
Maintenance	Low	Periodically	High
Plant communities	Moss-Sedum-Herbs and Grasses	Grass, Herbs and Shrubs	Lawn or Perennials, Shrubs and Trees
System build-up height and weight	60 – 200 mm 60 – 150 kg/m^2 13 – 30 lb/sqft	120 – 250 mm 120 – 200 kg/m^2 25 – 40 lb/sqft	150 – 1000 mm 180 – 500 kg/m^2 35 – 100 lb/sqft
Costs	Low	Middle	High

Source: Adapted from International Green Roof Association n.d.

Despite the costs, green roofs offer some unique benefits. Properly sized and maintained green roofs can extend the life of the underlying roof, and they can also provide significant value to cities struggling with stormwater management. Further, in dense urban areas with insufficient green space, green roofs provide additional space, with all the co-benefits that green cover brings. Residents and community groups can use this space for community gardens, which would be particularly beneficial in food deserts. Commercial rooftop agriculture can also provide jobs and economic benefits.

Given the cost premium, there is a risk that wealthy residents would largely benefit from green roofs on office buildings or condominiums. Instead, planning green roofs for public buildings, such as libraries, recreation centres and public housing would allow all residents, especially low-income ones, to enjoy the benefits. Likewise, when establishing new development zoning requirements, green roofs that are not accessible to the public should not count towards the percentage of required green spaces in the development zone.

Green walls are vertical systems of plants that are attached to an internal or external wall or are free-standing. Typically used on or in buildings, green walls can also be part of streetscapes, for example on columns or fences lining busy roadways to reduce air pollution and noise. A major benefit of outdoor green walls is that they are highly visible to the public and can provide a tangible image of a cooling initiative that might otherwise be less visible. Green walls are less common than other strategies, so markets are less developed and prices are often high. As prices fall, green walls can be a useful part of a city's cooling portfolio, especially in dense areas.

6.4 CONCLUDING NOTE

New development offers opportunities for city planners, parks departments and public works departments to plan for cooler urban areas from the start. Choosing where to site different types of buildings, planning for alternative modes of transport, and ensuring adequate, distributed and healthy green spaces can reduce the potential for urban heat in the first place. Even in already developed areas, cities have significant opportunities to encourage mode shift, add trees and other shading elements, connect green spaces, and use cool and reflective materials. In most cities, it will be cost-effective and justifiable to increase the proportion of green cover (water resources allowing), create green corridors, use cool roofs, use reflective pavement where appropriate, design for shading and ventilation, and shift transport away from single-occupancy vehicles. Qualitative costs and benefits of interventions for cities (assessed for both developed and developing-city typologies) are presented in figure 4.2.

FURTHER RESOURCES

- ***Primer for Cool Cities: Reducing Excessive Urban Heat,*** ESMAP, 2020. https://openknowledge.worldbank.org/handle/10986/34218
- ***A Practical Guide to Cool Roofs and Cool Pavements,*** Global Cool Cities Alliance, 2012. https://coolrooftoolkit.org/read-the-guide
- ***Smart Surface Analytic Tool,*** Smart Surfaces Coalition. https://smartsurfacescoalition.org/costbenefit-analytic-tool
- ***Urban Cooling Toolbox,*** C40, 2021. https://www.c40knowledgehub.org/s/article/Urban-Cooling-Toolbox
- ***Handbook on Achieving Thermal Comfort Within the Built Environment: Volume II,*** TARU Leading Edge, 2015. https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/thermal_comfort_handbook_volume_ii.pdf
- ***World Urban Database and Access Portal Tools (WUDAPT).*** https://www.wudapt.org
- ***IGNITION project***, Greater Manchester, UK. https://www.greatermanchester-ca.gov.uk/what-we-do/environment/natural-environment/ignition
- ***Principles for Delivering Urban Nature-based Solutions,*** UK Green Building Council, 2021. https://www.ukgbc.org/wp-content/uploads/2021/04/Principles-for-Delivering-Urban-Nature-based-Solutions-April-2021.pdf
- ***City-wide Public Space Assessment Toolkit: A guide to community-led digital inventory and assessment of public spaces,*** United Nations Human Settlements Programme (UN-Habitat), 2020. https://unhabitat.org/city-wide-public-space-assessment-toolkit-a-guide-to-community-led-digital-inventory-and-assessment

RECOMMENDED CITY ACTIONS

06

Heat accumulates in cities as a result of surfaces that absorb sunlight, anthropogenic sources of heat and the shape of the built environment. Cities can reduce urban heat by reducing solar gain, reducing the amount of heat produced in the city and dissipating heat. Measures for mitigating urban heat include attention to urban form and planning and using nature-based solutions and cool surfaces.

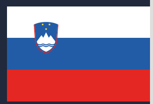
NO-REGRETS ACTIONS

- Establish the authority to expand zoning and planning requirements to include:
  - minimum area and distribution of green spaces
  - increased ventilation and waste heat management
  - street trees
  - cool and reflective surfaces.
- Preserve and establish authority/process to set aside land for green and blue spaces.
- Increase street tree coverage in high-priority areas.
- Add shading structures in key public areas.
- Apply cool roofs to all city-owned buildings.
- Use reflective surfaces in areas that will not cause unintended consequences (*e.g.*, parking lots).

CITY INTERVENTIONS CATALYSED BY TRIGGER POINTS

Trigger points					Interventions
1 Planned new development and/ or major re-development	2 Introducing or initiating city planning processes	3 Introducing new or updated codes/ zoning requirements	4 Evaluating or initiating major city infrastructure projects	5 Evaluating city land acquisition/sale	
✓	✓		✓		Prioritize mixed-use/transit-oriented development.
✓	✓				Incorporate shade and ventilation in the urban form.
✓	✓	✓		✓	Set aside green and blue spaces.
✓	✓		✓		Incorporate cool corridors.
		✓			Incorporate high-impact beyond-code requirements (or by-laws) such as for cool surfaces.
			✓		Evaluate the opportunity to use thermally efficient construction materials.

CASE STUDY 6.1 | VISION – LJUBLJANA, SLOVENIA



HIGHLIGHTS:

- Reducing driving
- Promoting alternative modes of transport
- New green areas
- Tree planting
- Ecosystem connection/green corridors

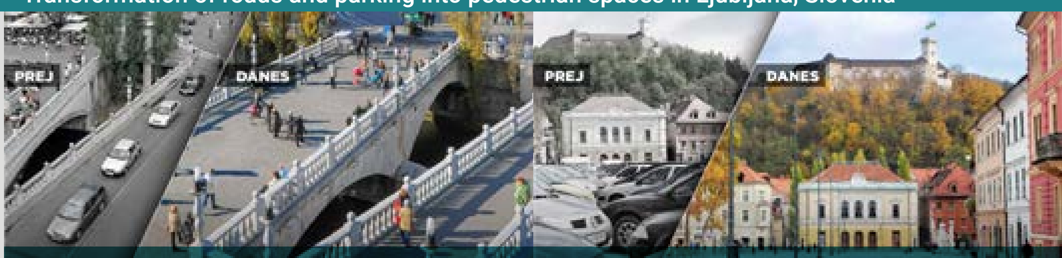
ADDITIONAL CHARACTERISTICS:

- People-centric development
- Public financing (local and national)

When Ljubljana produced its 2025 Vision in 2007, it had been over 20 years since the capital region's last comprehensive plan. In keeping with the city's existing high proportion of green space, two of the vision's three guidelines are to keep Ljubljana "an attractive, people-friendly city full of greenery" and to "provide direct access to open areas and the connectedness of the landscape system".

The flagship project implementing these guidelines is the Ecological Zone in downtown Ljbuljana. Beginning in 2007, the city closed over 10 hectares in the city centre to motor vehicle traffic, renovated major roads to be more pedestrian friendly, promoted walking and cycling (*e.g.*, a very successful bikeshare programme), planted trees, and provided free electric taxis to tourists and mobility-impaired residents. At the same time, Ljubljana was being overwhelmed with car commuters, so it modernized its public transport system, set up park-and-ride facilities on commuter routes and created dedicated bus lanes. These complementary efforts reduced downtown air temperature, air pollution, and noise pollution, highlighting key synergies between planning for green space and transport reduction.

Transformation of roads and parking into pedestrian spaces in Ljubljana, Slovenia



CASE STUDY 6.2 | SUPERBLOCKS AND GREEN AXES – BARCELONA, SPAIN

HIGHLIGHTS:

- Comprehensive planning
- People-centric development

ADDITIONAL CHARACTERISTICS:

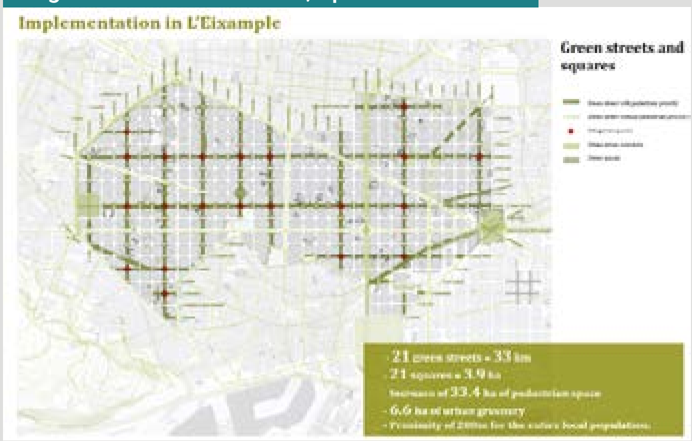
- Public financing (local)

In 2016, Barcelona began creating superillas, or "superblocks" – six groups of city blocks where car traffic was minimized in the interior and the resulting space was repurposed for community use. Now, according to the City, "[t]he Superblock programme is taking a step ahead and becoming the street transformation model for the entire city, with the aim of reclaiming for citizens part of the space currently occupied by private vehicles" and creating "healthy, greener, fairer and safer public space".

The project will begin in the Eixample district, one of the most trafficked areas of the city. Barcelona plans, from 2022 to 2032, to convert 21 streets and 21 intersections in Eixample into small parks and public squares. These conversions will represent one in three streets in the neighbourhood, covering an area of over 33 hectares. These "green axes" are meant to reduce air pollution and increase safety. Most car traffic will be restricted, and public transport will increase. The winning design proposals include elements such as tree pits, flower beds, permeable pavements and tree canopies meant to provide strategic shade.

Public spaces for kids to play in the street, Sant Antoni neighborhood Sant Antoni, Barcelona, Spain

Plan for green streets and squares in L'Eixample neighborhood of Barcelona, Spain



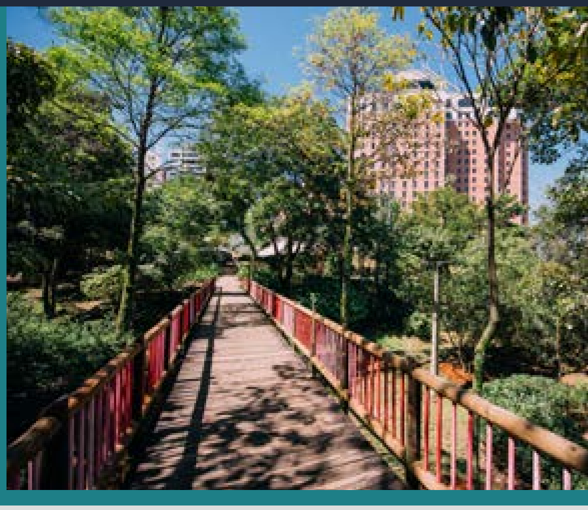
CASE STUDY 6.3 | GREEN CORRIDORS – MEDELLÍN, COLOMBIA

HIGHLIGHTS:

- Green corridors
- Tree planting

ADDITIONAL CHARACTERISTICS:

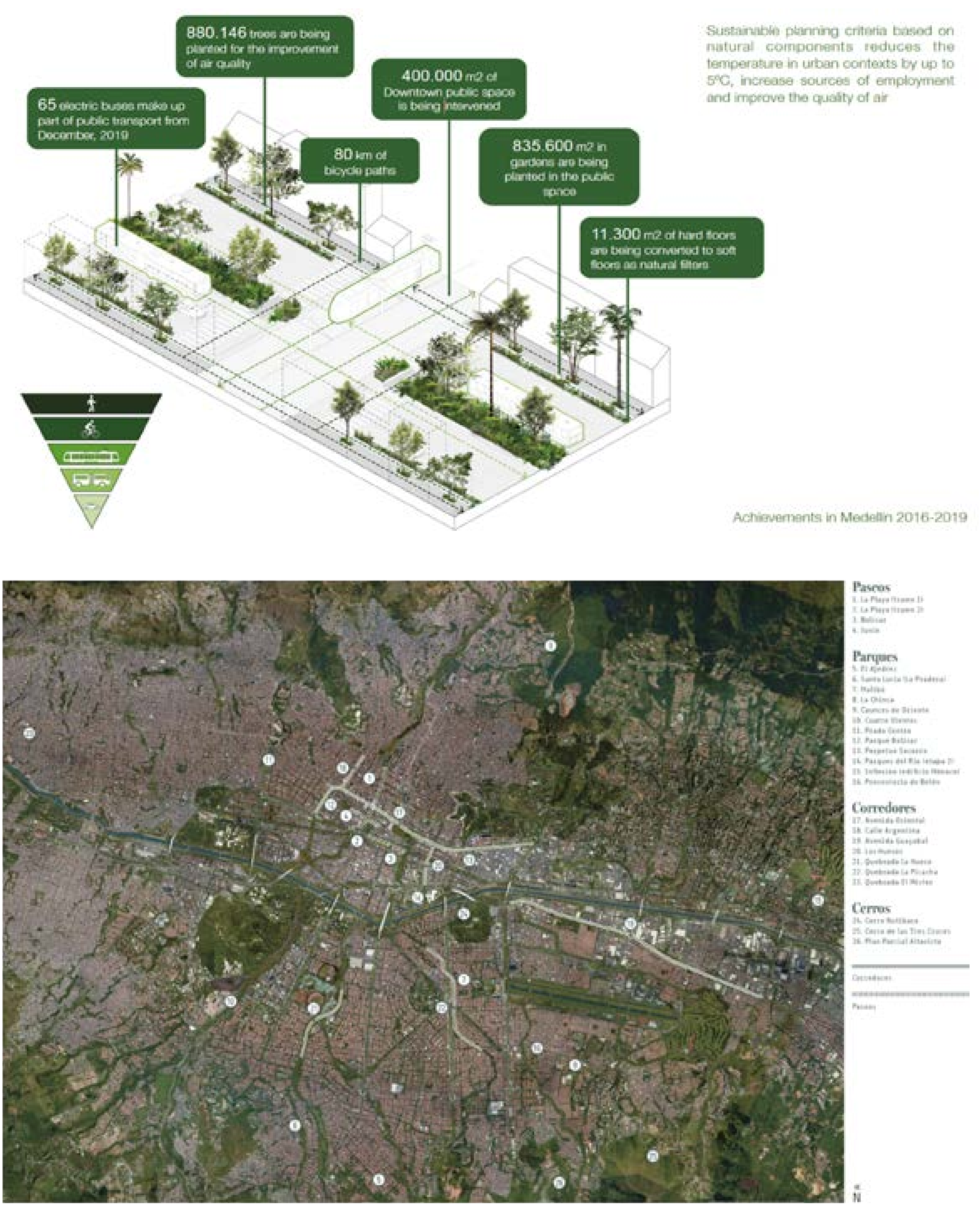
- Comprehensive planning
- People-centric development
- Participatory project design
- Public financing (local)



After experiencing rapid, unplanned growth that eliminated green spaces, created significant urban heat islands, and increased air pollution and respiratory diseases, the 2016-2019 Government Plan of the Mayor's Office of Medellín set goals to make the city healthier, more sustainable and equitable. Under the banner of the "Medellín, Environmental Urbanism" project, the city created green corridors that would follow and restore the geography of the area prior to recent development. From 2016 to 2019, the city created 36 corridors, 18 along major roads and 18 along waterways, covering over 36 hectares. The corridors connect the urban periphery, including neighbourhoods where vulnerable populations live, with the urban centre.

In addition to providing all the benefits of greening, the corridors provide safer and more comfortable access to transit options. Studies confirmed that areas with the least green spaces had the highest temperatures, so green corridors were focused on these areas. The areas with green corridors have already seen temperature reductions of up to 4°C.

Diagram of elements in a cool corridor (top) and map of existing and planned corridors (bottom) in Medellín, Colombia



DISTRICT COOLING 07

7.1 AN INTRODUCTION TO DISTRICT COOLING

In addition to the greater adoption of urban heat island mitigation strategies and building passive cooling approaches that can reduce cooling loads, mechanical cooling solutions for serving these loads will typically still be required. The business-as-usual approach to mechanical cooling solutions revolves around distributed equipment procured by developers and contractors that typically prioritize first-cost, ease of installation and ease of allocation of operating cost, with efficiency being of secondary consideration. Where long-term building owners are involved in the procurement decision, life-cycle cost, including efficiency, may gain greater prominence, but broader sustainability and equity considerations less so. And with the anthropogenic heat that air conditioners expel into the environment, further exacerbating the urban heat island effect, we are back to the vicious cycle where mechanical cooling is further warming our cities, necessitating even more cooling[22] and disproportionately impacting those that do not have the financial resources necessary to procure mechanical cooling solutions.

22 An estimated 20 per cent of urban warming. See Takane et al. 2019.

There is another way that is specific to dense urban environments that avoids local heat rejection: district cooling. Implementing district cooling systems in dense urban environments provides an opportunity to provide the same cooling utility as distributed cooling systems but with up to 50 per cent lower energy and emissions impact,[23] while avoiding the urban heat island effect associated with distributed equipment. In many climate zones that also have heating needs, district cooling can and should be considered in conjunction with district heating and even combined heat and power, leveraging locally available renewable resources; together, these are referred to as district energy. The focus of this guide, however, is on district cooling.

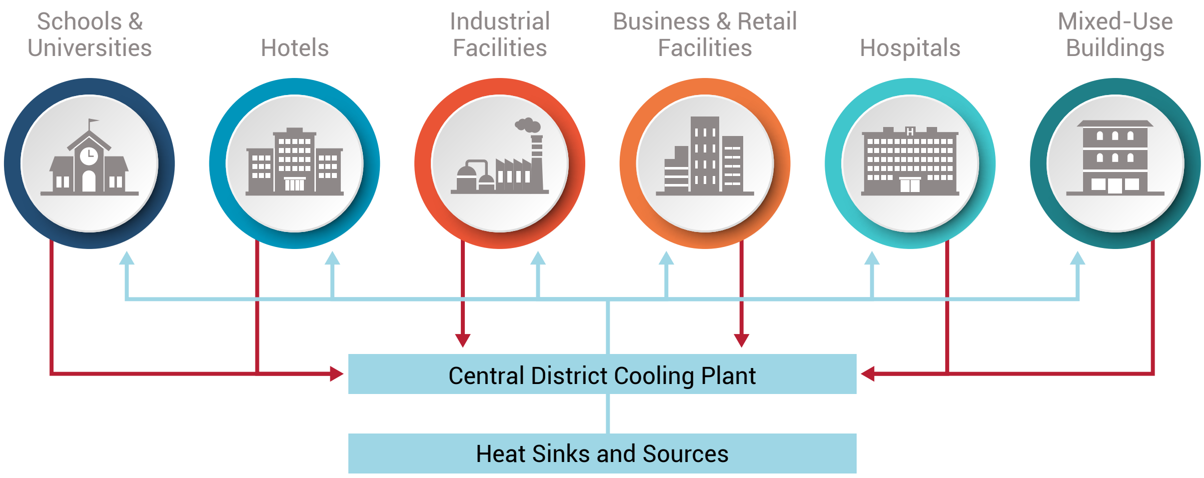
In district cooling systems (figure 7.1), chilled water is produced at a central chiller plant, which typically comprises multiple electric water-cooled chillers, although sometimes absorption chillers powered by locally available heat sources can be utilized. The chilled water is then distributed through insulated pipe networks, typically buried underground, to customer buildings. Heat exchangers in these buildings distribute the chilled water to air-handling or fan coil units, which in turn deliver the cooling demanded by the building. The supplied water, having absorbed heat from the customer's building, flows back to the central plant through a separate return pipeline, where it is again chilled and re-distributed.

As compared to distributed cooling systems, a district cooling plant provides significant efficiencies and economies of scale, partially offset by the pumping energy and thermal losses, and implementation cost associated with the distribution system. Of the estimated 2,199 TWh of cooling energy utilized for space cooling each year, an estimated 83 TWh is delivered by district cooling, with the greatest penetration in the United States followed by the United Arab Emirates and Japan (IEA 2019; IEA 2020).

Understanding the advantages and limitations that follow can help ensure the most appropriate application of what is widely viewed as the most sustainable mechanical cooling solution (when well designed) for dense urban environments.

23 Based on analysis done by the RMI. The analysis assumes a typical aggregated plant coefficient of performance (COP) of around 6 – including high-efficiency, variable-speed centrifugal water-cooled chiller, pumps and cooling towers. COP is a measure of the cooling efficiency expressed in terms of the refrigeration capacity at full load (in watts) per unit of electrical input power (in watts).

Figure 7.1 District cooling system



Source: RMI

7.2 WHY DISTRICT COOLING? UNDERSTANDING ITS ADVANTAGES AND LIMITATIONS

Subject to sufficient scale and density, district cooling can provide the lowest life-cycle and environmental cost in providing mechanical cooling to a district, incorporating all the benefits typically associated with a service delivery model (where customer buildings procure the service of cooling, not the assets that deliver the service). Understanding the advantages, limitations, potential barriers and typical trigger points that can enable a city to "step into" district cooling is critical to its integration to a city's plans and objectives alongside other utility infrastructure.

ADVANTAGES OF DISTRICT COOLING

Where an appropriate fit, the advantages of district cooling systems are many. The advantages start with the inherent "cooling as a service" business model, where building owners and users pay for the cooling that they use under long-term supply agreements, and system developers and operators earn their highest returns through ensuring that the supply of cooling is optimized for the lowest life-cycle cost. District cooling plants typically have a design operating life in excess of 30 years. Thus, optimizing for the lowest life-cycle cost will incorporate any efficiency measures that deliver a positive net present value after discounting at the investor's cost of capital. This approach benefits from:

- **Aligned incentives:** Under this model, incentives are fully aligned: district cooling customers seek to minimize demand for cooling, which is largely a variable cost to them, and suppliers seek out the lowest life-cycle cost of delivering cooling services. They do this by procuring the highest-efficiency cooling solution along with high-quality operation and maintenance practices, which enhances their profitability and competitiveness.
- **Use of best-in-class technology:** Although direct comparisons of systems are difficult due to the variables of a specific application, the performance rating of a high-efficiency, variable-speed centrifugal, water-cooled chiller plant, most typically used in electric-powered district cooling applications, will be 35-40 per cent more efficient than the best-in-class air-cooled chiller plant and around 80 per cent more efficient than a standard residential air conditioner.[24] Although any evaluations are subject to local conditions as a guide, it can be assumed that a well-designed district cooling plant utilizing cooling towers will conservatively be 55-65 per cent more efficient than a business-as-usual approach to cooling but will be subject to up to 15 per cent of pumping and thermal losses through the distribution network.
- **Ability to utilize heat sinks (or free cooling sources):** District cooling systems can more economically leverage heat sinks and even free cooling through natural bodies of water (see case studies 7.1 and 7.4) or geo-exchange[25] – taking advantage of the lower temperatures found underground – further increasing efficiencies in a way that is very difficult and expensive for distributed cooling systems to access. This can also avoid the requirement for make-up water associated with cooling tower use. A further advantage of heat sinks, although somewhat dependent upon diurnal and seasonal temperature changes that help recharge these sinks, is the avoidance of anthropogenic heat that is emitted by air-cooled solutions into the urban environment. If considering heat sinks, geo-technical conditions have to be assessed along with potential environmental risks of using natural water sources, primarily the impact on temperature levels in the water body, which, if raised materially, can affect nutrient balances, lead to deoxygenation and hurt local ecology.
- **Lower aggregate energy consumption:** While there are many variables to be considered in undertaking a cost and sustainability comparison of a district cooling system, compared to business-as-usual individual building systems an optimally sized district cooling system can be expected to operate with a net 40-50 per cent less energy for the served cooling load after deducting pumping and thermal losses through the distribution network, as compared to aggregate business-as-usual distributed cooling systems – and potentially more depending on the availability of heat sinks and free cooling sources (Power Engineering International 2015).
- **Ability to shift cooling loads:** Where demand response or utility time-of-use pricing is in place, significant economic benefits can accrue by shifting cooling loads typically accomplished by thermal storage, or more simply by making cold water or ice at times of low peak and pricing and utilizing this to deliver cooling at times of peak load and pricing. In urban environments where cooling can make up to 60 per cent of the peak cooling load, this can materially reduce required power generation and distribution capacity investments (Asian Development Bank 2017). The ability to shift loads will surely become more important with the increased variability of supply resulting from deeper penetration of renewable sources into the grid.

24 This is based on a typical aggregated plant COP of around 6 – including high-efficiency, variable-speed centrifugal water-cooled chiller, pumps and cooling towers. COP is a measure of the cooling efficiency expressed in terms of the refrigeration capacity at full load (in watts) per unit of electrical input power (in watts).

25 See case studies 7.1 and 7.4 as examples of leveraging free cooling through natural bodies of water.

- **Lower aggregate installed cooling capacity:** District cooling systems are typically sized for the highest aggregate cooling loads that can occur simultaneously across all the buildings being served, rather than the sum of the individual peak cooling loads of each building, This approach takes advantage of non-coincident cooling loads – that is, loads that naturally appear at different times of the day or week These include, for example, the sports complex that needs cooling for weekend events, the factory or office building that needs cooling during the workday, and the residential buildings that need cooling in the evening and through the night. With the addition of thermal storage, the aggregate installed cooling capacity can be further optimized by shifting cooling loads away from periods of highest use. This results in a significant reduction of installed capacity versus the distributed cooling systems model, providing further economic enhancement to the cost model. In a recent example, the assessment study of needed cooling capacity at GIFT City India, when fully built out the district cooling system would reduce the requirement for installed cooling capacity from 270,000 tons of refrigeration to 180,000 tons of refrigeration (945 megawatts (MW) of refrigeration to 630 MW of refrigeration).
- **Avoided capital costs for power providers:** With the much higher energy efficiency of district cooling and the ability to shift loads away from the peak, developing markets in particular could avoid the significant power generation and distribution infrastructure associated with business-as-usual growth in cooling demand.
- **Avoided capital costs for building developers and owners:** Connecting to a district cooling system avoids the need (and costs) for building a dedicated cooling plant and also frees up the square footage for other uses.
- **Accessibility:** With the elimination of the larger part of the capital costs associated with distributed cooling, affordable access to cooling is enhanced as it can be procured as a service with demand managed to align with financial constraints. This is somewhat dependent upon the fee structure, which can include one-time connection fees, fixed capacity availability charges and variable consumption fees with access enhanced, where variable consumption fees are the primary method of charging.
- **Increased reliability:** District cooling provides a more reliable and convenient supply of cooling due to its use of industrial-grade equipment and professional maintenance and operations staff and is able to cost effectively provide equipment redundancy.
- **Refrigerant management:** Central cooling systems have a considerably reduced risk of refrigerant leakage because they are actively maintained – as compared to distributed mechanical cooling solutions that will only be periodically maintained – and have a lower aggregate refrigerant charge associated with the lower aggregate installed capacity. Further, in district cooling there is an opportunity to utilize natural refrigerants and new refrigerant blends with low global warming potential that, due to their toxicity or flammability concerns, may be less acceptable for use in distributed equipment.
- **Greater opportunity to deliver on broader social objectives:** Under a public or hybrid business model, there is an opportunity to deliver on broader social objectives such as subsidized social housing supply, community cooling centres, and underground pedestrian and transit tunnels in support of transport system mode-shift initiatives.
- **Ancillary benefits:** Without the need to build dedicated equipment rooms, rooftop equipment and cooling towers, these spaces can be used to enhance building values whether through occupation, leisure facilities or building-integrated solar energy. Other benefits include the preservation of building façades from the installation of distributed cooling equipment, the reduction of cooling noise pollution, and the reduced risk associated with poor maintenance of cooling towers and potential pathogen release.

LIMITATIONS AND POTENTIAL BARRIERS OF DISTRICT COOLING

Over and above the sufficient scale and density required to make district cooling a viable solution, it is important to also understand inherent limitations and potential barriers.

- **Typically suited for new construction zones, districts or cities:** Existing buildings and zones are unlikely to be good candidates unless a unique set of conditions, or trigger points, exist. This is due to the increased costs and disruption of deploying a distribution network under existing streets and the loss of the avoided capital advantage, as existing buildings are likely to have mechanical cooling solutions already in place. The Climespace system in the City of Paris, France (case study 7.1) is a powerful example of how district cooling can be expanded over time in existing cities in conjunction with trigger points.

- **Require sufficient scale, density and diversity of loads:** District cooling systems are most effective when meeting the demand for multiple buildings, communities and districts. These systems are typically sized for the highest aggregate cooling load, which occurs simultaneously across all the buildings being served, rather than the sum of the individual peak cooling loads of each bringing some first-cost benefits that help overcome the costs of building a distribution network of chilled water piping and pumps. Insufficient scale, density or load diversity can combine to make a project non-viable, as these can equate to outsized distribution networks connected to a sub-scale district cooling plant.

- **Requires significant upfront infrastructure investment:** A potential barrier relates to the significant upfront investment necessary for the distribution network. Although typically for a greenfield development this will fall in the range of 15-25 per cent of the initial investment, it can represent as much as 75 per cent of a completed district cooling plant and network, depending on the length, local costs and complexity of deployment (especially in regard to deployment within existing city infrastructure) (Dinçer and Zamfirescu 2011).

- **Sufficient assurance of future off-takers is key to developing the system:** In addition to the typical risks associated with large-scale infrastructure development projects – such as design risk, permitting risk, construction risk, financing risk, fuel pricing risk and downstream operation risk – the primary risk for a district cooling plant developer is the "off-take risk" – that is, if it is built, will customers connect and the revenues flow. This is a key reason that district cooling does not scale by chance – it requires a framework of urban planning and municipal engagement, an understanding of trigger points that can point towards a potentially successful implementation, along with the primary enabling business models that can support public, private or hybrid development.

- **Access to technical assistance and "know-how":** A lack of institutional support or know-how can represent a significant barrier to cities looking to explore the district cooling opportunity in countries where district cooling is either non-existent or nascent. Access to technical assistance through multilateral organizations can present a pathway. Most notably, UNEP's District Energy in Cities Initiative is working with national governments to establish city support programmes giving technical assistance for district energy and to make available country-appropriate methodologies, tools and guidance. Beyond technical assistance, support services can be procured from the many international engineering consultancies that have developed the requisite expertise as the market for these solutions has expanded.

7.3 EVALUATING A DISTRICT COOLING APPROACH

The starting point for a city is to understand how district cooling fits into its sustainability, economic development and urban development objectives. Once it becomes embedded as a part of these objectives, then the evaluation of implementation becomes possible.

Trigger points: In the life of every city there are trigger points that indicate the viability of a district cooling approach. These trigger points are likely already visible within established urban planning and design frameworks and master plans. Some of the typical trigger points would include:

- Construction of large public facilities or a zone of new buildings or greenfield development is being planned.
- Large public facilities or a zone of existing buildings are being renovated, or a brownfield re-development is planned.
- Cooling systems within large public facilities are approaching the end of their useful life and replacements are planned.
- Major city infrastructure projects that could provide for a lower-cost deployment of the requisite cold water distribution system are being planned, such as sewage, utility or transit projects.

The scale of cooling loads, density and end-use diversity of these trigger points will determine the economic feasibility of district cooling, but it should be noted that district cooling often starts with smaller systems than optimal (as low as 3,000 to 5,000 tons of refrigeration capacity (10-17 MW of refrigeration) depending on local conditions), in alignment with the phasing of a development, but with the opportunity for expansion or integration with other nodal systems within the city environment.

Not only cooling: For each of these trigger points, the opportunity should be taken to look not only at cooling but also at any heating needs, as significant synergies will exist between the two. Not least of these is the opportunity to utilize heat pump chillers that are able to provide both cooling and heating simultaneously at even higher efficiency levels, as well as the use of any available waste heat of sufficient grade (*i.e.*, over 93°C for single-stage absorption chillers) that is able to be added to a network.

Depending on the nature of the development, there may well be an opportunity to expand further to a full Integrated Energy Services Provider (IESP) model, integrating cooling and heating with renewable energy and energy efficiency into the buildings connected to the network. This evaluation would typically need to be undertaken with reference to existing energy maps for the city.

Off-take risk: For each trigger point, the opportunity to reduce off-take risk is a key element of the evaluation and will ultimately have an impact on project viability and the eventual business model used.

- The presence of credit-rated anchor clients significantly reduces off-take risk. As an example, having a city government enter into a long-term agreement to take a significant proportion of cooling from the district cooling plant supports project viability and helps lower the cost of financing under a private or hybrid developed model.
- In greenfield and brownfield development, the opportunity to apply positive covenants (or zoning requirements) to the land that require developed buildings to connect to the district cooling plant will bring enhanced certainty of demand, supporting project viability and helping lower the cost of financing under a private developer model. In Hong Kong, all non-domestic buildings in the Kai Tak development must connect to the district cooling system, including hotels, hospitals, shopping centres, government offices and a planned multi-purpose stadium. In Dubai, all public sector buildings and all new developments are required to connect to the district cooling system (UNEP 2015).

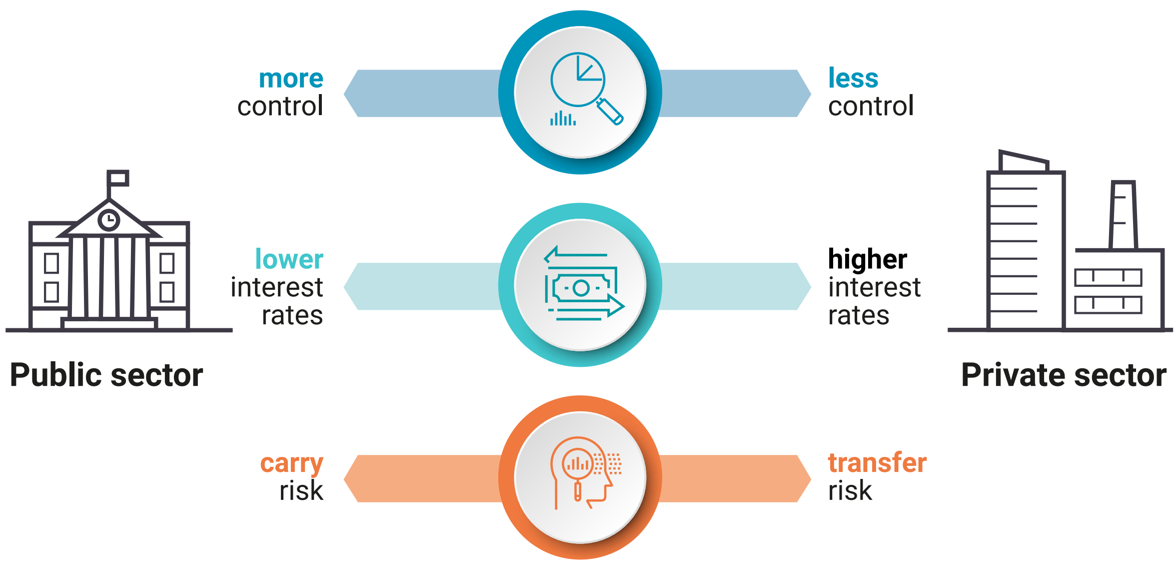
- Where off-take risk cannot be satisfied through anchor clients or positive covenants, some level of public and developer underwriting – such as through guaranteed minimum off-take, or take-or-pay arrangements – may be required in order for a project to move ahead.

The approaches to satisfying off-take risk all result in a potential monopolistic situation, and public oversight of tariffs should be considered. To ensure that end users who are mandated to connect are not disadvantaged, profits to district cooling companies are capped (as in Copenhagen), or tariffs are regulated to be lower than the life-cycle cost of similar technologies (as in Singapore) (UNEP 2015).

7.4 THREE PRIMARY DISTRICT COOLING BUSINESS MODELS

Although there are business model derivatives under each, there are three primary business models: public sector, private sector and a combination of the two (hybrid models). The fit with a city's economic, environmental and social plans, and the scope of services to be delivered (from district cooling to district energy) – along with a city's capacity to finance and tolerance for risk, as represented in figure 7.2 – will determine if a public sector option is viable.

Figure 7.2 Business model drivers for district cooling

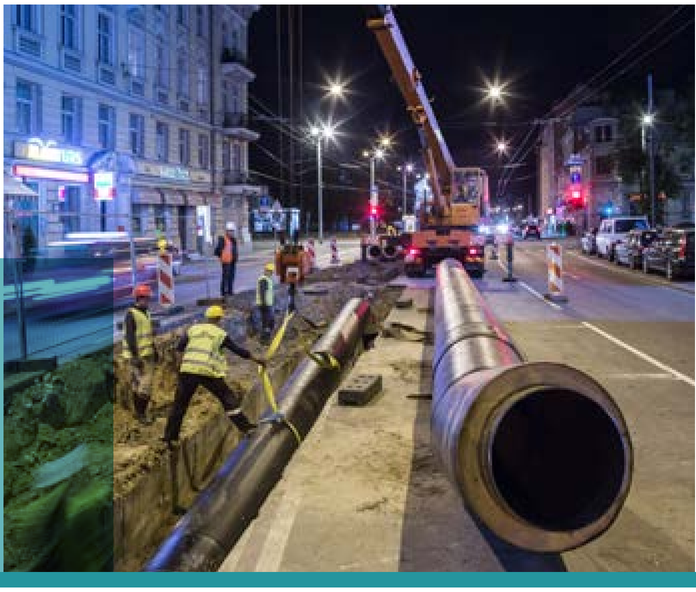


Source: Adapted from King 2012

The vast majority of district cooling plants fall under the hybrid (public/private) or private sector model. The higher interest rates associated with private sector financing can be offset with public sector underwriting or public sector supported off-take risk mitigation strategies, as described previously. This also reflects the favourable economics of a well-designed district cooling system, where lower costs of cooling can be delivered to building owners and occupiers while allowing for an attractive return on investment for private sector developers and operators.

Before selecting a model, a technical and financial feasibility study should be undertaken to determine if a project has a return on investment that will attract the private sector and the level of control desired by a local authority.

- **A wholly public business model:** The public sector, in its role as local authority or public utility, has full ownership of the system, which allows it to have complete control of the project and makes it possible to deliver broader social objectives, such as environmental outcomes and the alleviation of fuel poverty through tariff control. Under the public model, the local government will need to raise the capital for the project and carry full project risk. For broader district energy systems (incorporating heating and often combined heat and power), this model is the most common globally.



- **A hybrid (public/private) business model:** Under this model, a sufficient rate of return becomes necessary in order to attract the private sector, but the public sector is still willing to invest in the project, typically to retain some control. The arrangements can include:
  - A public and private joint venture where investment is provided by both parties that are creating a district cooling company, or where the private and public sector finance different assets in the district energy system (*e.g.*, production of heat/cooling versus transmission and distribution where timing of necessary investments can be materially different).
  - A concession contract where the public sector has some involvement in the design and development and possible ownership of a project, which is then developed and operated by the private sector for the period of the concession with hand-over provisions at the conclusion of the concession term. This approach is very much aligned with the public-private partnership model that is widely used to develop public infrastructure.

The growth in district cooling has attracted private sector companies, often part of major utilities, in the space, ensuring a competitive market. This relieves cities from having to identify and secure financing themselves, but it can reduce the amount of control that a city is able to maintain over its district cooling system. One of the approaches to maintaining an element of control, outside of regulation, is the opportunity for partial ownership of the district cooling system through investment or provision of land and distribution infrastructure. This would result in partial profit allocation back to the city that can be used for investments aligned to the social agenda of the city, such as subsidized cooling for social housing or community projects.

- **A private sector business model:** Where sufficient financial rate of returns are available, the full resources and expertise of the private sector can be engaged in the design, development and construction of the project. While public sector support is still required in order to mitigate off-take risk – that is, public sector off-take commitments, positive covenant support, financial incentives or subsidies – the primary risks of the project are transferred to the private sector.

7.5 FEASIBILITY ANALYSIS

While it is beyond the scope of this guide to detail the approach to a full feasibility analysis, a feasibility analysis is a critical assessment and evaluation tool covering technical, economic and commercial feasibility. A city government should ensure that providers of technical assistance and consulting services include the following major assessment components:

- Exploring the availability of grants and public sector funding for a feasibility study.
- Urban development design and plans, including land-use, energy and transit master plans.
- Understanding the thermal efficiency of buildings to be developed and to what extent this can be enforced through zonal codes.
- Projections for future cooling, heating and energy loads to help determine the appropriate scope (*i.e.*, district cooling or district energy incorporating sustainable heating and renewable energy solutions).
- Mapping future cooling demand and diversity factors to determine required capacity.
- Availability of waste thermal energy of appropriate grade (such as waste heat or waste cold from liquefied natural gas regasification plants) that can be used as an energy source.
- Availability of heat sinks or free cooling (such as water bodies, or ground access and soil suitable for ground-source cooling).
- Review of piping routes and topology for installing the distribution system.
- Undertaking an environmental impact assessment for the project.
- Developing an outline system architecture and technical solution, iterated based on life-cycle cost modelling outputs but ensuring that future expansion and technical future-proofing are considered.

- Developing a district cooling economic model based on life-cycle cost, typically using a 25-30 year term (construction and operations). Typically, multiple models will need to be run to identify the optimal, or lowest net present value life-cycle cost, by optimizing around system architecture, technical design and project phasing.
- Performing a sensitivity analysis and stress test assumptions to mitigate any bias. This should include development risk, such as real estate development that proceeds faster or slower than is planned, impacting customer connection timelines.
- Developing a baseline business-as-usual economic model based on life-cycle cost aligned to the district cooling life cycle, which will need to include asset replacement of shorter-life air-cooled cooling equipment.
- Once the life-cycle costs for the business-as-usual alternative is established, the price level for a district cooling service to customers can be developed. Here the challenge is creating a price level that is appealing to the customer and that secures a revenue stream that is sufficient to get the district cooling system financed and realized.
- Determining an optimal price structure between connection, capacity and usage fees to ensure that building developers, owners and occupiers each benefit from the advantages of a district cooling approach.
- Identifying and, where possible, quantifying ancillary impact differences between the two scenarios (*i.e.*, societal, environmental, energy system, community and development).
- Identifying project risks including off-take risks and permitting requirements.
- Identifying strategies to mitigate identified project risks.
- Determining an appropriate business model.
- Updating integrated development, energy and financial master plans.

FURTHER RESOURCES

- ***District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy*, United Nations Environment Programme, 2015.** https://wedocs.unep.org/handle/20.500.11822/9317
- ***District Energy in Cities Initiative homepage*, United Nations Environment Programme.** http://www.districtenergyinitiative.org
- ***Sustainable District Cooling Guidelines*, International Energy Agency, 2020.** https://iea.blob.core.windows.net/assets/a5da464f-8310-4e0d-8385-0d3647b46e30/2020_IEA_DHC_Sustainable_District_Cooling_Guidelines_new_design.pdf
- ***Governance Models and Strategic Decision-making Processes for Deploying Thermal Grids*, International Energy Agency, 2017.** https://www.districtenergy.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=e24e4c4e-3cd8-825e-d1eb-518dc945632c&forceDialog=0
- ***Community Energy: Planning,* Development and Delivery, International District Energy Association (M. King), 2012.** https://higherlogicdownload.s3.amazonaws.com/DISTRICTENERGY/998638d1-8c22-4b53-960c-286248642360/UploadedImages/Documents/Publications/USCommunityEnergyGuidelo.pdf

RECOMMENDED CITY ACTIONS

District cooling does not scale by chance – it requires a framework of urban planning and municipal engagement along with an understanding of trigger points that can enable a city to step into district cooling. While the opportunities may be greater in cities experiencing rapid development, opportunities will present themselves in all cities over time, and the key is to be prepared and to recognize the trigger points as they present themselves.

The scale of cooling loads, density and end-use diversity associated with these trigger points will determine the economic feasibility of district cooling. However, it should be noted that district cooling often starts with smaller systems than optimal, in alignment with the phasing of a development, but with the opportunity for expansion or integration with other nodal systems within the city environment over time.

NO-REGRETS ACTIONS

- Establish the authority to apply positive covenants applicable to district cooling connection on land to be developed/re-developed.
- Establish procedures to trigger evaluation of district cooling opportunity when cooling systems within large public facilities approach the end of life and replacements are being planned.

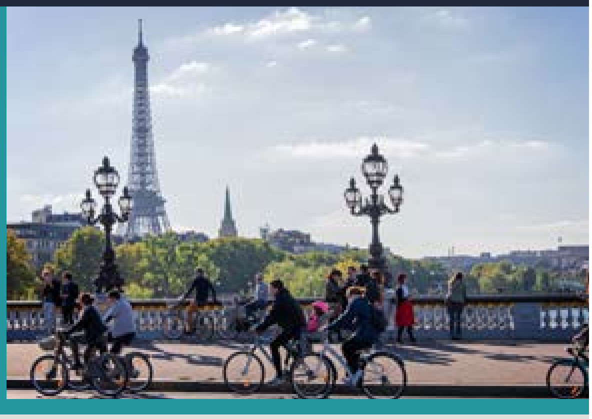
CITY INTERVENTIONS CATALYSED BY TRIGGER POINTS

Trigger points					Interventions
1 Planned new development and/ or major re-development	2 Introducing or initiating city planning processes	3 Introducing new or updated codes/ zoning requirements	4 Evaluating or initiating major city infrastructure projects	5 Evaluating city land acquisition/ sale	
✓					Explore the viability of district cooling to serve the cooling demand.
✓		✓			Where viable, apply positive covenants applicable to district cooling connection on land to be developed or re-developed.
	✓				Integrate mapping of future cooling demand.
			✓		Evaluate the opportunity to synergistically integrate a chilled water distribution system that would support a planned future district cooling system.
				✓	Identify and set aside land that would be suitable for district cooling development.

CASE STUDY 7.1 | CITY OF PARIS, FRANCE

HIGHLIGHTS:

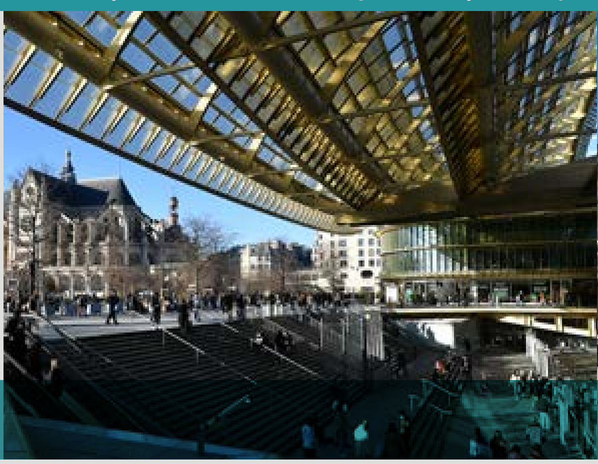
- **Hybrid model (public ownership, concession)**
- **Overcoming cost barriers to existing city deployment**
- **Use of heat sinks (or free cooling)**
- **Use of thermal storage**
- **Connected system with 10 distinct district cooling plants**
- **Regulated tariffs under the concession structure**

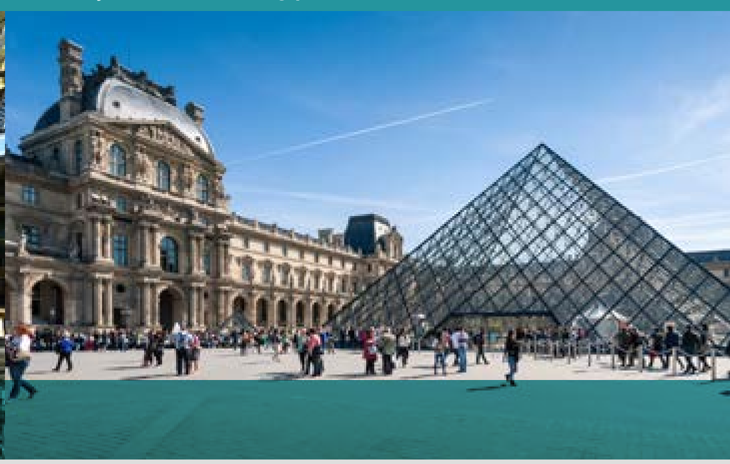


Paris has the first and largest district cooling system in Europe (Riahi 2015). Since 1991, Climespace, an ENGIE subsidiary, has had a concession to operate the district cooling system in Paris for offices, banks, stores, hotels, museums and other buildings. The company leverages the Seine River as an available heat sink in 3 of its 10 production sites, mitigating the need for more traditional cooling towers at these three sites that meet the system's base load. When the water temperature is below 8°C, water from the Seine is distributed directly through these sites as "free cooling".

During the night, when the demand for cooling is lower, Climespace takes advantage of off-peak electricity and stores thermal energy as either chilled water or ice, which is then used during the hours of peak demand during the day. This storage has the potential to decrease peak power for cooling by 15-50 per cent (Cecca, Benassis and Poeuf 2019). Approximately 60 per cent of the chilled water distribution system is routed through the city's sewage network, an innovative approach to implementing the system in an established city (Riahi 2015).

The Forum des Halles (left) and Louvre Museum (right) in Paris, France are both heated by the utility CPCU as well as being cooled by Climespace, the city's district cooling provider.

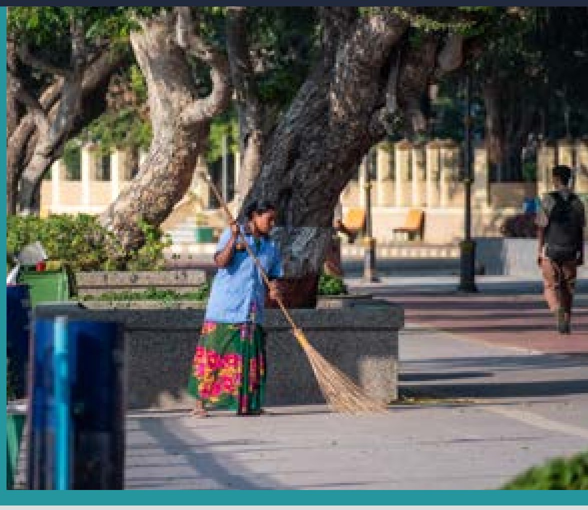




CASE STUDY 7.2 | GUJARAT INTERNATIONAL FINANCE TEC-CITY (GIFT CITY), INDIA

HIGHLIGHTS:

- **Hybrid model (public-private partnership)**
- **Greenfield development**
- **Planned phased deployment**
- **Optimizing cost of distribution network construction**
- **Lower aggregate installed cooling capacity due to diversity of loads**
- **Avoided capital cost for building developers**
- **Integration with green building rating systems**



Gujarat International Finance Tec-City (GIFT City), India, is being built as a high-density city with 5.8 million square metres of built-up area over 886 acres of land, making it more dense than the central business districts of Tokyo and London (Gujarat International 2019). GIFT City will be India's first city-scale district cooling operation, choosing to use district cooling due to its higher efficiency, lower operation and maintenance cost, reduction in necessary electricity generation capacity to support city development and contribution to greatly cutting the city's carbon emissions.

GIFT City consists of office buildings, residential apartments, schools, a hospital, hotels, retail stores and recreational facilities. The assessment study shows that when fully built out, the district cooling system would reduce the requirement for installed cooling capacity from 270,000 tons of refrigeration to 180,000 tons of refrigeration (945 MW of refrigeration to 630 MW of refrigeration), reflecting the benefit of diversity of loads. When fully developed, the system is expected to reduce the cooling power demand of the city, as compared to business as usual, by 105 MW of electricity. The district cooling system includes stratified thermal energy storage tanks that are used to meet the cooling loads during peak demand periods, thus reducing the total power demand of the system (Patel 2018).

The city has set up a special purpose vehicle to deliver the district cooling network through a public-private partnership model. The system initially will represent 10,000 tons of refrigeration (35 MW of refrigeration), combined with 10,000 refrigeration ton-hours of storage, and will later add to this as buildings are developed and connected. Developing the initial phase will reduce risk in future phases, lowering the overall cost of the project.

The system also will use a refrigerant that has a lower global warming potential than the decentralized chillers that otherwise would have been installed. Carbon reductions from the use of an environmentally friendly refrigerant as well as from the higher system efficiency are expected to count towards green building ratings in the city.

Construction in Gujarat International Finance Tec-City (GIFT City), India

CASE STUDY 7.3 | MARINA BAY DISTRICT COOLING SYSTEM – SINGAPORE

HIGHLIGHTS:

- Hybrid model (public-private partnership)
- Greenfield development
- Planned phased deployment
- Optimizing cost of distribution network construction
- Avoided capital cost for building developers
- City mandate to reduce off-take risk
- Regulated tariffs

Singapore does not have the land for giant solar and wind farms and has few resources for hydropower, which pushed the nation to concentrate on improving the efficiency of its energy use. The Marina Bay system, started in 2006, is the largest fully underground district cooling network in the world.

The project was conceived in the mid 1990s when the Urban Redevelopment Authority of Singapore (URA) conducted a feasibility study for the construction of common services tunnels in the new business district to house utility lines. The study also identified district cooling as a new urban utility suitable for introduction at Marina Bay. The system "eliminates the space requirements and upfront costs for customers' own on-site chillers and roof-top spaces for cooling towers", according to Singapore Power. The chief executive officer of the URA said developing the centralized district cooling network to serve the Marina Bay precinct is a "bold idea many years in the making" (Othman 2016).

Singapore District Cooling, a joint venture of Singapore Power, planned, designed, constructed, and now operates and maintains the Marina Bay district cooling system

The Marina Bay project was made possible by early government planning with the Energy Market Authority, mandating under the District Cooling Act for 1.25 million square metres of gross floor area to be set aside in Marina Bay, to be served by the district cooling system. The supporting regulatory framework requires the utility service to be priced at a level no higher than the equivalent costs of chilled water production by building-scale plants employing similar technology. Over time, the district cooling operator is allowed to earn a baseline return based on its invested assets. When the operator has recovered its start-up losses after achieving the critical mass of demand for efficient operation, any efficiency gain above the baseline return is shared equally between the operator and its customers. Customers are thus assured of long-term savings while the start-up demand risk associated with a greenfield project is also mitigated. Due to the benefit-sharing scheme inherent in the framework for efficiency improvement, the operator is incentivized to continually pursue economic and energy efficiencies without the need for intrusive regulatory oversight.

The system achieves a coefficient of performance for chilled water production in the range of 5.0-5.5 kWh of refrigeration per kWh of electricity, substantially outperforming the average benchmark of 3.5 for building-scale facilities in Singapore.

CASE STUDY 7.4 | DEEP LAKE WATER DISTRICT COOLING SYSTEM – TORONTO, CANADA

HIGHLIGHTS:

- **Hybrid model (public private partnership)**
- **Utilization of free cooling**

A unique partnership between Enwave and the City of Toronto enabled the city's downtown core to use an alternative to conventional, energy-intensive air conditioning and to implement the largest lake-source cooling system in the world. Commissioned in 2004, Enwave's 75,000 tons of refrigeration (264 MW of refrigeration) Deep Lake Water Cooling (DLWC) system uses Lake Ontario's icy water as a renewable energy source.

In winter, the surface of the lake cools to about 3.9°C. This cold water's density increases, causing it to sink. In summer, the surface water heats up, staying at the surface as it is not dense enough to sink. Over time, this phenomenon has created a permanent cold water reservoir at the bottom of Lake Ontario. Three pipes that run along the natural slope of the lake bottom pump water from a depth of 83 metres to the Toronto Island Filtration Plant. There, the cold water is processed, then directed to Enwave's Energy Transfer Station, where heat exchangers facilitate an energy transfer between the cold lake water and Enwave's closed chilled water supply loop. The lake water continues on to the city's potable water system.

Only the coldness of the lake water is harnessed, not the water itself. As a result, DLWC provides a unique, green alternative to conventional air conditioning. DLWC reduces electricity use by up to 90 per cent and reduces 61 MW of demand on the electrical grid each year, a shift that provides environmental benefits to all customers. The DLWC system eliminates ozone-depleting refrigerants and reduces emissions of harmful pollutants, including nitrogen oxides, sulphur oxides and CO_2.

Enwave's Deep Lake Water Cooling system on Lake Ontario, Canada

CASE STUDY 7.5 | HIGH CONCENTRATION OF DISTRICT COOLING SYSTEMS – DUBAI, UNITED ARAB EMIRATES

HIGHLIGHTS:

- **Hybrid model (public-private partnership)**
- **Greenfield development**
- **Planned phased deployment**
- **Optimizing cost of distribution network construction**
- **Avoided capital cost for building developers**
- **Commitment of anchor clients**
- **Mandate for new developments to connect**
- **Incentive for connected building thermal efficiency**

Dubai has seen the development of the world's greatest concentration of district cooling systems, meeting a demand equivalent to close to 2 million tons (7,020 MW) of refrigeration annually. These systems require around half the energy of the air-conditioning units that would otherwise have been deployed. This has enabled Dubai to limit growth in its electricity transmission network – a key objective of the expansion of district cooling in the Emirate.

One of the early catalysts for this growth was through the forging of a public-private partnership between TECOM Investments, a real estate developer and the operator of Dubai's leading business parks, and the public utility Dubai Energy and Water (DEWA).

Dubai, an environment enabled for district cooling

The resulting special purpose vehicle, called Empower (Emirates Central Cooling Systems Corporation), designs, builds and operates its systems under a 25-year concession contract. Both DEWA and TECOM provide anchor loads, including significant loads from government buildings. The presence of DEWA in the partnership brings a focus on energy efficiency and thermal energy storage, which are seen as beneficial to the energy system and to the Emirate, along with supporting regulations requiring new developments to connect to the district cooling system.

This expansion was further driven by the presence of other real estate developers such as Emaar and district cooling developers and operators such as Tabreed and Emicool. While Empower maintains its leadership position in the Emirate, Tabreed and Emaar – through their partnership in the Dubai Downtown district cooling system – operate the single largest district cooling system in the Emirate, with all developers and operators able to enjoy the benefits of an environment enabled for district cooling.

CASE STUDY 7.6 | ATLANTIC STATION CHILLED WATER PLANT – ATLANTA, UNITED STATES

HIGHLIGHTS:

- **Private sector**
- **Brownfield development**
- **Optimizing cost of distribution network construction**
- **Avoided capital cost for building developers**

Atlantic Station, a mixed-use development at the north-western edge of Midtown Atlanta, Georgia, is a 24-hour community, providing homes for 10,000 people, employment opportunities for 30,000, and shopping and entertainment for millions more. First planned in the mid-1990s and officially opened in 2005, its 138 acres represent urban renewal on the former brownfield site of the Atlantic Steel mill. The ultimate build-out is projected to include 12 million square feet (1.1 square kilometres) of retail, office, residential, and hotel space, as well as 11 acres (4.5 hectares) of public parks.

To ensure the comfort of the residents, workers and visitors at Atlantic Station, Veolia Energy North America owns, operates and maintains a 7,500 tons of refrigeration (24 MW of refrigeration) central chilled water plant with a pipe distribution network of 3.2 kilometres. Plant operations are remotely monitored, with only one employee on site. Notably, most of the piping that distributes the chilled water from the central plant to the various buildings within the development is located in the common parking structure and is not buried under the ground, providing a lower cost of deployment than underground piping.

Atlantic Station, a mixed-use brownfield development in Midtown Atlanta, Georgia

CASE STUDY 7.7 | DISTRICT COOLING SYSTEM – NORTHGATE CYBERZONE, PHILIPPINES

HIGHLIGHTS:

- Private sector
- Brownfield development
- Conversion of existing buildings to district cooling
- Planned phased deployment to future buildings

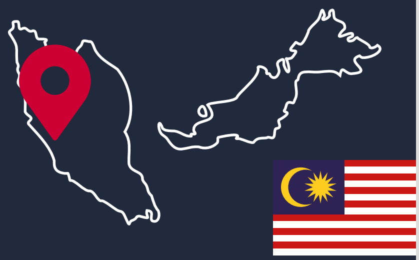
Philippine DCS Development Corporation (PDDC) – a joint venture between Filinvest Land, Inc., one of the largest property developers in the country, and ENGIE – commenced operation in 2017, becoming the largest district cooling system in the country. The plant will expand in phases to provide an energy-efficient cooling system to both existing and future office buildings within the 18.7 hectare premier IT Park.

District cooling plant in Northgate, Philippines

The initial 8,000 tons of refrigeration (28.2 MW of refrigeration) plant in Northgate Cyberzone caters to 16 buildings through a 3.4 kilometre underground distribution network. A unique aspect of this project was the conversion of existing and occupied Filinvest buildings on the site to the district cooling network, replacing the older and relatively inefficient building-distributed cooling systems with a net 40 per cent reduction in energy consumption claimed – in addition to enhanced building aesthetics and improved environmental rating of the existing buildings.

Future buildings will be added to the district cooling system as constructed, with the plant anticipated to service the entire Northgate Cyberzone, expanding to a total capacity of over 12,000 tons of refrigeration (42 MW of refrigeration) based on currently planned development. With Filinvest being the developer, the subsequent building owner and the joint venture partner of the district cooling system, incentives were naturally aligned, bringing economic benefit to the developer and avoiding issues associated with off-take risk.

CASE STUDY 7.8 | DISTRICT COOLING PLANT – MEGAJANA, MALAYSIA



HIGHLIGHTS:

- Hybrid model (public-private partnership)
- Greenfield development
- Avoided capital cost for building developers
- Commitment of anchor clients
- Planned phased deployment to future buildings
- Use of thermal storage

Pendinginan Megajana Sdn Bhd (Megajana District Cooling) is a joint venture between Cyberview Sdn Bhd (the site developer and a subsidiary of the Ministry of Finance) and ENGIE Services Malaysia Sdn Bhd. It is the sole provider of district cooling system services in Cyberjaya, a tech hub that forms a key part of the Multimedia Super Corridor in Malaysia. It is located in Sepang District, Selangor. Cyberjaya is adjacent to, and developed along with, Putrajaya, Malaysia's government seat.

Megajana District Cooling Systems commenced operations in November 1999 with a capacity of 1,500 tons of refrigeration (5.3 MW of refrigeration) and has since expanded to 25,950 tons of refrigeration (91.3 MW of refrigeration) across two district cooling plants, growing in conjunction with the needs of the developing city. The system serves 48 buildings through a 12 kilometre pre-insulated distribution pipe network. The system also includes 115,500 refrigeration ton-hours of thermal storage, which enables the plant to operate at a 10-20 per cent lower electricity tariff.

Megajana District Cooling Plant #1, Malaysia

While there is no mandate for buildings in the city to connect to the district cooling plant, the government committed to connect all of its buildings in the territory (effectively becoming the "anchor client") and also encouraged private companies to do the same. Megajana District Cooling Systems is the sole provider but still has to compete against the distributed cooling system option. In this regard, they claim that they have been able to optimize their pricing to be around 10 per cent lower than distributed cooling systems, ensuring a strong economic incentive to building owners in addition to higher reliability, enhanced building aesthetics and improved environmental ratings.

Additionally, Megajana District Cooling Systems offers its customers heating, ventilation and air-conditioning (HVAC) maintenance services along with cooling advisory and training services to help ensure efficient and optimized operations within customer buildings.

CASE STUDY 7.9 | CENTRAL COOLING PLANT – PEARL RIVER NEW CITY (ZHUJIANGXINCHENG), GUANGZHOU, CHINA

HIGHLIGHTS:

- **Hybrid model (public-private partnership)**
- **Greenfield development**
- **Avoided capital cost for building developers**
- **Commitment of local government**
- **Planned phased deployment to future buildings**
- **Use of thermal storage**

The Guangzhou Municipal Government made the decision to implement regional centralized cooling as part of a green and environmentally friendly modern urban centre in the core area of the Pearl River New City development. In 2008, the Guangzhou New Axis Construction and Development Co. established Guangzhou Zhujiang New Town Energy Co. to be responsible for the investment, construction and operation of the central cooling project at the core of the development.

The central cooling plant covers an area of around 10,000 square metres and was the first fully underground "garden-style" cooling centre to be put into operation in China. The first phase of the project of 25,000 tons of refrigeration (88 MW of refrigeration) went into operation in 2010 and was expanded to 40,000 tons of refrigeration (140 MW of refrigeration) in 2018. The plant also includes an ice thermal storage system to be able to manage load away from the peaks by producing ice at night when demand is low; this stored capacity can increase the overall plant cooling capacity for daytime use by up to 40 per cent. The plant currently serves 16 contracted users (6 public buildings, 9 commercial buildings and the Guangzhou Metro) with a combined cooling area of around 2 million square metres.

Pearl River New City (Zhujiangxincheng), Guangzhou, China

The total installed capacity of air-conditioning and refrigeration equipment in the core area of the Pearl River New Town was reduced by an estimated 20-25 per cent as a result of the optimization of non-coincident loads, and the local environmental temperature in the core area of Zhujiang New Town was contained by 2-3°C through a reduction in anthropogenic heat from the avoided distributed cooling systems.

Guangzhou Zhujiang New Town Energy Co also offers its customers HVAC maintenance services along with cooling advisory and training services to help ensure efficient and optimized operations within customer buildings.

CASE STUDY 7.10 | LA ALPUJARRA DISTRICT COOLING PLANT – MEDELLÍN, COLOMBIA

HIGHLIGHTS:

- **Owned and operated by the city utility**
- **Conversion of existing government buildings to district cooling**
- **Involvement of national government in developing pedagogy**
- **Hydrochlorofluorocarbon- / Hydrofluorocarbon-free cooling**

Empresas Públicas de Medellín (EPM), Medellín's public utility company, commenced operation of the La Alpujarra district cooling system in 2016, becoming the first district cooling system in Colombia and all of Latin America. The project was co-financed by the Switzerland State Secretariat for Economic Affairs (SECO) and the Multilateral Fund to implement the Montreal Protocol through the Ozone Technical Unit of the Ministry of Environment and Sustainable Development (Minambiente), to both de-risk the project for the primary investor, EPM, and ensure capacity to develop a "first of its kind" project in the country and the Latin America region. Colombia's Minambiente was a core local partner of the project, aiding in promoting tax-exempt status, encouraging the use of a refrigerant with zero ozone-depleting potential and global warming potential, and also in the development and amplification of key learnings and pedagogy in support of broader replication.

The initial 3,600 tons of refrigeration (12.6 MW of refrigeration) plant originally served three existing government buildings that joined the original development effort, replacing their existing energy-intensive cooling equipment. The underground distribution network has since been expanded to 1.5 kilometres serving a total of seven government and institutional facilities. There is no mandate for connection to the plant and as such no regulation of tariffs; expansion occurs based on establishment of negotiated commercial arrangements.

The plant has a dual power source, both grid-supplied electricity and natural gas-fuelled micro-turbine electricity with waste heat captured for supplemental absorption cooling; primary cooling is provided by electric chillers using the refrigerant ammonia (zero ozone-depleting potential and global warming potential). The plant claims a 34 per cent reduction in energy as compared to the baseline scenario with distributed cooling systems (based on 2018 data).

This leaves the question as to whether this "first of a kind" project was able to catalyse the expansion of district cooling as a sustainable cooling approach in Colombia. With the CELSIA plant in Cartagena and the CELSIA + NOVUS CIVITAS plant in Serena Del Mar, Cartagena in advanced stages of development, the prognosis is a positive one.

La Alpujarra district cooling plant, Medellín, Colombia

08 ENERGY-EFFICIENT AND THERMALLY EFFICIENT BUILDINGS

Recent analysis shows that greenhouse gas emissions associated with cities can be brought close to net zero by 2050 by using technically feasible, widely available mitigation measures that deliver a positive net present value (Coalition for Urban Transitions 2019). An estimated 58 per cent of the total emissions reduction opportunity of 15.1 gigatons of CO_2-equivalent (equivalent to the combined 2014 energy-related emissions of the two largest emitters, China and the United States) (Coalition for Urban Transitions 2019) is attributable to the buildings sector alone. Transforming residential and commercial buildings in cities not only offers an immense opportunity to mitigate warming in cities, but is also one of the most significant contributors to avoiding a global temperature increase exceeding 1.5°C.

To achieve this mitigation potential, improving the energy efficiency of buildings, in particular through sustainable space cooling, is a significant lever. Space cooling is an integral part of energy efficiency in buildings and can represent a dominant share of the energy use in the buildings sector, particularly in hot climates. In Singapore, for example, space cooling represents up to 70 per cent of the total energy load in buildings (Roberts 2015). Therefore, the interventions that facilitate sustainable space cooling may not be so different from those that would be considered for enhancing the overall energy efficiency of buildings. However, space cooling does have some unique attributes – such as the impact on energy systems in terms of driving peak load and the role of refrigerants and their impact on emissions – and therefore is particularly important in the context of both sustainable urban cooling and building decarbonization.

To facilitate and accelerate the transformation of urban buildings, regulatory frameworks and standards established by, and with support from, national and state governments are particularly important. Operating within these frameworks, city governments can – at a local level – play a meaningful role in driving the transformation of the buildings sector. This chapter discusses the opportunities for transforming urban buildings and presents key interventions for driving thermally efficient and energy-efficient buildings that are within the purview of cities.

8.1 UNDERSTANDING OPPORTUNITIES FOR TRANSFORMING THE BUILDINGS SECTOR

Buildings have a long lifespan covering many decades, and therefore efficiency measures embedded into buildings can have significant benefits that persist far into the future. Passively cooled and efficiently designed and constructed buildings can impact urban cooling in inter-related ways: by reducing the overall heat gain and heat island effects such as through appropriate materials and surfaces; by reducing the overall energy requirements and related emissions; and by reducing the requirement for mechanical cooling and the associated energy, emissions and anthropogenic heat.

On a broader (district or neighbourhood) scale, greenfield or brownfield development projects present the opportunity to apply positive covenants to the land, requiring developed buildings to connect to district cooling, where district cooling systems exist or are being contemplated. On a building scale, an ideal opportunity for impacting a building's energy and emissions footprint is during its design and construction, when passive cooling and efficiency measures can be most holistically and cost effectively integrated into new buildings.

A similar opportunity exists during the life of existing buildings at times of major renovation and repositioning, when a broad swathe of measures are able to be integrated cost effectively, taking advantage of the incremental cost economics that come from integration with the (re)construction process. That said, several stand-alone passive design measures can be economically applied to, and benefit, existing buildings – such as high-performance windows, adding insulation, adding shading devices and installing cool roofs – and should be leveraged to the fullest extent possible to reduce the building's energy footprint during its remaining lifespan.

PASSIVE BUILDING DESIGN STRATEGIES

The key passive design strategies (also summarized in figure 2.2 in chapter 2) are described as follows:

- **Building orientation:** Appropriate orientation can minimize direct heat gain and increase natural ventilation.
- **Envelope:** A combination of appropriate building materials and design features in the building envelope minimizes heat gain due to thermal transmittance. Key features include:
  - Insulation: Insulation acts as a barrier to heat flow, reducing heat loss in winter to keep the interior of a building warm and reducing heat gain in summer to keep the interior of a building cool. Inadequate insulation and air leakage are key reasons for heat gain or loss in buildings. Sealing up air leaks also helps manage moisture intrusion in buildings in hot and humid climates.
  - Cool/green surfaces: Studies show that the roof is one of the main solar heat gain points in a building, so using a high level of insulation and surface treatment for roofs can reduce heat conduction to the interior of the building. Common examples include highly reflective surfaces that reflect more sunlight and absorb less heat than a standard roof and use of vegetation that can provide a high level of insulation. Cool walls are similar to cool roofs, in terms of mitigating urban heat islands, but applied to vertical building surfaces. For example, simulations predict that increasing wall solar reflectance throughout Los Angeles County would lower the daily average outside air temperature in the "urban canyon" between buildings by about 0.2°C during the hot summer month of July (ESMAP 2020a).
  - Windows: Windows are typically a significant source of heat gain in a building and therefore should be carefully positioned, keeping the local climate and latitude in mind. For example, in the southern Indian states, where the climate is tropical, north-facing windows help to keep the interiors cool naturally. In comparison, in the northern part of the United States, windows should be on the south to maximize the solar gains from the winter sun while protecting the building (using shading devices) from intense solar gain in summer. The use of appropriate materials in windows is also critical for controlling heat transfer. Common strategies include using double- or triple-paned windows and using high-performance glass that controls thermal conductance and solar heat gain.
  - Shading: Shading is a simple method to block the sun before it can enter the building and is akin to putting a wide-brimmed hat on the building. By minimizing the incident solar radiation and thus keeping the building cool, shading can have a meaningful impact on building energy performance. This is commonly achieved through trees and foliage, architectural features such as overhangs, and shading devices such as louvers and canopies.
- **Ventilation:** Air movement cools people by increasing evaporation, and ventilation cools the building naturally at lower ambient temperatures by removing heat. When outdoor temperature, humidity, and air quality allow, free cooling through open windows (also referred to as "natural ventilation") may be all that is required to improve temperature and humidity in closed indoor spaces.
- **Thermal mass:** Thermal mass is a property of the mass of a building that enables it to store thermal energy, providing inertia against temperature fluctuations. Materials used for thermal mass are typically heavy and dense, including concrete or filled concrete block, stone or masonry usually used in floors or walls. Used properly - the right amount in the right place, with proper external insulation – thermal mass stabilizes interior temperatures by leveraging daily outdoor temperature swings to flatten interior temperature peaks and troughs, thus saving energy that would otherwise be used for mechanical cooling or heating. In hot climates, thermal mass in a building should be shaded from direct sunlight to the extent possible and be exposed to cooling breezes to provide some cooling on hot days and nights.

While passive cooling strategies are the logical foundational step when addressing the cooling needs of the buildings sector, in hot climate zones, passive strategies will typically have to be complemented with mechanical cooling to meet the occupants' thermal comfort needs. Mechanical cooling ranges from the use of fans, air coolers and air conditioners to complex HVAC systems. To lower the energy and emissions in buildings while ensuring thermal comfort, an optimal combination of both passive and mechanical cooling strategies is essential. Building energy codes – which typically cover the building envelope and also incorporate codes and standards applicable to HVAC systems, lighting and water heating systems – are a critical regulatory tool to drive this.

BUILDING ENERGY CODES

Building energy codes are regulations mandating or encouraging lower energy use in buildings and are necessary to overcome the split-incentive issue where the developer is responsible for building design and construction decisions, but the occupier is responsible for the "hidden" consequences of those decisions – the energy bills. They can be an effective way to integrate passive cooling strategies into the building stock, thereby reducing the need for mechanical cooling, and to drive the energy efficiency of mechanical cooling.

Building energy codes can govern up to 80 per cent of a building's energy load (US DOE n.d.) and therefore are a powerful way to reduce the energy-related emissions from the buildings sector. In China, implementation of and compliance with building energy codes across new and existing urban residential, and commercial and rural residential buildings has the potential to reduce the energy demand of the buildings sector between 13 and 22 per cent by the end of the century (Evans, Roshchanka and Graham 2017). In India, a robust implementation of the building energy code in commercial buildings – which includes measures for climate-appropriate building envelopes – can reduce the cooling demand of the commercial building stock by an estimated 20 per cent by the year 2037-38 (Ministry of Environment, Forest and Climate Change 2019).

Building energy codes can be prescriptive, performance-based or outcome-based.

- **Prescriptive codes:** These set performance requirements for specific building components, such as insulation requirements or HVAC efficiency.
- **Performance-based codes:** These set a maximum level of energy consumption or intensity for the whole building, but allow flexibility and trade-offs (for example, less insulation but more efficient windows) in how these levels are achieved.
- **Outcome-based codes:** Outcome-based codes are similar to performance-based codes in that they do not prescribe specific energy-efficient measures, but they require a specified energy performance to be achieved and verified over a period of at least 12 months once the building is in use. Outcome-based codes are less common.

Typically, prescriptive codes are the entry point for establishing a code framework but over time can be complemented or stretched with the addition of performance- or outcome-based codes. These approaches can also be combined. For example, ideally, a performance-based code for the whole building would incorporate prescriptive code elements to target the worst-performing building components. These codes can also include requirements for measurement and verification of the operational performance of buildings, such as measuring energy use after construction, to ensure that predicted performance in the design is delivered.

Building energy codes should also be combined with incentives, capacity-building and financing programmes, to encourage actors to meet the established performance requirements and maximise the effectiveness of the codes.

For cities experiencing substantial new construction, code implementation can be particularly beneficial in terms of locking in thermal efficiencies in the built environment that will reduce cooling loads, anthropogenic heat and emissions for decades to come.

The following discussion explores the key strategies in the buildings sector that cities can leverage to drive and maintain energy efficiency throughout the life cycle of a building.[26]

8.2 BUILDING ENERGY CODES AND THE ROLE OF CITIES

Building codes are generally legislated by state or national governments that play a key role in the adoption and stringency of these codes. Operating within these broader frameworks, cities can take a range of actions that help significantly in maximizing the potential benefits of codes and supplementing with additional measures for better building performance.

MAXIMIZING THE BENEFITS OF BUILDING CODES

Cities can act in two key ways to leverage national or regional codes to their fullest benefit:

- **Fully adopt and enforce building energy codes by strengthening institutional capacities:** The enforcement of codes typically falls to local governments. Ensuring adequate capacities and providing training and tools to local authorities can help them see the importance of enforcement and then carry it out effectively. In parallel, contractor training programmes on the latest codes or best practices can boost code compliance. Third parties can be leveraged to support implementation – such as allowing certified third parties to perform the building code compliance checks – which also reduces costs for local governments.

  The BayREN Codes and Standards Services – a programme run by a collaborative of nine county governments in the Bay Area of California, in the United States – is an example of these strategies for assisting local governments with energy code compliance (BayREN n.d.). The programme offers a number of resources to support code enforcement including training for city staff, consultants, and contractors, and compliance resources such as permit guides and an online permit tool for common project types.

26 *While the equipment and appliances used in a building and the user behaviour of the occupants will also impact the overall energy footprint of a building, those are a separate intervention area (energy-efficient cooling technologies and optimal operations). The focus of this chapter is primarily on the building sector policies and programmes that can drive and maintain energy efficiency throughout the life cycle of a building.*

- **Raise the bar where possible by adopting more stringent codes for a city or development zone or district within a city:** Working within the broader framework of national or state-wide codes, cities can, in some cases, choose to adopt more stringent requirements to accelerate the transition towards efficient buildings.[27] Often referred to as "stretch code", the stricter codes introduce a more ambitious code to be applied to new buildings of a certain size or through positive covenants as a requirement for new buildings in development or eco-zones.

  Stretch codes can also be voluntary, with some incentives attached to meeting them. For example, in the city of Virginia Beach, Virginia, in the United States, if a commercial or residential project is 30 per cent more efficient than the state energy code, the owner pays reduced property taxes (US DOE 2011). Another example of an incentive is expedited permitting – such as in the US cities of Scottsdale, Arizona and Albuquerque, New Mexico – which not only saves time but speeds up project completion as well, which can increase the payback in investment in the project (US DOE 2011).

  Voluntary stretch codes can gradually become standard practice, at which point the next stretch code is introduced. Cities can establish regular updated cycles, such as every three years, as steps towards a final near or net zero carbon goal for buildings.

BY-LAWS TO MANDATE BETTER BUILDING ENERGY PERFORMANCE

Where cities do not have the regulatory power to develop their own codes, or to strengthen codes set by higher levels of government, by-laws, or ordinances, are a useful option. By-laws can be narrow in scope, targeting specific building elements, such as green or cool roofs, or can incorporate a broader range of mandatory and voluntary standards (such as in Tshwane, South Africa). For example, the city of Cordoba in Argentina passed a by-law requiring all buildings – new or existing – with rooftop space of 400 square metres or more to be turned into green roofs (Living Roofs 2016). Other cities with green roof by-laws include Copenhagen, Denmark and Recife, Brazil.

As an example of a broader set of by-laws, Tshwane has adopted a green building by-law that includes nine mandatory and eight voluntary energy standards, in addition to requirements for water, transport and health. Buildings that do not comply with the mandatory standards cannot be approved and may have their occupation certificate withheld. Fast-tracked applications, access to green building technical training, municipal discounts for energy efficiency technologies and other incentives are used to promote uptake of the voluntary standards (C40 Knowledge Hub 2019a).

27 *There may be cases where states require cities to follow whatever code is set at the state level (for example, in the US states of Connecticut, Florida, Kentucky and Ohio). In such cases, cities have the opportunity to advocate for more stringent codes.*

FOCUS ON EXISTING BUILDING STOCK THROUGH BUILDING PERFORMANCE STANDARDS

While building codes apply to both new and existing buildings, their application and benefits can be skewed towards new buildings and the major renovation of existing buildings because of the ease and cost-effectiveness of broader integration of code into the (re)construction project. In cities with a substantial stock of existing buildings, significant advancement in their energy performance can remain a weak link, as the routine upgrades are not of sufficient scale to trigger application of the building energy code. Even the best of energy efficiency programmes targeting existing buildings have rarely resulted in the upgrade of more than 1 to 2 per cent of eligible buildings annually (York *et al.* 2015).

Given the urgency to achieve emission reduction targets at scale, new and more aggressive approaches that target energy efficiency in existing buildings are needed. A mandatory "building performance standard" (BPS) is one such approach. Foundationally a performance-based code, a BPS is a forward-thinking policy commitment for existing buildings in which a city establishes a long-term, high-performance standard, with interim targets that ratchet up over time.

While the typical policies in the buildings sector require specific improvements at specific times, a BPS requires greater changes but allows building owners broad flexibility to use whatever technologies and operational strategies they decide are most effective and economical to meet the target (Institute for Market Transformation 2020). A BPS allows cities to leverage synergies and pursue deeper commitments by encompassing multiple city priorities at once, including carbon reductions, building electrification, energy efficiency, and peak demand reductions, to name a few. Cities collect data throughout the performance improvement cycles and work with the private sector, utilities and others to create incentives, programmes and technical assistance (Nadel and Hinge 2020). A BPS approach is being successfully implemented in Tokyo, Japan and in Boulder, Colorado in the United States, and is in the early stages of adoption in a number of other US cities and states.

In Europe, the mandatory performance standards – more commonly referred to as MEPS for buildings – are regionally established and thus far have been introduced in Belgium, France, the Netherlands and the United Kingdom.

8.3 SUPPLEMENTING CODE: ENABLING VISIBILITY OF BUILDING ENERGY PERFORMANCE

To manifest the full potential of emission reductions in the buildings sector, a foundational step is to gain visibility into the building energy performance to understand the current energy efficiency and emissions status of the city's building stock and assess the scope for continuous improvement. Reporting and disclosure policies and programmes are vital to enable this, by delivering valuable energy-use data to the city and to building owners and managers. These approaches facilitate benchmarking and comparisons – even healthy competition – and by stimulating demand, they help catalyse wide adoption of energy-efficient design and practices.

City governments can be an important market catalyst by establishing locally focused mechanisms that make building energy performance visible – either as voluntary approaches or mandatory policies. Such mechanisms mainly include the following:

GREEN BUILDING RATING AND CERTIFICATION SCHEMES TO SET MINIMUM PERFORMANCE STANDARDS

Many well-regarded national and international green building rating and certification schemes have been in practice in parts of the world, generally administered at the federal or regional level. These schemes can be voluntary or mandatory. For example, the US Energy Star[28] commercial buildings programme and the internationally recognized Leadership in Energy and Environmental Design (LEED) are voluntary building energy rating systems. NABERS,[29] Australia's national rating system that measures the environmental performance of buildings, tenancies and homes, is a mandatory programme as part of a building energy disclosure policy measure driven by the Australian government. Another mandatory scheme is the European Union's building classification using labels from A to G under the Energy Performance of Buildings Directive. Cities can leverage these nationally and internationally recognized building rating and certification schemes – as an easy way to measure a range of sustainability features, including energy efficiency – or develop their own schemes tailored to the local context.

These schemes can be used in addition to, or as a replacement for, building energy codes, and can have a transformative impact on the local market. They are especially useful for cities with limited regulatory powers to issue their own building energy codes. The minimum required certification level can be strengthened over time to further improve building performance.

For example, the city of Toronto, Canada built on the region's Ontario Building Code to develop its Toronto Green Standard, which has been strengthened to include stepped performance targets as the city's pathway to a zero-emissions building framework (see case study 8.2). As another example, in 2019 Chicago introduced an energy performance certificate scheme called the Chicago Energy Rating System, building on the success of its Energy Benchmarking and Transparency Ordinance. Whereas in the benchmarking programme all eligible buildings were required to be scored along the 1-100 ENERGY STAR scoring system, the new energy rating system uses the results from these benchmarking reports and assigns an energy performance rating of 1-4 stars, required to be displayed in a prominent location and disclosed at the time of listing for sale or lease (C40 Knowledge Hub 2019b). Buildings that do not submit benchmarking information receive zero stars.

28 Energy Star is a voluntary endorsement label run by the US Environmental Protection Agency and the US Department of Energy. It goes beyond appliances to cover building products (windows, doors, roof products, etc.) and even entire homes. Space cooling appliances covered include central air conditioners, room air conditioners, heat pumps and fans. See www.energystar.gov.

29 The National Australian Built Environment Rating System (NABERS) uses a six-star scale to help building owners understand how their buildings impact the environment. See www.nabers.gov.au.

Supplementing energy ratings with recommendations can increase the likelihood that building owners will make upgrades. These recommendations are particularly effective if they include an estimation of operating cost savings from making the improvements. For example, when the European Union's Energy Performance of Buildings Directive was revised in 2010, it mandated that the energy performance certificates include recommendations on how to improve the energy efficiency of buildings. The certificates were required to include all cost-effective upgrades along with their associated costs, benefits, and payback periods, with the objective of catalysing further improvements in the energy efficiency of buildings.

BUILDING ENERGY BENCHMARKING

Benchmarking allows a building's energy efficiency performance to be monitored over time and to be compared to other similar buildings. It enables cities to create a baseline for building energy performance for segments of its building stock, as well as to understand variation and the scope for improvement. The energy data can be accessed in many forms. For example, New York City has three local laws addressing access to building energy performance data, requiring:

- buildings to submit energy and water consumption benchmarking data,
- periodic energy audits and retro-commissioning measures, and
- buildings to install electrical sub-meters for large non-residential tenant spaces and to provide monthly energy statements.

Cities typically target benchmarking policies at larger buildings, over a specified size, requiring annual reporting to the city (and/or disclosure to the public). A key consideration is partnering with utility providers that can help to gather energy-use data for specific segments of the city's building stock.

Over time, benchmarking builds and refines the city's datasets on building energy efficiency, enabling more tailored policies and programmes to reduce building sector emissions. The transparency that these data enables is significantly helpful in promoting wider market adoption of building energy efficiency measures and technologies, by providing evidence of the energy and cost savings they deliver.

MANDATORY ENERGY DISCLOSURE ORDINANCES

Cities can lead by example through public disclosure of the energy performance of all government owned and managed buildings. For example, the Tokyo Metropolitan Government publicly discloses emissions from several thousand public buildings online. Energy disclosure ordinances can also be applied to private buildings. For example, in 2013, the City of Boston enacted the Building Energy Reporting and Disclosure Ordinance and promulgated regulations for its implementation. The ordinance requires all non-residential buildings over 50,000 square feet (4,645 square metres) to report their annual energy and water use and greenhouse gas emissions to the City, which then makes the information publicly available. Buildings are also required to conduct an energy assessment or action every five years, with exemptions provided for buildings that are already efficient or making significant progress.

ENERGY AUDIT POLICIES

The term energy audit is commonly used to describe a broad spectrum of energy studies – which may include analysis of building and utility data, study of the installed equipment and analysis of energy bills, and understanding the building operating conditions – with the objective of identifying cost-effective energy conservation opportunities. Well-designed audits can provide richer information than benchmarking, by enabling a view into system-level information – as well as an auditor's energy efficiency recommendations – thus enabling more informed and accurate targeting of energy-saving opportunities. Audits can be conducted on a voluntary basis. However, to maximize their uptake and effectiveness they should be made a mandatory requirement for priority building types.

Mandatory audits usually follow 5- or 10-year cycles and target buildings over a certain size or age. Many cities mandate building energy audits for large non-residential buildings. For example, Austin in the United States requires energy audits and disclosure for residential and multi-family units older than 10 years, alongside annual reporting of an energy rating for commercial buildings over 10,000 square feet (929 square metres). Audits can also be timed with milestones or events in the building life cycle. For example, Vancouver, Canada mandates energy audits for single- and two-family homes when owners apply for a building permit for home refurbishments

Audits may apply to the whole building, or only to specific building components. For example, Singapore mandates energy audits specifically for building cooling systems. Hong Kong's 2012 Energy Audit Code requires owners of commercial buildings, or of the commercial part of larger buildings, to carry out an energy audit every 10 years on four main types of central building services (EMSD 2012). The recommended measures that emerge from the energy audit are then classified and reported (the implementation of efficiency measures is voluntary).

Cities can also provide free or subsidized voluntary audits to target groups to encourage uptake. For example, many cities do this in partnership with local utilities to drive energy efficiency among single-family homeowners.

FURTHER RESOURCES

- **Energy Efficiency Literacy: Online Learning covering the basics of air conditioning and refrigeration and how to mitigate their climate impact, developed by UNEP OzonAction, in cooperation with United for Efficiency (U4E), Kigali Cooling Efficiency Programme (KCEP) and ASHRAE.** https://www.unep.org/ozonaction/resources/factsheet/energy-efficiency-literacy-online-learning-covering-basics-air-conditioning-and
- ***Accelerating Building Efficiency: Eight Actions for Urban Leaders*, World Resources Institute, 2016.** https://www.wri.org/research/accelerating-building-efficiency
- ***Linking Building Energy Codes with Benchmarking and Disclosure Policies: Key Synergies That Drive Building Energy Performance*, Global Building Performance Network, 2014.** https://www.gbpn.org/wp-content/uploads/2021/06/Linking_Codes_With_Benchmarking-1.pdf
- ***Building Code Resource Library*, Institute for Market Transformation.** https://www.imt.org/resource-library/?keyword=&imt_resource_years=&imt_resource_types=&imt_program_areas=823
- ***Urban Efficiency II: Seven Innovative City Programmes for Existing Building Energy Efficiency*, C40 Cities Climate Leadership Group, Tokyo Metropolitan Government Bureau of Environment, CSR Design Green Investment Advisory Co., 2017.** https://www.c40knowledgehub.org/s/article/Urban-Efficiency-II-Seven-Innovative-City-Programmes-for-Existing-Building-Energy-Efficiency

RECOMMENDED CITY ACTIONS

08

Advancing the thermal efficiency and energy efficiency of urban buildings offers an immense opportunity to mitigate warming in cities in several inter-related ways: by reducing the overall heat gain and heat island effects such as through appropriate materials and surfaces, by reducing the overall energy requirements and related emissions, and by reducing the requirement for mechanical cooling (without sacrificing comfort) and the associated emissions and anthropogenic heat.

NO-REGRETS ACTIONS

- Establish the authority to apply covenants on land to be developed or re-developed that can apply conditions beyond code.
- Where significant existing building stock exists, establish policies/programmes for building energy disclosures. Greater visibility of energy performance in buildings starts to attract higher valuation for high-performing buildings and stimulates demand.

CITY INTERVENTIONS CATALYSED BY TRIGGER POINTS

Trigger points			Interventions
1 Planned new development and/ or major re-development	2 Introducing or initiating city planning processes	3 Introducing new or updated codes/ zoning requirements	
✓	✓		Evaluate the opportunity to apply covenants on land to be developed or re-developed, such as requiring connection to district cooling if available, adopting stretch codes or adding high-impact beyond code requirements such as cool roofs and high-albedo surfaces.
✓			Adopt building codes – adapted to the natural conditions – for all new construction (and major renovation of existing buildings) and ensure capacities and means to enforce code compliance. New building design and construction, as well as major renovation of existing buildings, are ideal opportunities for impacting its energy and emissions footprint when measures can be most holistically and cost effectively integrated, taking advantage of the incremental cost economics that come from integration with the (re) construction process.
	✓		If not already in place, introduce policies/programmes for building energy disclosures.
		✓	Incorporate high-impact, low-cost beyond code requirements (or by-laws), such as for cool roofs.

FACILITATIVE INTERVENTIONS

- Ensure capacities – both in the public sector as well as among the workforce – for code compliance.
- Take measures to enhance awareness about the importance of energy-efficient and thermally efficient buildings and the related policies and programmes.
- Utilize well-calibrated incentives to encourage adoption of stretch codes. These incentives could be in the form of expedited permitting or reduced property taxes.

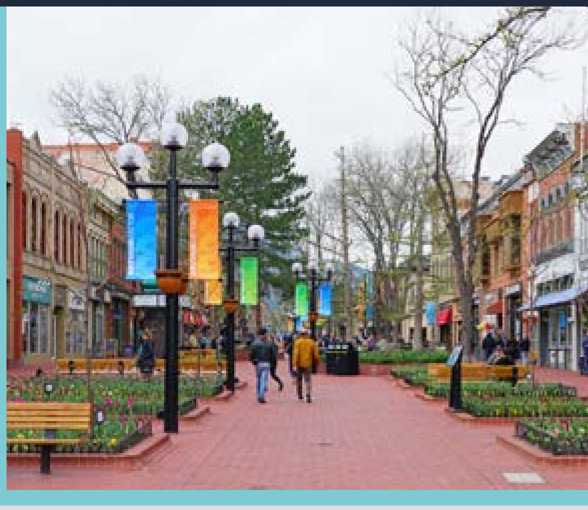
CASE STUDY 8.1 | FLAGSHIP CITY FOR BUILDING ENERGY EFFICIENCY INITIATIVES – BOULDER, COLORADO, UNITED STATES

HIGHLIGHTS:

- **Stringent building energy codes**
- **Mandatory building energy performance standard**

ADDITIONAL CHARACTERISTICS:

- **Partnerships and collaboration**
- **Implementation support (information, financial assistance for residents)**



The City of Boulder in Colorado, the United States is planning a pathway for its energy code to meet zero energy performance by 2030. Each code cycle ramps down an energy target for various building types, ultimately reaching "zero energy ready" performance targets. The city has customized the targets and pathways for each building type.

Commercial buildings (both new and remodel projects) in Boulder are required to meet the city's Energy Conservation Code, which sets stringent requirements for 30 per cent better performance than the energy efficiency requirements of ASHRAE/IESNA Standard 90.1 or 2012 IECC. The code was updated in 2017 and again in 2020 (City of Boulder 2020). Code compliance – for any building larger than 20,000 square feet (1,858 square metres) – is monitored through third-party performance modelling that is approved by the city manager.

For residential buildings, the city has a mandatory building energy performance standard – Boulder Green Points Building Program – that requires a builder or homeowner to include a minimum amount of sustainable building components based on the size of the proposed structure. Similar to the US Green Building Council's LEED programme, the Boulder Green Points programme awards points as per a scoring checklist developed by the City of Boulder based on energy and carbon savings for specific sustainable building practices. Renewable energy and energy efficiency technologies are among the optional components a builder can use to earn points. New construction projects also must show energy efficiency compliance through the national Home Energy Rating System (HERS). Multi-family residential units are also included, and each dwelling in a multi-unit dwelling is required to meet the green point requirements separately.

EnergySmart – a collaborative partnership with Boulder County, the City of Boulder, the City of Longmont and the local utilities, Xcel Energy and Platte River Power Authority – helps homes and businesses identify, finance and schedule energy improvements in their buildings, and minimizes participation barriers by providing them an energy adviser at no cost. EnergySmart is funded by Boulder County, the City of Boulder Climate Action Plan (CAP) tax and the City of Longmont.

CASE STUDY 8.2 | PATHWAY TO A ZERO-EMISSIONS BUILDING FRAMEWORK – CITY OF TORONTO, CANADA

HIGHLIGHTS:

- Mandatory green building standard
- Stepped performance target as pathway to zero emissions
- Building labelling and energy disclosure

ADDITIONAL CHARACTERISTICS:

- Holistic approach to reducing building sector emissions
- Covenants for district energy connection
- Building commissioning
- Cities leading by example

The City of Toronto updated its Toronto Green Standard (TGS), with effect from 2018, to include stepped performance targets to approach zero emissions for all new buildings by 2030 (Canadian Architect 2018). Whereas the previous versions of the TGS used a reference building approach – that is, "percent better" than the Ontario Building Code – the new TGS (Version 3) shifts to an absolute performance target-based approach to help close the performance gap between building design and operations.

Version 3 includes critical improvements over the previous version and is the backbone of Toronto's Zero Emissions Buildings Framework, a holistic approach to reducing building sector emissions. Under the Framework, new developments in Toronto are required to reach select levels of performance in three primary metrics (City of Toronto 2017):

- Total Energy Use Intensity, to encourage higher-efficiency buildings and lower utility costs;
- Thermal Energy Demand Intensity, to encourage better building envelopes, improve occupant comfort and enhance resilience; and
- Greenhouse Gas Intensity (GHGI), to encourage low-carbon fuel choices and reduce building emissions.

The inter-related set of performance targets work together to encourage improvements in energy efficiency, reduce heating and cooling demand, and incentivize a shift towards low-emission sources of energy. For example, while in the previous version of the TGS, there was no incentive for a new development's connection to a low-carbon thermal energy network (*i.e.*, district energy system), under the new targets-based framework, connection to district energy systems is now recognized and rewarded in that the achievement of GHGI targets is eased wherever that system uses a low-carbon source of energy (*e.g.*, deep lake water cooling, geo-exchange, solar thermal, waste heat recovery, biofuels, etc.). Requiring inter-related targets has additional potential benefits, such as reductions in peak energy demand and improved thermal comfort and construction quality.

► Continued

CASE STUDY 8.2
PATHWAY TO A ZERO-EMISSIONS BUILDING FRAMEWORK – CITY OF TORONTO, CANADA

To supplement the performance targets, a set of new or updated prescriptive requirements has also been recommended to help ensure that modelled performance targets are realized in practice. Some key areas included in these requirements are:

- **District energy connection:** Buildings designed to enable connection or actually connect to a district energy system (where one exists or is slated for development) will help the City of Toronto reduce emissions from the buildings sector.
- **Building commissioning requirements:** Fundamental commissioning and enhanced commissioning requirements help to ensure that buildings are constructed and operated properly, improving overall building energy performance.
- **Building labelling and disclosure:** Requirements for buildings to annually report their energy consumption aligns with provincial requirements, while the City of Toronto ensures that it can track and help to improve buildings' energy performance over time.

TGS Version 3 represents a critical step towards achieving the city council's low-carbon goals established in Toronto's Climate Action Strategy. The City is leading by example by setting higher standards for its own new buildings, requiring all public non-residential buildings to meet the more ambitious Tier 2 standard. Financial incentives are offered for public (and private) planning applications to meet the voluntary Tier 2-4 standards.

09 CITIES LEADING BY EXAMPLE

While cities can demonstrate climate leadership in many ways, "leading by example", in the context of this chapter, refers to efforts that city governments could undertake to support heat mitigation and the adoption of more climate-friendly cooling solutions on buildings and assets that they control.[30] City governments are often one of the largest buyers, long-term owners or tenants of a significant portfolio of buildings and can set the precedent and catalyse market transformation towards sustainable urban cooling.

In the context of sustainable urban cooling, city leading-by-example strategies largely apply in three key areas: buildings, cooling equipment and transport.

BUILDINGS

City-owned buildings represent a major part of a typical city building stock. Cities should take aggressive steps towards enhancing the thermal efficiency and energy efficiency of their own buildings, thereby reducing their cooling loads and emissions. As a minimum, this includes stringent adoption of building energy codes and ideally would include the adoption of stretch codes or standards for all new construction for city-owned buildings, retrofitting existing buildings to enhance their thermal efficiency (such as through shading, cool roofs and high-performance windows) and adopting green leasing practices.

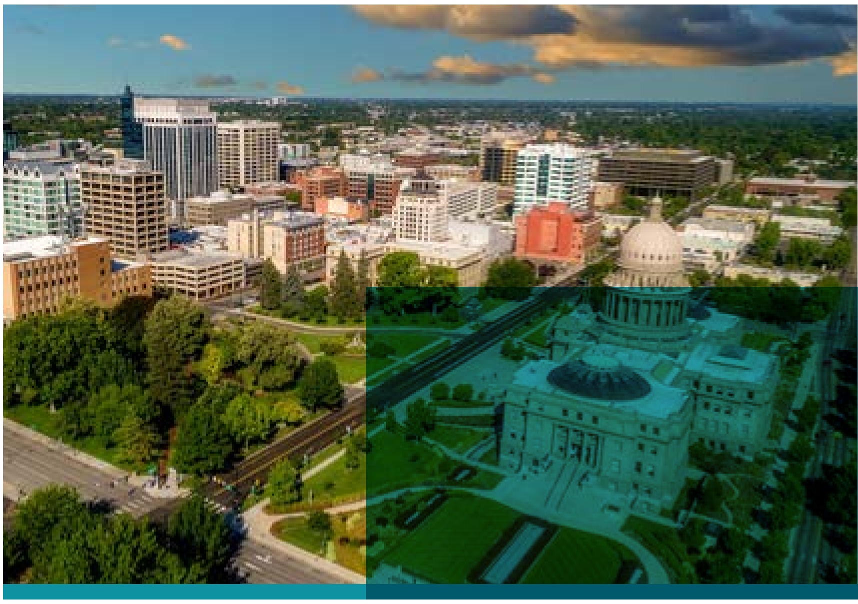
30 This includes solutions that apply to the buildings, cooling equipment and transport assets owned/controlled by the city. It excludes solutions for urban design and infrastructure, which is outside of the scope of this intervention and is covered in chapter 6.

For example, the majority of local authorities in the United Kingdom have incorporated the BREEAM® building certification system into their planning process as a mandatory requirement for all new buildings. In parallel, it is important that cities make their building energy performance data visible to the wider public. By demonstrating the energy performance and the benefits of efficient buildings, cities can instill market confidence and promote wider adoption of passive cooling and energy-efficient building practices. The strategies discussed in chapter 8, such as benchmarking of city-owned buildings, green buildings standards, and building energy performance standards, are effective ways to transform city buildings to be thermally and energy efficient.

City-owned properties generally span multiple building typologies – such as offices, public/social housing complexes, community and recreation buildings, police and fire stations, airport complexes, and wastewater management, to name a few. Certain building types, generally the ones with more complex building systems – for example, airports and sanitization facilities – represent greater opportunity for optimizing the building's emissions footprint. Cities may want to prioritize efforts across these building typologies, particularly where resources are limited.

For example, in its efforts to achieve a 50 per cent reduction in energy use on average in existing buildings by 2030 (against a 2010 baseline), the city of Boise, Idaho in the United States analysed 50 municipal buildings. The city identified 17 high-priority buildings that use about 70 per cent of all energy in the city's portfolio. The airport terminal alone accounts for more than half of all energy use portfolio-wide (Miller 2019). The city is now focusing limited auditing resources on the highest-priority buildings across the entire building portfolio, using benchmarking to track energy performance and achievements.

Public/social housing complexes are another typology that could be prioritized. While these buildings may not have energy-intensive systems, they are typically large-scale, and any improvements in their thermal efficiency will translate to household savings for low-income residents, who are typically responsible for paying their utilities.



COOLING EQUIPMENT AND SYSTEMS

The cities' adoption of lower-climate-impact cooling technologies builds market confidence and helps catalyse their market demand. Public procurement can also be a way to drive the transition towards refrigerants with lower global warming potential. In addition, practices that optimize operations – such as building automation and controls, good maintenance and servicing practices, and adaptive thermal comfort practices – can further reduce harmful emissions and warming. By demonstrating these efficient practices and their benefits to the public, cities can influence wider adoption.

The cooling needs of city buildings can also be a catalyst for district cooling plant development, where the presence of municipal entities as credit-rated anchor clients greatly reduces off-take risk. Having a city government enter into a long-term agreement to take a significant proportion of cooling from the district cooling plant supports project viability and helps lower the cost of financing under a private or hybrid developed model.

TRANSPORT

Cities typically own a fleet of vehicles, as well as generate transit movement of their employees. While transport strategies are not directly related to cooling – with the exception of mobile air conditioning – and hence are not a focus of this report, they are indirectly linked due to their impact on urban heat islands and greenhouse gas emissions, and therefore important to acknowledge. Key strategies include avoiding the direct combustion of fuels, such as through electrification of the municipal fleet (including, where possible, transit electrification), encouraging use of transit and alternative modes (walking, biking, micro-mobility) by city employees, and implementation of transport demand management (TDM) policies that encourage more work from home. The reduced anthropogenic heat and reduced emissions would help mitigate excessive urban warming, and also support cleaner air quality.

Cities' lead-by-example strategies may first apply to efficient/sustainable cooling equipment, as these may be easier to implement and involve fewer interdependencies (compared to those for buildings). In comparison, lead-by-example strategies for energy-efficient buildings will generally require greater institutional capacity due to the increased complexity in managing whole-building strategies and establishing oversight. Implementation of lower-climate-impact transport strategies is dependent on the transit service, urban form, and viability and availability of alternative modes such as electric vehicles and electric vehicle supply equipment.

All three areas offer meaningful opportunities for cities to demonstrate climate stewardship and influence a whole-system approach and action towards sustainable urban cooling. A necessary underpinning for this is greater coordination across municipal departments – such as between urban planning, environment, and energy and transport departments – for facilitating integrative solutions.

9.1 KEY APPROACHES FOR CITIES LEADING BY EXAMPLE

Prime opportunities for cities to roll cooling efficiency and energy efficiency improvements into other projects will generally occur at specific points in time: when addressing deferred maintenance, at equipment end of life, and in the course of major renovation and new construction. Leveraging these trigger points to transform their assets to support sustainable urban cooling, cities can adopt some key approaches that are applicable across buildings, cooling equipment and systems, and transport. These are summarized in Figure 9.1 and discussed below.

Figure 9.1 Key approaches for cities leading by example

CITY LEADING-BY-EXAMPLE APPROACHES	BUILDINGS	COOLING EQUIPMENT AND SYSTEMS	TRANSPORT
	CONSIDERATIONS AND INDICATIVE EXAMPLES		
Establish sustainable procurement, contracting practices and internal policies for municipal government	■ For all new construction, adopt stretch codes to go beyond today's building energy code requirements; drive passive design practices and efficient building materials through design and construction specifications; encourage the use of voluntary building rating programmes (such as LEED). ■ Include requirements for building energy labels where applicable. ■ Set minimum energy performance thresholds (such as through building rating requirements) for leased buildings. ■ Evaluate the opportunity to source cooling as a service either from an existing district cooling service provider or by catalysing the development of a district cooling plant through the surety of long-term city off-take.	■ For cooling equipment, include performance-based requirements that cover not only energy performance but also emissions to show the overall climate impact. ■ For maintenance and servicing, require hiring of trained/ licensed HVAC technicians only.	■ Fleet electrification. ■ Incentives for municipal employees to use transit and alternative modes. ■ Transport demand management / work-from-home policies.
Leverage innovative business models	■ Public private partnerships for lowest life-cycle cost construction procurement. ■ Energy services company (ESCO) model for energy efficiency retrofits.	■ Demand aggregation for cost-effective procurement of efficient cooling equipment.	■ Public-private partnerships for urban transport. ■ Demand aggregation for electric vehicles.
Provide training, outreach and tools to promote behaviour change among procurement staff	Applies across categories.		
Monitor compliance and track impact for continuous improvement	Applies across categories.		

ESTABLISHING SUSTAINABLE PROCUREMENT AND CONTRACTING PRACTICES FOR MUNICIPAL GOVERNMENT

Cities can establish procurement specifications, as well as contracting practices, that promote sustainable urban cooling by integrating heat considerations into regular maintenance, replacement schedules and capital budgets for municipally controlled buildings and assets. Some examples include: establishing energy-efficient design and materials specifications for all new construction; requests for information for skilled suppliers that signal a market demand for sustainable urban cooling solutions; and hiring only trained/licensed HVAC technicians for city buildings to spur market demand for skilled technicians. In the case of vapour compression-based air conditioners, the procurement specifications should consider disallowing or disincentivizing products with refrigerants that have ozone-depleting potential and high global warming potential subject to phase-out or phase-down under the Montreal Protocol and its Kigali Amendment. These procurement strategies are also a way for cities to potentially create pilot projects to demonstrate the local efficacy of heat mitigation strategies.

Adjusting internal rules and policies is often a foundational step to cities establishing a sustainable public procurement policy. This may involve, for instance:

- Ensuring that the procurement policies enable and encourage third-party ownership, such as energy services company (ESCO) and public-private partnership models. Cities are often limited in their ability to pursue these models because of internal rules and the incentive to spend their annual capital budgets.
- Requiring lowest life-cycle cost procurement, including by requiring a life-cycle cost analysis to factor into procurement decisions (instead of selecting the lowest first-cost option, which typically is the least energy efficient).
- Ensuring transparency in procedures to facilitate better understanding between the public and private sectors, such that the requirements are well aligned with the possible technical solutions and business models.
- Encouraging aggregated procurement within city government (as well as within a group of cities). Often, different city departments handle their procurement on their own, missing the opportunity to leverage the city's overall buying power.

A logical next question may be how to define the buildings or products that meet the procurement aims. Several approaches can be followed, such as:[31]

- Labels, standards and codes: When existing labels (or codes) are available, require cooling equipment (or buildings) to reach a certain level.
- Catalogue of technical specifications: Maintain a document with technical specifications or energy efficiency standards for equipment that is frequently purchased.
- Energy-efficient preferences: Award extra points or price preferences for more energy-efficient products.
- Qualifying product list: Maintain a database of specific products – such as cooling equipment and building materials – that meet government energy efficiency specifications.

31 This list is adapted from Singh, Culver and Bitlis (2012).

While the above is a general list, it can be adapted to apply to buildings, cooling equipment or vehicles.

An important consideration is to make energy-efficient or sustainable procurement supported by life-cycle-cost analysis the default option. A voluntary energy-efficient or sustainable procurement policy (including the transition towards more climate-friendly refrigerants) is a good first step while beginning with a small set of products, conducting analyses and developing the full programme infrastructure. However, once the programme is established, its impact will be far greater if it is mandatory. If procurement officers want to procure non-energy-efficient equipment, they should be required to make the case supporting that decision. For example, US government agencies must procure Energy Star or Federal Energy Management Program-designated equipment. If no options are available or cost-effective, the head of the agency must state that in writing in order to be granted an exemption (Acquisition.gov 2019).

Energy-efficient procurement practices should extend to buildings as well, promoting high-performance buildings – whether owned or leased – that have a lower energy intensity and generally lower operational costs. For example, per the Australia Energy Efficiency in Government Operations policy, all government operations above a certain size are required to lease space only in buildings that meet a National Australian Built Environment Rating System (NABERS) rating of 4.5 stars or higher. Over the past 10 years, the energy intensity (measured in energy use per person per year) of the spaces rented by government entities has improved by 28.5 per cent (Department of Resources, Energy and Tourism 2013). Following the government's example, many major corporations have followed suit, leasing space in energy-efficient buildings. The government's action has thus advanced the market demand for energy-efficient buildings.

For all new construction, cities can drive passive design practices and efficient building materials through design and construction specifications, as well as by going beyond the building energy code to implement all possible measures that deliver a favourable net present value. This reduces the burden on taxpayers as well as minimizes the emission footprint for cooling the building.

Cities can also set an example for low-climate-impact mobility solutions through addressing the municipal fleet. For example, as part of its Sustainable City pLAn, which aims to cut greenhouse gas emissions 80 per cent by 2050, the city of Los Angeles in the United States has already converted more than half of the municipal light-duty fleet to electric. Going a step further, the city has piloted an electric vehicle car-sharing scheme to create equitable access to electric vehicles and increase low-carbon mobility in low- and middle-income areas, and supplemented this with the installation of 1,000 publicly available chargers. This public sector investment in charging infrastructure is designed to spur private engagement and lead to a quarter of all vehicles being electric by 2035 (C40 Cities 2017).

Cities can also explore joint procurement opportunities in partnership with other cities, which can lower the collective administrative burden and bring cost benefits due to economies of scale. This is discussed further in the section "Demand aggregation".

LEVERAGING INNOVATIVE BUSINESS MODELS

Multiple proven business models can be effectively leveraged by cities towards driving and scaling up sustainable urban cooling practices. Some common examples include:

Energy services company (ESCO) model for energy efficiency retrofits

ESCOs shift the project performance risk away from facility owners and end users and bring commercial finance into the market, allowing the energy efficiency market to grow. Projects can be undertaken as stand-alone cooling projects or as part of a larger energy efficiency project (which increases the project size, allowing better debt terms to be secured), where the ESCO entity either guarantees energy savings to the client or has its compensation tied to a share of energy savings actually achieved. Where enabling regulatory and market conditions are present, ESCOs effectively provide a delivery mechanism for sustainable space cooling (and, more broadly, energy efficiency) to the market, providing not just the technologies but installation, warranty, performance assurance, financing, and a neutral or positive cash flow.

Public-private partnerships

In public-private partnerships, public money is leveraged with private investment to fast-track critical projects. The long-term responsibility to maintain that infrastructure falls to private partners. These performance-based contracts have proven highly effective and valuable in many countries, including Canada, Chile, Australia, Sweden, the United Kingdom and the United States, to name a few.

Public-private partnerships for public transport can be an effective way to build and implement new infrastructure or to renovate, operate, maintain or manage existing transport infrastructure facilities (see case study 9.3). Cities can leverage several existing resources while considering public-private partnerships, such as: the Urban Bus Toolkit, designed by the World Bank and the Public-Private Infrastructure Advisory Facility, to help government officials and policymakers evaluate existing and alternative urban bus systems in developing and transitional countries; and the European ITS Toolkit, a decision-support toolkit for Intelligent Transport Solutions developed by the European project 2DECIDE.[32]

While the public-private partnership model originated in large-scale infrastructure projects, it has also gained traction as a viable model for public buildings – such as schools, hospitals and wastewater facilities – also referred to as social infrastructure projects. The municipality as the facility owner contracts with an entity (the contract holder) to develop, design, finance, build, and operate and maintain the project until an agreed-upon contract term.

While many of the benefits of public-private partnerships for city government entities (such as transfer of construction and asset life-cycle risk) can be achieved using other models of procurement, the unique advantage of public-private partnerships is in extracting long-term value-for-money through procuring a building designed for its intended use at the lowest life-cycle cost for the period of the concession (typically 25 years). This ensures that the most energy- and cost-efficient approaches to cooling can be integrated to the benefit of the parties, ensuring that the right steps in the right order are taken, namely design to reduce cooling loads, serve cooling loads efficiently and optimize through controls and operation. Public-private partnerships for public building projects are being leveraged by cities across several countries, such as Canada, Australia, the United Kingdom, and many European countries, and are also fast gaining traction in the United States.

Demand aggregation for cost-effective procurement of climate-friendly solutions

Demand aggregation is the practice of bringing together a sufficiently large demand and leveraging the resulting scale to secure lower prices and higher-quality products from suppliers. Demand aggregation is generally an effective way to enable bulk procurement to drive down the typically higher first-cost of sustainable solutions and cooling equipment in markets where a sufficiently large volume of demand aggregation can be ensured. At larger scales, demand aggregation can transform a market, bringing scale to manufacturers and lowering prices for all consumers. Demand aggregation as a model has been successfully used by municipalities in adjacent industries, such as for driving down the cost of rooftop solar installations. In recent years, it is being effectively applied in the transport sector.

For example, in the Piedmont region in north-west Italy, four of the most populous cities – Alessandria, Asti, Cuneo and Turin – joined hands for the purchase of electric buses. The joint procurement resulted in lower administration costs related to electric bus procurement and implementation, and better pricing for the Piedmont region's operators (Bailey *et al.* 2020). In another example, Los Angeles spearheaded an unprecedented aggregation of municipal demand across the United States with its Electric Vehicle Request for Information released in 2017. This initiative bundled demand for electric vehicles from several cities in order to prove the demand for the vehicles and drive down prices (C40 Cities 2017).

32 These examples, and several others compiled by the World Bank, are available at: https://ppp.worldbank.org/public-private-partnership/sector/transportation/toolkits.

For the adoption of high-efficiency cooling appliances – while not a municipal initiative – the demand aggregation model for super-efficient air conditioners, managed by India's Energy Efficiency Services Limited (EESL), a public energy service company, sets a precedent that could be adopted by cities or a cohort of cities. In August 2017, India's Ministry of Finance directed all central government offices (2,500 buildings) to switch to energy-efficient appliances – in particular, LED lights and super-efficient air conditioners (Vyawahare 2018). The super-efficient air conditioners are expected to consume 30 per cent less energy, translating to reductions in greenhouse gas emissions.

This is part of a broader strategy to reduce the emissions intensity of the buildings sector in alignment with the goals of India's Nationally Determined Contribution to address climate change. Of 100,000 high-efficiency air conditioners procured during the first phase of this initiative, 40 per cent also used the refrigerant R-290, which has low global warming potential . It is envisioned that this bulk procurement will build greater market confidence in R-290-based super-efficient air-conditioning appliances available in the Indian market and encourage the transition to refrigerants that have zero ozone-depleting potential and low global warming potential, to accelerate the phase-down of hydrofluorocarbons. EESL has also made bulk purchases of high-efficiency fans for government buildings.

PROVIDE TRAINING, OUTREACH AND TOOLS TO PROMOTE BEHAVIOUR CHANGE AMONG CITY STAFF

It is important to establish an understanding of the urgency for sustainable cooling solutions and practices among city staff – for example, city planners, architects and environment departments – such that the decisions across municipal departments support sustainable urban cooling. This is particularly relevant for city procurement staff who routinely make purchasing decisions on behalf of municipal governments. They should have an understanding of why sustainable procurement is important, what are the jurisdictions' policies and practices, and what resources are available to them. Cities can provide these tools, trainings and outreach themselves, or leverage any state- or nationally administered resources, or work with partners or consultants to provide the best service.

For example, the Green Purchasing Network – a non-state, non-profit organization established in 1996 with the Japanese government's support, to promote sustainable purchasing in Japan (Green Purchasing Network 2019) – provides training to local government officials and maintains sustainable purchasing guidelines and an eco-products database. It also facilitates sharing of experiences, and honors businesses and governments with innovative purchasing programmes at its annual awards.

Even with training, procurement staff may still be hesitant to use sustainable procurement practices if they require more work or introduce new risks. Therefore, incentives for either institutions or individuals are often helpful to bring about behavioural change. For example, the Republic of Korea's Ministry of Environment requires each city, county and province to report its purchases annually and provides grants or subsidies to local governments that have strong sustainable purchasing records (Singh, Culver and Bitlis 2012).

33 R-290, also referred to as propane, is a natural refrigerant with favourable thermodynamic characteristics, zero ozone-depletion potential, and a global warming potential (GWP) of just three (compared to most hydrofluorocarbons, which have a GWP in the thousands). However, it has high flammability and thus is restricted in the quantity that can be used for indoor applications, due to occupant safety concerns.

MONITORING COMPLIANCE AND TRACKING IMPACTS FOR CONTINUOUS IMPROVEMENT

Monitoring compliance and tracking the impacts – both environmental and financial – is key to measuring the success and reinforcing the benefits of any sustainable public procurement programme. This practice is also important for understanding where improvements can be made.

Cities can maintain their own annual records tracing sustainable procurement performance and noting key milestones, activities and benefits, or leverage any state- or nationally administered programme where available – such as the Republic of Korea Ministry of Environment's annual tracking initiative.

For buildings, energy data visibility and tracking are important for promoting energy efficiency in public buildings. Cities can leverage available energy data management systems to enable understanding, monitoring and the setting of targets for continuous energy efficiency improvements. One such example is the Standard Energy Efficiency Data (SEED) Platform, an open-source, secure enterprise data platform for managing portfolio-scale building performance data from a variety of sources (US DOE 2019). The SEED Platform eliminates many of the technical and workflow challenges associated with collecting and managing performance data for large building portfolios. It has the potential to significantly reduce the administrative effort required by public agencies or other organizations to implement building performance reporting and transparency programmes.

9.2 BROAD BENEFITS OF CITIES LEADING BY EXAMPLE

Cities' leading-by-example strategies not only lower the energy and emissions footprint of the city-owned assets but have multiple cascading benefits. They demonstrate the benefits of and build market confidence in sustainable solutions, send demand signals to the market and catalyse wider adoption of sustainable urban cooling solutions. Cities can also consider forming a cohort to share best practices and resources, and to explore collective opportunities such as for aggregating demand.

FURTHER RESOURCES

- ***Public Buildings Portfolio Management Implementation Guide,* New Buildings Institute, 2018.** https://newbuildings.org/resource/public-buildings-portfolio-management-implementation-guide
- ***Transportation PPP Toolkits,* World Bank.** https://ppp.worldbank.org/public-private-partnership/sector/transportation/toolkits
- ***Going Green: Best Practices for Sustainable Procurement,* Organisation for Economic Co-operation and Development, 2015.** https://www.oecd.org/gov/public-procurement/Going_Green_Best_Practices_for_Sustainable_Procurement.pdf
- ***Public Procurement of Energy Efficient Products: Lessons from Around the World,* J. Singh, A. Culver and M. Bitlis, Energy Sector Management Assistance Program, World Bank, 2012.** https://openknowledge.worldbank.org/bitstream/handle/10986/17485/735070ESM0P12700EEProducts0TR003012.pdf

RECOMMENDED CITY ACTIONS

In the context of this chapter, leading by example refers to efforts that the city government could undertake to support heat mitigation and the adoption of more climate-friendly cooling solutions on buildings and assets that they control. City governments are often one of the largest buyers, or long-term owners (or lessees), of a significant portfolio of buildings, cooling equipment, and transport, and can set the precedent and catalyse market transformation towards sustainable urban cooling.

NO-REGRETS ACTIONS

- Assess opportunities for transitioning to more sustainable cooling approaches in city assets, such as assessment of cooling loads in city buildings and the age of cooling infrastructure (which could also support renovation, replacement or evaluation for district cooling); and assessment and age of the city vehicle fleet to support the transition to low-carbon vehicles.
- Mandate beyond energy code (or stretch code) compliance for new city buildings or buildings planned for major renovation. Establish energy performance requirements for all new leased city buildings.
- Establish procurement specifications, as well as contracting practices, that promote sustainable urban cooling by integrating life-cycle analysis and sustainable cooling considerations into regular maintenance, replacement schedules and capital budgets for municipally controlled buildings and assets.

The above preparatory actions will set the foundation for sustainable procurement, such that when the opportunity arises – such as during lease renewals, new asset acquisition (end-of-life replacement or additions), or regular maintenance and retrofit cycles – city assets can be transformed to support sustainable urban cooling. The no-regrets interventions for sustainable procurement include:

- Comply with stringent energy performance requirements for all new leased city buildings.
- Comply with low-climate-impact performance standards for all new city assets (or during regular maintenance and retrofit cycles).

CITY INTERVENTIONS CATALYSED BY TRIGGER POINTS

Trigger points	Interventions
1 Planned new development and/or major re-development	
✓	New construction or major retrofit of city building – this is an opportunity to enforce stretch code compliance for city buildings.

FACILITATIVE INTERVENTIONS

- Supplement with training for staff to drive awareness of the need for low-climate-impact and lowest life-cycle cost procurement.

CASE STUDY 9.1 | PUBLIC SECTOR LEADERSHIP IN BUILDING ENERGY EFFICIENCY AND SUSTAINABLE PROCUREMENT – SINGAPORE

HIGHLIGHTS:

- **Leading by example: energy-efficient city buildings**
- **Energy service company (ESCO) model for energy efficiency retrofits**
- **Sustainable procurement based on life-cycle costs**
- **Training and up-skilling**

Introduced in 2006, Singapore's Public Sector Taking the Lead in Environmental Sustainability (PSTLES) initiative demonstrates the public sector's commitment to taking the lead in environmental sustainability and adopting a long-term view in resource efficiency. PSTLES was enhanced in 2014 to encourage agencies to focus attention on sustainability outcomes and to put supportive organizational processes in place.

Improving energy efficiency is a key thrust under the PSTLES initiative. New public sector buildings with more than 5,000 square metres of air-conditioned floor area, including buildings with the development cost fully or partly funded by the public sector, are required to attain the highest (platinum) level certification under the local Green Mark rating scheme. Existing public sector buildings, over a certain size of air-conditioned floor area, undergoing major retrofitting are required to attain high (GoldPlus or Gold depending on their size) Green Mark ratings.

For existing buildings, public sector agencies are encouraged to adopt the Guaranteed Energy Savings Performance (GESP) contracting model when undertaking retrofit projects. Under the GESP contracting model, an accredited energy services company is engaged to carry out an energy audit and to identify and implement energy savings measures. The ESCO:

- guarantees the efficiency of the chilled water plant or air-conditioning system, as well as the annual energy savings from the implementation of other energy savings measures over the contract term (*i.e.*, typically five years), and
- provides comprehensive maintenance to the retrofitted equipment during the contract term for better accountability.

On average, these GESP contracts help building owners save 15 per cent of their total electricity use, which translates to $13 million annually for the public sector.

Public sector agencies that lease office spaces are required to lease from buildings with at least a Green Mark GoldPlus rating when their current lease expires. The city's stewardship for building energy efficiency does not stop at owned or leased buildings but also extends to any building that the public sector may use, such as for events and functions, requiring selection of venues that are Green Mark rated. This in effect is a meaningful demand signal to the market for high-efficiency buildings.

Public sector agencies are required to procure the most cost-effective appliances, taking into account life-cycle costs. For electrical appliances that are under the National Environment Agency's (NEA) mandatory Energy Labelling Scheme, (*e.g.*, lamps and air conditioners), the public sector is required to procure appliances with higher ratings. To support the public sector's efforts in sustainability, training and up-skilling opportunities are available through collaboration with Singapore's Building and Construction Authority and the NEA.

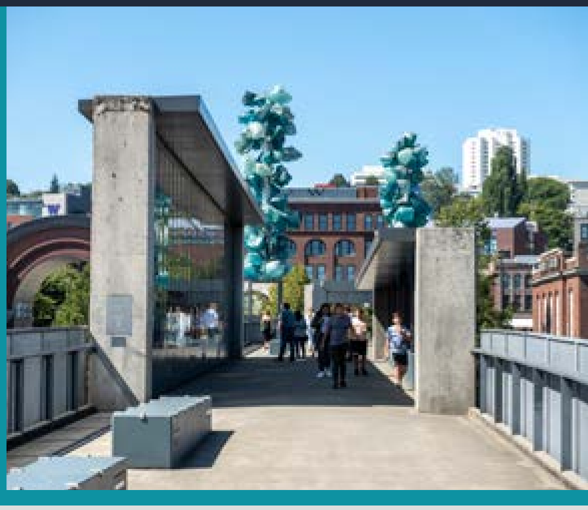
CASE STUDY 9.2 | COMPREHENSIVE MANAGEMENT OF MUNICIPAL BUILDINGS PORTFOLIO – CITY OF TACOMA, WASHINGTON, UNITED STATES

HIGHLIGHTS:

- **Lead by example: energy-efficient city buildings**
- **Benchmarking**

ADDITIONAL CHARACTERISTICS:

- **Long-term vision and goal-setting by cities**
- **Partnership with utility**
- **Capacity-building**



The mayor of Tacoma signed the US Mayors Climate Protection Agreement pledging that Tacoma would strive to cut emissions 7 per cent from 1990 levels by 2012 as established in the Kyoto Protocol. In 2008, the City of Tacoma formalized a Climate Action Plan that set a greenhouse gas emission reduction target of 40 per cent over 1990 levels by the year 2020.

The City partnered with Northwest Energy Efficiency Alliance (NEEA), a non-profit think tank working to accelerate energy efficiency in the region, to undertake a comprehensive approach to efficiency in the municipal portfolio. The NEEA also brought Tacoma Public Utilities (TPU) into the partnership, which not only helped make utility data available for benchmarking, but also committed to helping the city with ongoing benchmarking and identifying energy-saving opportunities. Over a series of facilitated meetings, key city staff created an action plan that consolidated the approaches into one working document. The key actions taken by the group were:

- Established an energy team: The City hired a Resource Conservation Manager to act as the energy champion, and assigned staff to resource conservation management activities.
- Set up a process to automate energy benchmarking: The team inventoried 98 individual facilities and benchmarked 68 in Energy Star® Portfolio Manager. TPU was able to create a framework for automated benchmarking that could also serve as an example for other utilities. Once the energy data were centralized, this enabled the team to progress from benchmarking to deeper building performance analysis.
- Developed Energy Use Intensity (EUI) targets for different building types.
- Established clear metrics to track energy performance and measure success.

The process has helped the City of Tacoma take important steps and make steady progress towards meeting its carbon reduction goals. The utility has benefited in two important areas: energy efficiency savings and customer satisfaction.

CASE STUDY 9.3 | Leading the way in environment-friendly transport – City of Shenzhen, China

HIGHLIGHTS:

- **Lead by example: environment-friendly city fleet**
- **Public-private partnership**
- **Innovative procurement model**
- **Sustainable procurement**

In 2017, Shenzhen, a fast-growing mega-city in China with a population of around 12 million, became the world's first city to realize the full electrification of its bus fleet. The city's 16,000 electric buses are responsible for around 48 per cent less carbon dioxide and many fewer pollutants, significantly reduce noise pollution and are cheaper to operate (Keegan 2018).

The Shenzhen Bus Group Company Ltd. (SZBG), one of the three major bus operators in Shenzhen, was the first public transport operator in China and the world to electrify its entire fleet of around 6,000 electric buses. SZBG's electrification happened in phases, starting with a demonstration stage in 2009-2011, followed by small pilots from 2012 to 2015 and large-scale electrification from 2016 to 2017.

The government mandate to completely shift to clean energy buses, accompanied by generous national and local government subsidies, supported the fast and full electrification of the bus fleet in Shenzhen by significantly lowering the upfront cost. The municipal government of Shenzhen matched the national subsidies, and together these subsidies contributed more than 60 per cent of the total procurement cost of the electric buses from 2015 to 2017, which was critical for the programme's large-scale

▸ Continued

CASE STUDY 9.3
LEADING THE WAY IN ENVIRONMENT-FRIENDLY TRANSPORT – CITY OF SHENZHEN, CHINA

adoption (World Bank 2021). These subsidies helped reduce the cost of ownership of the electric bus (present value) to 36 per cent less than that of a diesel bus (Berlin, Zhang and Chen 2020). The municipal government of Shenzhen also made significant efforts to resolve the land availability issue for building new charging stations and provided subsidies for this construction.

Close collaboration between public and private stakeholders was crucial to the success of the rapid electrification. The main public stakeholder was the Shenzhen Energy Conservation and New Energy Vehicle Demonstration and Promotion Leading Group (SNEVLG), which facilitated the cooperation among municipal departments. The main private stakeholder was the bus manufacturer. The manufacturer not only provided an eight-year product warranty, which covers the lifetime of a bus in Shenzhen but also maintenance support, as well as training for operator staff. This relieved the operator's concern over technology uncertainty and reduced the maintenance cost, and at the same time incentivized the manufacturers to keep innovating and improving electric bus performance.

To reduce the upfront costs of the rapid fleet renewal, the SZBG used a financial leasing model where the financial leasing company purchased and owned the vehicles and leased them to the SZBG for a period of eight years. Since the leasing period equals the total life of the buses, this arrangement turned the high-cost procurement into more manageable annual rental/lease payments.

The subsidies – both national and from the Shenzhen municipal government – were a game changer. In combination with the effective partnership between municipal departments, bus operators, bus manufacturers, and financial organizations, they contributed towards making this project a success.

10 COMMUNITY-CENTRIC INITIATIVES TO ADVANCE HEAT EQUITY AND ACCESS TO COOLING

Community-centric initiatives can have a broad definition, but within the scope of this report they are viewed as a way to advance social equity and environmental justice goals by involving marginalized communities in ensuring that cooling benefits also reach them. The key categories of such initiatives include provisioning of public cooling infrastructure, partnerships with the community to install nature-based solutions and cool surfaces, and establishing tools to protect the public during periods of extreme heat. In addition, awareness and outreach programmes are foundational to enhancing the effectiveness of urban cooling interventions and should be an underpinning strategy.

10.1 ENGAGING THE COMMUNITY TO ADVANCE HEAT EQUITY

Most cities contain "intra-urban" heat islands, where some areas in a city are hotter than others due to uneven distribution of trees and greenery, parks, and heat-absorbing pavement and buildings. These differences can result from historic and current disparities in the way communities are planned, developed and maintained. For example, in the United States the spatial distribution of heat in cities is directly correlated with racial segregation and the "redlining" of neighbourhoods in the 1940s (Hoffman, Shandas and Pendleton 2020). Similarly, in South Africa, the distribution of green infrastructure is correlated with unequal investments made during apartheid (Schäffler *et al.* 2013).

Today, the urban heat island effect is strongly correlated with majority-minority, historically disadvantaged and low-income neighbourhoods in cities across the world. A study of 25 cities found that the highest levels of urban heat island distribution inequity are in the United States, South Africa and Brazil, where income segregation is high within cities (Chakraborty *et al.* 2019). This phenomenon is also self-perpetuating, where high-income communities have higher-value homes and therefore high property tax revenues per resident that can be used for provision of public services and infrastructure as compared to low-income communities.

Heat equity can be improved by tailoring a city's response to heat to meet the needs of the most at-risk residents and ensuring that all residents have access to local heat island mitigation programmes. Considerations to advance heat equity include:

- Ensuring that processes are fair and inclusive of vulnerable communities in the development and implementation of any urban cooling programme or policy.
- Ensuring that resources or benefits and burdens of any urban cooling policy or programme are distributed justly, prioritizing those with the highest need first.
- Creating institutionalized structures that address heat equity over the long term and to prevent future inequities.
- Correcting past institutionalized harm that is related to the inequitable distribution of heat within a city.
- Engaging with the public to understand the risks and potential impacts of heat and engaging them in developing solutions.

While poor and marginalized groups are the most vulnerable to climate change, they are often left out of the climate planning process, and some adaptation measures may inadvertently exacerbate existing inequalities (Guardaro *et al.* 2020). Cities can build trust with underserved communities through transparent communications, partnerships with trusted community organizations and leaders, and ample investment to provide needed cooling resources. Cities should also ensure that the district budgets are tailored to neighbourhood needs.

Community and equity-centric initiatives save lives. Many community-centric initiatives, such as cooling centres and heat-health alerts, can reduce heat mortality and morbidity for the most vulnerable to heat-related illness, including outdoor workers, older adults, children, marginalized racial and ethnic groups, the homeless, individuals with a mental disability, individuals with chronic medical conditions, individuals without access to cooling and low-income communities (Fecther-Leggett *et al.* 2016).

Meaningful engagement with the most marginalized and at-risk communities is essential to advancing heat equity and ensuring that these populations receive access to and benefits from cooling.

10.2 TYPES OF COMMUNITY-CENTRIC INTERVENTIONS THAT CITIES CAN IMPLEMENT

Policymakers can support a range of community-centric initiatives to advance heat equity in cities. The key categories of such initiatives include provisioning of public cooling infrastructure, partnerships with the community to install nature-based solutions and cool surfaces, and establishing tools to protect the public during periods of extreme heat. In addition, awareness and outreach programmes are foundational to enhancing the effectiveness of urban cooling interventions and should be an underpinning strategy. Together, these initiatives and interventions aim to ensure, educate and/or enable the public to stay safe during high-heat conditions as well as engage the community in longer-term measures for mitigating the urban heat island effect.

PUBLIC COOLING INFRASTRUCTURE

Public cooling infrastructure includes indoor and outdoor spaces with amenities available to all residents in a city during periods of extreme heat. Public cooling infrastructure may be identified and developed as part of a larger community heat action plan or on an as-needed basis in response to heat. Spending just a few hours in a cool environment can reduce vulnerable populations' risk from heat exposure. People who adjust their behaviour to spend time in a cool place during a heatwave are less likely to suffer from heatwave mortality (Semenza *et al.* 1996; Vandentorren *et al.* 2006; Luber and McGeehin 2008). A meta-analysis found that the act of visiting an air-conditioned space reduced the risk of mortality by roughly 66 per cent compared to those who did not (Bouchama *et al.* 2007). Typical examples of public cooling infrastructure include community cooling centres, cooled transit stations and public water features.

Community cooling centres

Community cooling centres are a relatively straightforward strategy that policymakers can use to leverage existing infrastructure to alleviate the problem of heat stress by providing temporary shelter to the public during extreme heat periods.

Also referred to as a "cool site" or "cooling shelter", these centres are typically an air-conditioned or cooled building that is designated as a site to provide respite and safety from heat. Cooling centres may be run in city-owned buildings such as a library, school or office building; a public or private community centre; a religious centre, recreation centre, or senior centre; or a private business such as a shopping mall or movie theatre. Cooling centres may be in permanent locations or constructed temporarily. These centres can be implemented by a variety of stakeholders including a city government, health department, non-profit organization, private business, or combination of agencies and partners (Centers for Disease Control and Prevention [CDC] 2017a).

Cities should explore opportunities for repurposing suitable existing structures for use as community cooling centres where such opportunities exist. One example is the historic stepwells in the state of Gujarat in India. Typically, a stepwell is a unique form of underground well architecture where a long, stepped corridor leads down five to six storeys until it reaches the aquifer. In the old days, the well, at the far end of the L-shaped structure, remained filled with clean and naturally filtered water throughout the year. None of the stepwells are functioning today, due to a combination of the shrinking water table and the availability of municipal water supply. However, these tiered structures are designed to provide shelter from the hot and dry weather, and the construction materials – typically brick, sandstone and lime mortar – keep the surroundings cool. Typically located along important trade routes and near settlements, these structures, if appropriately repurposed, could effectively serve as community cooling centres in the hot and dry climate of Gujarat.

Good practices and considerations for effective community cooling centres include:

- **Appropriate siting:** Location of the cooling centres should consider proximity to – and ease of access for – large heat-vulnerable populations. Cities may also consider situating cooling centres along bus routes or altering the bus routes to stop at designated cooling centres. Case studies from the United States show that outdoor cooling sites such as public parks or pools and private malls and movie theatres are often more utilized than government-run indoor cooling centres. For outdoor cooling, park hours can be extended during extreme heat events to allow residents who lack air conditioning to visit parks at night to cool off (US EPA 2016). Opening schoolyards to the general public during non-school hours is one way to increase access to green space in neighbourhoods that lack parks (Trust for Public Land 2020b).
- **Targeted for specific populations:** Cooling centres may be targeted to serve a specific portion of the population. For example, governments may run cooling centres for low-income families at schools, enact policies that require employers for outdoor workers to provide access to shade or cooling, or operate cooling centres targeted at the homeless. Homeless residents are uniquely exposed to heat and may face additional challenges accessing public cooling infrastructure including stigma, lack of transport, not wanting to leave behind possessions or pets, and harassment. Planning to serve the homeless during heat months requires partnerships that link support from communities to government programmes and financial resources. For example, Maricopa County in Arizona, United States runs separate cooling centres for the homeless where they can sit in a cool area and have access to safe drinking water. Some provide additional accommodations such as food, clothing, and referring services to shelters, health care and food banks (White-Newsom *et al.* 2014).
- **Cost considerations for access:** The cost associated with the access needs to be low for the public at large. Free and accessible transport can improve cooling centre utilization (CDC 2017a; Nayek *et al.* 2019). Local governments can provide transit vouchers to low-income residents who otherwise cannot travel to a cooling centre or work with local emergency responders to provide rides. Public-private partnerships can help ensure that low-income individuals who may lack transport and financial resources can also have access to these cooling spaces at minimal or no cost. This may include programmes for free or discounted tickets to museums or movie theaters or vouchers for food to access restaurants and coffee shops (CDC 2017a). This approach also avoids adding a new air-conditioned space that could further contribute to the heat event and burden the electricity grid.
- **Timely and tailored communication:** Cooling centres should be advertised to the public ahead of the extreme heat season, and through a variety of channels (*i.e.*, city website, print newspapers, radio announcements, social media, mailers, phone outreach to home care agencies) in all appropriate languages. For example, the City of Philadelphia engaged vulnerable populations with pamphlets and brochures in seven different languages and at community churches to raise awareness of cooling centres (CDC 2017a). Cooling centres should be marked with visible signage to ease access.
- **Providing essential amenities:** Most cooling centres provide water and some also provide food and entertainment. Based on their resources and requirements, cities can establish guidelines for appropriate amenities. For example, Health Canada recommends that cooling centres have back-up power generation, drinking water, medical supplies, heat-health education materials and trained staff who can recognize the signs of heat illness (Health Canada 2012).

Public water features

Public water features provide people access to cooling and hydration in public spaces during peak heat-stress months, helping to alleviate heat-related exhaustion and dehydration. These features could include hydration stations and drinking fountains, as well as recreational water features such as spray parks, splash pads, misting stations, public pools and fountains. Key considerations when planning different water features are discussed as follows.

- **Hydration stations and drinking fountains:** Hydration stations include public drinking fountains, businesses or community centres that will give away free water, and pop-up water distribution sites. Hydration stations should be placed on streets that have a high volume of pedestrians (particularly in heat-vulnerable communities), near public transit stops, and in other public spaces like parks and plazas. Pop-up water distribution sites should be tented or otherwise provide shade. Engaging the community in the design and placement of hydration stations and drinking fountains is especially important to ensure that they are placed in areas that will get the most use. For example, community members may have deeper insight than city planners on which streets are used most for walking. The Heat Action Planning Guide for Neighborhoods of Greater Phoenix suggests that drinking fountains be placed at least every mile and at public transit stops (see case study 10.2) (The Nature Conservancy 2019).
- **Recreational water features:** White recreational water features have the potential to help moderate outdoor temperatures through evaporative cooling in some climates, this chapter focuses on their use to provide direct cooling benefits to people who use them. Recreational water features are especially important for providing cooling respite for children. These include passive water systems, such as pools and immersive fountains, and active or hybrid water systems like spray parks, splash pads and misting stations.

Spray parks, splash pads and misting stations can be installed in public parks or at schools. They are less expensive to install than pools and do not require staffing. In addition to being safe for kids, splash pads can be accessible for the elderly and people with disabilities (Walker 2019). Sprinklers are another low-cost way to provide access to a recreational water feature. Cities that already irrigate parks can turn on sprinklers at designated times to allow children to play (The Nature Conservancy 2019). Public pools and fountains can be repurposed and operated as outdoor cooling centres during extreme heat days. To increase accessibility, public pool hours can be extended to allow for morning and nighttime use.

Local governments should create online and print maps of public water features that include any pertinent information such as hours of operation. In humid cities, recreational water features should only be installed if the added humidity will not exacerbate heat stress. In places that are significantly water stressed (for example, in several Indian cities where groundwater reserves are already depleted and the water table is falling fast), recreational water features may have limited applicability; highly water-efficient splash systems – if available in the local markets – can be leveraged for such regions.

Public transit stops – bus and train stations

Public transit riders are vulnerable to heat stress because of the necessity to walk and wait outdoors. Health impacts of heat stress are compounded when people are exposed to ground-level air pollution. Public transit stops can be designed to support a cooler and more comfortable commute through strategies such as shading , incorporating greenery, and water features (and energy-efficient air conditioning where necessary and feasible). Cooled public transit stops can be an important feature of heat-resilient urban design, and also support comfortable access to cooling centres and public water features.

Good practices and considerations for designing cool public transit stops include:

- **Appropriate design:** Public transit stops can be cooled with shade, greenery and misting (and high-efficiency air conditioning where feasible). Cooling benefits can be further extended by installing drinking fountains at cooled transit stops. Cooled transit stops should be made accessible to pedestrians and cyclists to cool off while commuting. Seating should be installed at cooled transit stops with materials that will stay cool during excessive heat. Cities can also design transit stops to help address air pollution. For example, the Airbitat Oasis Smart Bus Stop in Singapore uses an energy-efficient evaporative cooling technology to cool the air with 70 per cent less energy as compared to conventional air conditioning with a similar cooling capacity, and generates zero waste heat . Additionally, the bus stop is equipped with air purification technology to remove air pollutants including $PM_{2.5}$ (Smart Energy International 2018).

- **Siting:** Cities can work with communities to identify priority transit stops for installing cooling infrastructure, such as at the most trafficked transit stops, those along popular cycling and pedestrian corridors, and those in neighbourhoods that lack street trees. Cities can additionally prioritize cooled bus shelters in places frequented by those most vulnerable to heat, such as shelters near senior centres or hospitals. For example, when cities in Australia ran a design competition for bus shelters, the winning project was selected in part for its location across the street from a hospital frequented by frail, elderly and disabled people. The bus stop design was created with input from commuters to directly address the challenges they faced. The new bus shelter design leads to temperatures 4°C lower than the original and has been received with overwhelmingly positive feedback (Penrith City Council 2018a).
- **Reducing wait times:** Many cities are installing real-time communication measures with digital signs at transit stops and phone apps that alert riders to real-world wait times. Clear communication about wait times can enable transit riders to access nearby cool spaces and minimize outdoor exposure while waiting for transit.

34 See chapter 5 for more discussion about shading principles to make outdoor transit stops more comfortable.
35 For more on the Airbtat technology, see https://airbitat.com.

NATURE-BASED SOLUTIONS AND COOL SURFACES FOR ADDRESSING HEAT INEQUITY

Nature-based solutions and cool surfaces are two important components of heat-resilient urban design. While these are covered in detail in chapter 6, this chapter focuses on how these solutions can be applied for heat-vulnerable communities to mitigate heat islands and enhance thermal comfort from heat.

Urban greening programmes in vulnerable neighbourhoods

Trees and other green infrastructure are not evenly distributed throughout cities. In cities around the world, trees are spatially correlated with income, and poorer neighbourhoods tend to have fewer street trees and other green amenities, leading to an uneven distribution in the urban heat island (Chakraborty *et al.* 2019). In cities that historically have had racially segregated urban planning, such as in the United States and South Africa, tree distribution is correlated with race (Schäffler *et al.* 2013; Hoffman, Shandas and Pendleton 2020). Because tree planting programmes tend to be self-selecting, there is a risk that trees will not be planted in the areas that need them most.

Proactive outreach and meaningful involvement is necessary to ensure that targeted communities participate in street tree programmes. Additionally, active engagement with communities to shape greenery in their own neighbourhoods is one strategy to prevent "environmental gentrification", a phenomenon where low-income residents are displaced after investments are made in green infrastructure and other amenities that improve a neighbourhood (Gerish and Watkins 2018).

Some important considerations bringing equity in urban greening are:

- **Planting and maintaining trees:** Tree giveaways and other programmes to encourage tree plantings will be most successful when paired with training on how to properly plant and care for the tree for the establishment period of two or more years to improve survival and encourage maximum health and growth potential. Tree-planting programmes may be paired with a site visit from a trained professional to help place the tree in the optimal location, for example to maximize residential or sidewalk shading.

The City of Durban, South Africa is using tree giveaways to advance social and economic uplift goals. The municipal government provides residents with seedlings or young trees and pays residents to care for them in areas with high heat or stormwater management risks. Residents form small nurseries and provide maintenance services for trees in their community. The programme has brought cost savings to the municipal budget, improvements in tree health and survivability, and new economic opportunities for under-resourced communities (de Guzman *et al.* 2020).

Tree giveaway programmes are most effective when paired with a training, site visit or care guide to teach participating housings to care for their trees (ESMAP 2020a) (see case study 11.1 for an example of a tree giveaway programme). Giveaway programmes are self-selecting. To ensure that giveaways reach target areas or demographics, cities should conduct outreach to prioritized demographics and partner with trusted organizations and businesses as hubs for giveaways. (Giveaways can take other forms, as described later in this chapter under the cool roof programme discussion).

- **Reaching target communities:** Many communities face barriers to adopting street trees and other urban greenery including lack of information about their benefits, lack of trust in government agencies creating these programmes, and a lack of resources to support ongoing maintenance. Street tree and other urban greening programmes can best reach target communities through early communication and involvement with target communities that creates a sense of ownership on street tree programme design.

For low-income and other marginalized communities, the cost and other maintenance required to support street trees can be a barrier. Designing programmes to bring tangible benefits to communities before the environmental benefits of street trees occur can be essential to reaching target communities and building support. This can include partnering with community-based non-profits, schools, and volunteers, or hiring members of marginalized communities to administer street tree programmes.

Cool roof programmes targeting low-income communities and informal settlements

Cool roofs can help build community resilience to extreme heat events and are an effective way to help reduce present-day heat exposure in low-income housing and informal settlements. These areas tend to be more exposed to extreme heat because they are typically more dense than other urban areas and tend to lack vegetation and tree cover.

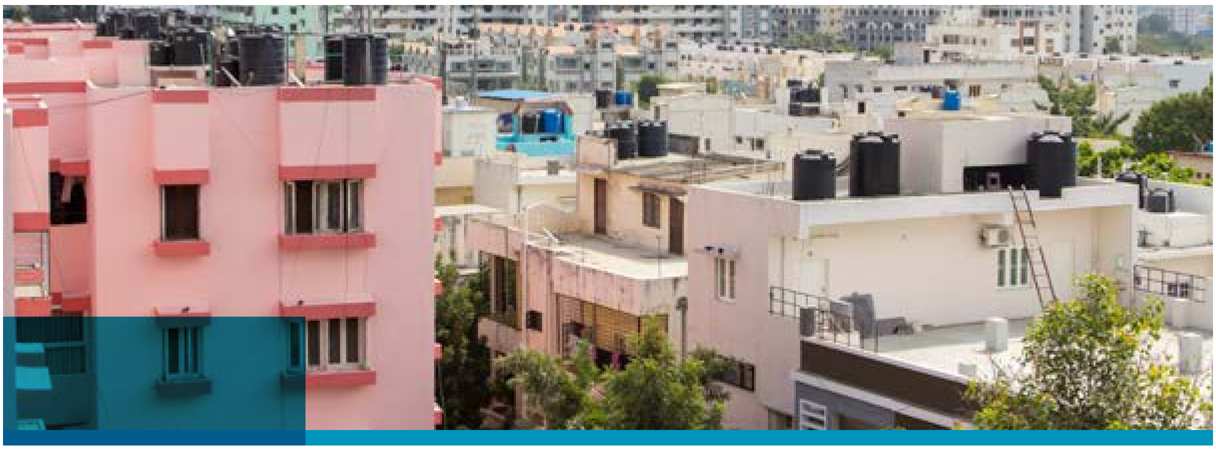
Cities should be especially concerned about the impacts of heat in informal settlements – with over 1 billion urban residents as of 2018 (United Nations 2019) – because those living in them are at higher risk of developing a heat-related illness and lack many adaptation options available to other city residents. Additionally, materials used in many informal settlements – such as tin and asbestos – trap heat and do not allow air to flow through the structure, exacerbating indoor air temperatures.

Households in low-income communities and informal settlements are generally less likely to have access to air conditioning and are more likely to rent; therefore, cost motivation is not sufficient to lead to cool roof installation. Targeted programmes to engage these communities and overcome financial barriers are necessary to ensure installation of cool roofs. Local governments can engage the community as part of a strategy to grow cool roof programmes from a single neighbourhood to a city-wide effort by starting with pilot projects and voluntary initiatives to gain support and expertise needed for city-wide initiatives such as building codes and other mandates.

Good practices and considerations for targeted cool roof programmes for heat-vulnerable communities include:

- **Pilot projects on low-Income housing:** Pilot projects are an important way for cities and researchers to test the application and cost-effectiveness of different cool roof technologies for specific local conditions. Intentionally focusing pilot projects in low-income neighbourhoods brings the benefits of cool roofs to these communities first, allows for solutions to be identified that meet the specific conditions of low-income housing, and trains and educates the community to continue installing cool roofs.

  Giveaways can also be combined with demonstration or pilot projects in under-served communities to amplify their effectiveness. In situations where conventional financial incentive programmes exclude the poorest residents who may not be able to afford any upfront investments, giveaway programmes that provide direct resources can be a helpful approach. For example, a cool roof pilot programme in Ahmedabad, India applied cool roofs for free on 3,000 low-income households. Some of the roofs were coated with heat-reflective paint provided free of cost by a local business, and the rest were coated with three layers of lime by contractors hired by the city. Other cities in India have similarly conducted cool roof pilots in low-income neighbourhoods and informal settlements, providing materials for free. Cool roof projects in Ahmedabad and Hyderabad that were piloted as free "giveaways" have been followed by voluntary adoption of cool roofs on nearby buildings (NRDC 2018).



- **Dedicated funding:** While the potential for long-term cost savings is a motivator for cool roofs in higher-income households, other means of financing are necessary to ensure cool roof implementation on low-income housing. Cities can address this by dedicating funding for financial incentives, to pay for direct implementation of cool roofs on low-income housing and to fund cool roof awareness programmes and worker training programmes (NRDC 2018). Cities can utilize public funds already allocated to "smart city" or energy efficiency efforts or offer property tax rebates for cool roof installation.
- **Partnerships:** Partnerships can bring needed resources to supplement municipal funding for cool roof programmes. Cities can partner with businesses and non-governmental organizations for donations of materials to use in cool roof implementation in low-income communities and informal settlements. For example, many Indian cities are partnering with businesses to meet their corporate social responsibility contributions with donations for cool roof pilots (NRDC 2018).
- **Educating and engaging the community:** Cool roof programmes in heat-vulnerable communities should focus on educating community members on the benefits of cool roofs and how to install them with local materials. When working with limited resources, municipalities can also engage residents in the installation process, such as in the Ahmedabad cool roof programme, where residents of the informal settlement took part in the installation of the cool roofs. This not only gives community members a new skill, but also helps ensure better maintenance and longevity of the cool roofs.

ACTION PLANS AND WARNING SYSTEMS FOR HEAT EVENTS

Cities can plan ahead for hot-season and extreme-heat events with tools such as health alerts, warning systems, wellness check programmes, and heat-health hotlines, or with a comprehensive action plan – incorporating many of these tools – known as a Heat Action Plan. While Heat Action Plans are beneficial for the entire city population, they are perhaps the most critical – even life-saving – for heat-vulnerable populations that have limited means and adaptations available to protect themselves from extreme heat.

Heat Action Plans provide a comprehensive framework for the implementation, coordination and evaluation of extreme heat response in a city. They are often coordinated across multiple government departments and may include public-private partnerships to ensure smooth and effective responses to dangerous heat conditions (ESMAP 2020a). The effectiveness of any Heat Action Plan depends on the ability to deliver useful, timely, accessible, consistent and trustworthy information to target audiences and high-risk populations. Some key considerations for establishing and maintaining public trust, which is foundational for the effectiveness of any Heat Action Plan, are as follows (Matthies *et al.* 2008).

- **Announcing early:** The parameters of trust are established in the first official announcement, where the message's timing and comprehensiveness can set the tone for the public's receptiveness.
- **Transparency:** Transparent communication that is candid, easily understood, complete and factually accurate allows the public to view and understand the risk-assessment and decision-making processes associated with the heat response.
- **Understanding the public:** Understanding the public is critical to effective communication about the risks and responses to heat. Heat-risk communication should be tailored to a specific audience's beliefs, opinions, and knowledge about specific risks, and include clear information about what the public can do to be safer.
- **Build capacity and leverage partnerships:** Heat-health-related messages are often delivered by intermediaries such as the media, non-governmental organizations and faith groups, or health-care workers. City governments should work with these entities to align on what key messages need to be announced and how to best share information about actions that people and health professionals should take during heat events.

While the Heat Action Plans will be tailored to best fit each city's specific requirements and context, some core components that are generally common are discussed as follows.[36]

Heat-health alerts and warning systems

Heat-health alerts, also called Heat-Health Warning Systems (HHWS) or Heat Warning Systems (HWS), are communications to warn the public about the arrival, duration and severity of dangerous heat conditions. Heat-health alerts may include information about predicted high and extreme temperatures, information to recognize and alleviate the signs of heat stress, and communications about public services for heat relief, including access to public cooling infrastructure. Heat-health alerts are shown to reduce mortality during heat events (Ebi *et al.* 2004; Chau *et al.* 2009). One study from France estimated that 4,400 excess deaths were avoided after implementing a Heat Warning System in 2006 (Toloo *et al.* 2013).

Cities use a variety of metrics and thresholds to trigger emergency communications, including days with daytime maximum temperatures above a certain degree, days with maximum apparent temperature above a certain level (to account for the effect of humidity on the experience of heat) or number of days above a certain daytime maximum temperature. Criteria used to establish the threshold for a heat event must reflect local conditions to which people are accustomed. Further, cities should leverage partnerships with relevant regional or national entities.

36 There are resources in the public domain that describe the characteristics and core elements of a Heat Action Plan. One such resource, with examples from several European countries that have begun their implementation and evaluation, is the World Health Organization's Heat-health Action Plans Guidance (WHO 2008).

For example, over 100 cities and districts in India have set up heat alert systems with the support and guidance of the Indian Meteorological Department (IMD) and the National Disaster Management Authority. The IMD also provides over 350 cities with seasonal and daily temperature forecasts, which are a critical trigger for prompting early heat-warning communication by city officials (NRDC 2019). Cities in the United States can also include emergency communications with the National Weather Service. Around 40 cities worldwide use a more sophisticated system that uses locally specific algorithms based on increases in predicted mortality when particular air masses are present over a city (ESMAP 2020a). Incorporating evidence of heat-attributable adverse health impacts based on health outcomes and weather conditions can enhance criteria development (US EPA 2016).

Heat-health alerts are most effective when timely information is disseminated through multiple channels – such as via social media, mainstream media, radio, television, posted on a city website, or sent through text and phone call alert systems – and in all appropriate languages. The City of Boston's Keep Cool app, which provides alerts on extreme heat events and maps nearby cooling centres, categorizing them by type, is an example of communicating risk and mitigating it in real time (Harmon 2017). Some European cities, including Athens and Paris, are also developing smartphone apps that communicate directly with users when they enter an area of excess heat, to provide directions to cooling infrastructure, and pro-actively message personal contacts set by the user to check in (ESMAP 2020a). Trusted members of the community, including health-care workers and pharmacists, can also be used to disseminate information contained in heat-health alerts (Matthies *et al.* 2008).

Heat-health alerts can be targeted to specific vulnerable populations, for example the elderly (Matthies *et al.* 2008). Additionally, cities may target heat education for first responders, local emergency management personnel, and those who provide care for older individuals, the very young, the homeless, and those with physical illness or mental disability (US EPA 2016).

Wellness check programmes

Wellness check programmes train members of the community to recognize the signs of heat stress and to share information on how to reduce vulnerability to and symptoms of heat-related illness during extreme heat conditions. Wellness check programmes can complement municipal heat alerts that may not effectively reach or be highly trusted by the most at-risk audiences. This is especially important for the elderly, the socially isolated, and the homeless, for whom passive information has proven not to be sufficient (Matthies *et al.* 2008). As an added benefit, the applicability of wellness check programmes can be expanded to cover other health goals for the community as well (beyond heat-related).

Wellness check programmes may include buddy systems, home visits or daily phone calls. Wellness check programmes can focus on capacity-building for medical professionals, including primary medical officers, paramedics and community health staff to recognize and treat the signs of heat-related illness. For example, New York City launched a "Be-A-Buddy" pilot programme in 2018 to train home health-care aides to recognize the early stages of heat stress in their clients and on how to reduce their risk (ESMAP 2020a). Wellness check programmes may be implemented with the help of social services to actively identify, contact and follow up with people at risk during a heat wave (Matthies *et al.* 2008).

Cities may launch campaigns to encourage residents to check on heat-vulnerable family members, neighbours or friends (US EPA n.d.). The US Centers for Disease Control and Prevention recommends the use of a buddy system to, twice per day, check on people over 65 who are overweight, who work outdoors or who are physically ill (CDC 2017b). Cities may also establish partnerships with trusted organizations like community groups and religious institutions to implement wellness check programmes in heat-vulnerable communities.

Heat-health hotlines

Heat-health hotlines are telephone helplines available during periods of heat that can provide information and real-time advice to any member of the public that requests it. Heat-health hotline staff should be equipped to provide information about cooling resources (including location and transport to cooling centres, wellness check programmes, available programmes to assist low-income residents to pay for or otherwise access cooling, among others) and on the symptoms and antidotes of heat-related illness, and be able to triage with emergency medical services.

Depending on the climate, heat-health hotlines may operate year-round, seasonally or be activated when a heat event is forecast. Heat-health hotlines may be established within an existing phone line (like a City 311 line) or be set up independently. For example, during extreme heat events, the Philadelphia Corporation for Aging's Senior Line doubles as a heat-health line with extended hours. To enable access, heat-health hotlines should be established with a toll-free number. Heat-health hotlines are most effective when trained medical professionals are on-call to help address specific medical questions (US EPA 2016). In some cases, it may be necessary to proactively make phone calls to heat-vulnerable communities who may not otherwise contact a heat-health hotline.

Data collection programmes

Data collection programmes can help cities monitor the impacts of heat events on health and well-being, evaluate the effectiveness of heat action plans, and guide future allocation of resources and heat response. They include real-time monitoring of hospitalizations for heat-related illness, tracking heat-related deaths, and evaluating the use of cooling interventions and their effects. Tracking any increases in the demand for medical services such as ambulance calls and emergency services can also help guide resource allocation across multiple entities that may be responsible for health-care provision in a city.

Cities can track the number of people who use public cooling infrastructure, including how long people stay at cooling centres, as well as the number of people who receive heat alerts, participate in wellness check programmes or call health hotlines. To better assess how the community is being served, cities can collect demographic data to track participation based on factors such as age, race or location of residence. Data collection programmes should be used to guide policymakers when updating heat response plans. However, cities should not use data collection programmes as the basis for establishing a heat warning and instead should focus on using data collection to evaluate the effectiveness of interventions (Matthies *et al.* 2008; US EPA 2016).

10.3 CONCLUDING NOTE

Meaningful engagement with the most marginalized and at-risk communities is essential to ensuring that they receive benefits from cooling. Engaging with the communities as key stakeholders early-on can lead to cooling policies and programmes that are better received by the community and more likely to be sustainable over a longer period. This, in turn, enhances heat equity across the population, manifesting long-term benefits for communities including improved quality of life, trust, empowerment, knowledge and capacity-building.

FURTHER RESOURCES

- ***Heat-health Action Plans,* World Health Organization, 2008.** https://www.euro.who.int/en/publications/abstracts/heathealth-action-plans
- ***Heat Action Plans and Case Studies,* Global Heat Health Information Network.** https://ghhin.org/heat-action-plans-and-case-studies
- ***Cool Roofs: Protecting Local Communities and Saving Energy,* Natural Resources Defense Council, Indian Institute of Public Health, Gandhinagar, International Institute of Information Technology, Hyderabad, Administrative Staff College of India, and Mahila Housing SEWA Trust, 2018.** https://www.nrdc.org/sites/default/files/ib_-_cool_roofs_-_hyd_workshop.pdf
- ***Policy and Planning Tools for Urban Green Justice, ICLEI – Local Governments for Sustainability,* Barcelona Lab for Urban Environmental Justice and Sustainability, 2021.** https://www.c40knowledgehub.org/s/article/Policy-and-Planning-Tools-for-Urban-Green-Justice
- ***Heat Action Planning Guide for Neighborhoods of Greater Phoenix,* The Nature Conservancy *et al.*, 2019.** https://www.nature.org/content/dam/tnc/nature/en/documents/Phoenix-Arizona-Heat-Action-Plan.pdf
- ***Urban Heat and Equity: Experiences from C40's Cool Cities Network,* C40 Cities Climate Leadership Group, 2021.** https://www.c40knowledgehub.org/s/article/Urban-Heat-and-Equity-Experiences-from-C40s-Cool-Cities-Network?language=en_US
- ***Communicating Heat Risk: Experiences from C40's Cool Cities Network,* C40 Cities Climate Leadership Group, 2020.** https://www.c40knowledgehub.org/s/article/Communicating-Heat-Risk?language=en_US
- ***Neighbourhood Level Cooling: Experiences from C40's Cool Cities Network,* C40 Cities Climate Leadership Group, 2021.** https://www.c40knowledgehub.org/s/article/Neighbourhood-Level-Cooling-Experiences-from-C40s-Cool-Cities-Network?language=en_US

RECOMMENDED CITY ACTIONS

The negative impacts of excess warming are often placed disproportionately on those least likely to be able to afford or access thermal comfort. It is therefore an urgent priority for cities to implement urban cooling solutions for these heat-vulnerable communities, ensuring their cooling benefits and protection from extreme heat.

10

NO-REGRETS ACTIONS

- Establish a heat alert system as a basic measure to alert the public for anticipated periods of heat. This can be supplemented with information on how to reduce vulnerability to and symptoms of heat-related illness during extreme heat conditions.
- Identify vulnerable communities that have no local access to public cooling infrastructure and develop plans to make access available.
- Identify and make available cooled spaces that are accessible to heat-vulnerable communities in the event of heatwaves.
- Establish a heat alert system as a basic measure to alert the public for anticipated periods of heat.
- In climates prone to extreme heat, implement low-cost measures in the heat-vulnerable communities such as cool roofs for housing.

CITY INTERVENTIONS CATALYSED BY TRIGGER POINTS

Trigger points			Interventions
1 Planned new development and/or major re-development	2 Introducing or initiating city planning processes	3 Evaluating or initiating major city infrastructure projects	
✓		✓	Ensure appropriate prioritization of interventions for heat-vulnerable communities/neighbourhoods. For example, a development/re-development project may trigger an opportunity for a neighbourhood revitalization or greening programme.
	✓		Integrate the need for urban heat island mitigation and access to cooling for heat-vulnerable communities.

FACILITATIVE INTERVENTIONS

- Apply targeted messaging to enhance public awareness about the hazards of extreme heat and the available facilities (such as cooling centres) and means to stay safe during high-heat conditions.
- Build and leverage partnerships with non-governmental organizations, faith groups, health-care workers and media to expand outreach and heat-health-related messaging to vulnerable communities.
- Provide targeted incentives for low-income communities to bridge the higher acquisition cost of energy-efficient cooling equipment.

CASE STUDY 10.1 | HEAT ACTION PLAN – AHMEDABAD, INDIA

HIGHLIGHTS:

- Municipal heat action planning
- Reaching low-income and marginalized communities
- Early heat warning systems
- Public awareness and community outreach
- Capacity-building among health professionals
- Reducing heat exposure and promoting adaptive measures

Following a deadly heatwave in 2010, the Ahmedabad Municipal Corporation (AMC) created its first Heat Action Plan and warning system in 2013. The main goal of the Heat Action Plan is to alert the public that is most at risk of heat-related illness that extreme heat conditions exist or are imminent and to take appropriate precautions. The Heat Action Plan also includes longer-term measures, such as the Ahmedabad Cool Roofs Program (NRDC *et al.* 2018). A peer-reviewed study found that AMC's Heat Action Plan avoids over 1,190 deaths each year, with the biggest decrease in deaths on the hottest days (Hess *et al.* 2018).

Ahmedabad's Heat Action Plan engages the community with capacity-building and training, education and outreach, and targeted actions to assist vulnerable populations. The Heat Action Plan identifies vulnerable populations, the causes of their higher risk, and strategies and coordinated responses to address heat. To assist with the original Heat Action Plan, the city in partnership with researchers and the Natural Resources Defense Council published studies on household vulnerability, excess mortality associated with the 2010 heatwave, evidence-based recommendations to address heat for residents of informal settlements and outdoor workers, and recommendations for health professionals and government officials (NRDC 2013a; NRDC 2013b; NRDC 2013c; NRDC 2013d; Tran *et al.* 2013; Shah Azhar *et al.* 2014).

The Heat Action Plan is evaluated and updated every year, allowing the city to scale its ambition and iterate on lessons learned. Ahmedabad's Heat Action Plan is based in four key areas: an early warning system and inter-agency emergency response plan, public awareness and community outreach, capacity-building among medical professionals, and reducing heat exposure and promoting adaptive measures (ESMAP 2020a).

- **Early warning system and inter-agency response plan:** Ahmedabad's Heat Action Plan is founded in its early warning system that is used to identify when the city should activate its Heat Action Plan. An appointed AMC Nodal Officer coordinates stakeholders and ensures implementation of the Heat Action Plan. When the temperature forecast triggers issuance of a heat alert or heat warning, the AMC Nodal Officer alerts government agencies and non-governmental organizations and triggers each entity's pre-determined interventions.
- **Public awareness and community outreach:** When a heat alert or heat warning is triggered, the AMC alerts phone companies to send text messages, and coordinates media and press to assist with outreach including television, print, and radio alerts, sharing posters and pamphlets, and promoting Ahmedabad's Heat Hotline. The Heat Action Plan also includes preventative training and outreach for school children and weekly meetings with non-governmental

▸ Continued

CASE STUDY 10.1
HEAT ACTION PLAN – AHMEDABAD, INDIA

organizations and slum leaders. Public awareness also includes a wellness check programme where people are encouraged to check on neighbours and elderly family members to ensure they are taking appropriate measures to stay cool.

- **Capacity-building among health-care professionals:** The Heat Action Plan includes training for health workers to recognize and respond to heat-related illnesses. This includes outreach to primary medical officers, paramedical staff and community health workers to increase their ability to effectively prevent and manage heat-related cases and reduce heat-related morbidity and mortality.

- **Reducing heat exposure and promoting adaptive measures:** The Heat Action Plan includes providing access to potable drinking water and cooling spaces during extreme heat days. Additionally, the Heat Action Plan includes a cool roof programme to promote passive cooling roofs. The iterative nature of the Plan has allowed the AMC to scale cooling efforts and build off past success. The 2017 and 2018 Heat Action Plans included pilot projects to install 500 and 3,000 cool roofs respectively on low-income housing. Building off this success, the 2019 Heat Action Plan included mandatory cool roofs for all municipal, commercial and government buildings and voluntary cool roofs on residential buildings.

Public outreach heat awareness poster as part of the Ahmedabad Heat Action Plan 2019 update

CASE STUDY 10.2 | NEIGHBOURHOOD HEAT PLANNING – MARICOPA COUNTY, ARIZONA, UNITED STATES STATES

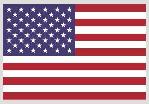
HIGHLIGHTS:

- Neighbourhood heat action planning
- Partnerships with non-governmental and community organizations
- Community engagement and capacity-building
- Transforming neighbourhoods to promote heat resilience
- Reaching low-income and marginalized communities

Maricopa County, Arizona is home to the City of Phoenix, the hottest metropolitan area in the United States (The Nature Conservancy 2020). The hottest neighbourhoods in Maricopa County can be around 7°C hotter than others and have the least number of trees and the highest rates of childhood poverty (The Nature Conservancy 2020). Additionally, the number of heat-related deaths in Maricopa County has risen each year since 2015, and more than 250 people died of heat-related deaths in 2020 (Arizona Department of Health Services 2020).

To respond to this, in May 2017 a coalition of organizations – including The Nature Conservancy, the Maricopa County Department of Public Health, the Central Arizona Conservation Alliance, the Urban Resilience to Extremes Sustainability Research Network, Arizona State University's Urban Climate Research Center and the Center for Whole Communities – launched a participatory planning process to engage community organizations and residents in three of Maricopa County's hottest neighbourhoods to identify mitigation and adaptation strategies to reduce heat directly and improve the ability of residents to respond to heat. The process was designed to develop awareness and social cohesion in under-represented communities and to help these communities play a more active role in making their neighbourhoods heat-resilient. The three neighbourhoods were chosen based on their high surface temperatures, low vegetation index, presence of outdoor public spaces and public transit, and history of heat-related illnesses and deaths (The Nature Conservancy 2019).

Three workshops in each neighbourhood brought together residents, community organizations, researchers and city officials to learn about the urban heat island, map community hot spots and cooling assets, and create a resident vision for a cooler neighbourhood. Additionally, seven demonstration projects helped maintain enthusiasm, identify barriers, create small wins, foster new relationships and create accountability with target communities. More than 200 residents across the three neighbourhoods participated in the workshops and demonstration projects. In each neighbourhood, a community organization with long-standing relationships within the target community was responsible for resident recruitment, selecting the location of workshops, providing input and approval of workshop agendas, and launching demonstration projects. City employees from the City of Phoenix streets, parks, neighbourhood services, and transit departments, and the Maricopa County health department participated to share stories, show pictures of cool places and answer questions (Guardaro *et al.* 2020).



CASE STUDY 10.2
NEIGHBOURHOOD HEAT PLANNING – MARICOPA COUNTY, ARIZONA, UNITED STATES

► Continued

Planning for a cooler neighbourhood: Water park for children

The end result was three neighbourhood-specific heat action plans. Each neighbourhood plan includes community-created maps to help identify points of intervention to improve thermal comfort. These include a map of hotspot intervention points that show areas where community members experience difficulty with heat, as well as community cool spots that show existing cooling assets such as heat relief stations, hydration stations and cooling centres. This process enabled detailed local knowledge about where to place key cooling infrastructure to be captured that might otherwise be missed in a top-down city planning process.

The bottom-up, neighbourhood-based process enabled each community to identify its own priorities for urban cooling. For example, the Edison-Eastlake neighbourhood focused on re-imagining bus stops to include relief from heat; the Mesa Care neighbourhood prioritized water features for children and drinking water access in public spaces; and the Lindo-Roesley neighbourhood prioritized street trees and shading. The other supporting organizations, researchers and city planners used the resident-led visions to create finished plans.

Building off of this success, The Nature Conservancy and partners launched a five-month (virtual) Urban Heat Leadership Academy in 2021 to build the capacity of community residents in Phoenix to advocate for more trees, cool walkable corridors, and the use of rainwater for trees and vegetation. The programme taught participating residents about the systemic drivers of urban heat, air quality, and water, as well as about proven solutions for reducing urban heat. Additionally, the programme included training on advocacy, facilitation, communication and storytelling to equip participants with skills and tools needed to mobilize their communities.

11 AWARENESS AND CAPACITY-BUILDING TO SUPPORT SUSTAINABLE URBAN COOLING

The impact and potential benefits of most urban cooling efforts will be enhanced when supplemented with facilitative strategies. Facilitative strategies enable cities to influence or facilitate actions towards sustainable urban cooling through policies and programmes in three broad areas: raising awareness, building capacities and enabling financing solutions. This chapter focuses on awareness and capacity-building, and also discusses partnerships and collaborations that are an important underpinning to these facilitative strategies, meaningfully engaging relevant stakeholders to support cities' efforts and advance cohesive action. The financing solutions are discussed in chapter 12.

While the appropriateness of the facilitative interventions will depend on the specific context of each city, when applied in conjunction with other urban cooling interventions, they support successful implementation and wider adoption, thus helping cities drive meaningful change and maximize benefits.

11.1 AWARENESS, OUTREACH AND SOCIAL CAMPAIGNS

Raising mass awareness about sustainable urban cooling can include a range of activities to engage and inform the public and other stakeholders about urban heat mitigation, low-climate-impact cooling solutions, and how to engage in the city's cooling initiatives. Some proven means to enhance awareness are discussed as follows.

GUIDELINES, TOOLKITS AND HANDBOOKS

Cities can target key stakeholders with dedicated guidelines, toolkits and handbooks to guide implementation of urban cooling solutions. Design guidelines can provide a connection between planning policies, existing zoning and regulations, cooling goals and tools needed for successful implementation. Guidelines, toolkits and handbooks are especially effective for sharing technical guidance for implementing urban cooling solutions. Cities may publish guides written for architects, developers and the construction industry on cool roof options, their installation, appropriate use cases and their cooling benefits for the building and surrounding community. For example, the City of Delhi published a design manual to promote cool roofs to decision-makers, citizens and industry that includes information on the benefits of cool roofs, cool roof materials, and case studies, and has a focus on low-cost, low-tech solutions that can be applied in vulnerable communities (NRDC 2018).

Green guides can be written to guide landscape architects and developers so the city can meet its urban forestry and green infrastructure goals. For example, the City of Melbourne's Growing Green Guide promotes vegetated surfaces and provides technical advice on how to design, build and maintain green roofs, walls and façades. Cities that do not have capacity to make their own guidelines, toolkits or handbooks can draw on those created by other cities in similar geographic, climatic and economic contexts. In addition there are many reputed organizations and alliances – such as the C40 Cities Climate Leadership Group (C40), the Coalition for Urban Transitions, the Global Cool Cities Alliance and the Smart Surfaces Coalition, to name a few – with a growing body of work to support a worldwide transition to cooler, healthier cities; additionally, several knowledge products – such as the World Bank's *Primer for Cool Cities: Reducing Excessive Urban Heat* and *Primer for Space Cooling* – can inform and support cities' efforts towards sustainable urban cooling practices.[37]

AWARENESS AND EDUCATION CAMPAIGNS

Local governments can run outreach campaigns to educate the public about the urban heat island effect, the health impacts of heat stress and ways to participate in urban cooling solutions. Many cities around the world including Ahmedabad, India and Karachi, Pakistan are integrating heat awareness and education in emergency heat plans, including creating informational posters and pamphlets, sharing information on government websites and social media accounts, and partnering with mobile phone providers and local media to share heat alerts and other heat awareness messages via SMS or WhatsApp and local media broadcasts. Communications can include information about temperature forecasts, tips on how to stay cool, information on the signs of heat stress, and ways to access available government resources, such as community cooling centres.

Better-resourced cities, including New York City and Toronto, publish detailed heat vulnerability index maps online that combine heat variability within the city with socioeconomic data alongside information on where to access cooling centres (C40 Knowledge Hub 2019c). Awareness and education campaigns can also be used to promote engagement with implementing urban cooling solutions, such as participation in street tree or other urban greening programmes. While municipal communications are useful, they may not effectively reach or be trusted by the most at-risk residents. Partnerships and diverse modes of communication can help overcome communication barriers. This is discussed in greater detail in chapter 9.

37 This is not meant as a complete and comprehensive list of organizations or of publications, and the examples noted are only indicative of the vast and growing body of knowledge on sustainable urban cooling.

DEMONSTRATION AND PILOT PROJECTS

City governments alone or in partnership with each other, businesses and non-profit organizations can use demonstration and pilot projects to model and test specific heat island mitigation strategies. Demonstration and pilot projects can be used to test the effectiveness of different cooling approaches in a local micro-climate and provide opportunities for public feedback. Such projects may be appropriate when the city government is not the primary agent able to implement the cooling strategy. For example, a cool roof pilot project in Hyderabad, India found that 76 per cent of residents were satisfied with the cool roofs and led to other residents in the neighbourhood applying makeshift cool roofs in response to positive feedback by the trial (NRDC 2018).

Demonstration and pilot projects have been found to be successful when they are highly visible to the public, measure cooling benefits and communicate findings, and convey lessons learned to make projects easier to replicate and improve (US EPA 2008).

BEHAVIOUR CHANGE CAMPAIGNS

Cities commonly engage in behaviour change campaigns to encourage voluntary engagement with energy efficiency and other sustainability programmes. Behaviour change campaigns draw on insights from the social sciences to guide human behaviour and include elements such as changing defaults to the desired action, creating social norms through public commitments, anchoring actions to existing behaviours and ensuring that the proper messenger delivers timely, action-oriented information. In the context of urban cooling, behaviour change campaigns are especially useful when barriers to individuals adopting a cooling solution cannot be overcome with awareness-raising measures alone.

Local governments can embed behaviour change campaigns into Heat Action Plans to increase participation in cooling interventions such as visiting cooling centres or wellness check programmes in identified vulnerable communities. Cities can explore and promote an adaptive model of thermal comfort: for example, behaviour adaptation in the form of clothing adjustment, as is being explored in the semi-outdoor spaces in Tokyo city (Junta and Shin-ichi 2020), raising the air-conditioner set-point temperatures, and leveraging natural ventilation when the weather permits.

Behaviour change campaigns can also be applied towards the success of urban greenery and street trees by creating better outcomes for ongoing maintenance during establishment periods. The Los Angeles Urban Cooling Collaborative is tailoring behaviour change campaigns to help specific neighbourhoods overcome identified barriers to maintaining street trees and using innovative tools such as commitment stickers and car air fresheners to remind people to water their street trees (de Guzman *et al.* 2018).

AWARDS AND COMPETITIONS

Awards and competitions can effectively support behaviour change measures by providing a mechanism for incentivizing and driving change. Competitions help in motivating action and promoting a sense of excitement towards implementation. Cities can use tools like awards and competitions to increase public engagement in sustainable urban cooling initiatives as well as to promote innovation.

For example, the city of Louisville in Kentucky, United States launched the Kilowatt Crackdown competition to promote improvements in commercial building energy performance and to support the city's climate stewardship (Louisville Energy Alliance n.d.). The competition awarded the most energy-efficient building in the following categories: Best Performer (2020) and Most Improved (2019-2020) across multiple building types. Managed by the Louisville Energy Alliance, the competition leverages the Energy Star platform to help building owners achieve greater energy performance with measurable results, as part of the Mayor of Louisville's effort to reduce greenhouse gas emissions community-wide. Several other US cities – such as Cincinnati, Portland (Oregon) and Seattle – have held similar competitions in collaboration with partners such as local utilities and the local building owners and managers associations.

Cities can also leverage inter-city competitions that can be an effective platform for spurring innovation and knowledge exchange. As an example, the Climate Smart Cities Challenge is an open call and opportunity for cities to participate as implementation partners in a city-based innovation competition that will invite a global pool of technologists, businesses and investors to develop, test and scale cutting-edge solutions to reduce greenhouse gas emissions and create a better future for all (Nesta Challenges n.d.). These could include a wide range of interventions across multiple sectors, such as urban form and physical design, transport, energy systems, housing, use of public space and others. (The full Climate Smart Cities Challenge was expected to launch at the World Expo in Dubai in October 2021).

11.2 CAPACITY-BUILDING AND TRAINING

Capacity-building and training programmes can increase the level of success of urban cooling initiatives by increasing the ability of city authorities and key actors to enforce and implement urban cooling initiatives, by developing the requisite workforce and technical capacities for appropriate delivery of sustainable cooling solutions, and by involving additional people – such as trained volunteers – with the knowledge and tools to support success.

INSTITUTIONAL CAPACITIES

It is critical to provide training, resources and ongoing support to city officials in regulatory and policy bodies. It is also important to develop systems that can be self-sustaining (for example, trained individuals who can go on to train others) and survive changes in political leadership (for example, storing and maintaining training resources that can be passed on to future officials). Given the cross-cutting nature of cooling — which includes aspects of building energy efficiency, cooling technologies and refrigerants –capacity-building efforts should cover multiple departments including sustainability offices, energy, facilities, general services, public works, codes and permitting, planning and transport.

Training and capacity-building efforts should also extend to critical institutions along the entire value chain for sustainable urban cooling, such as utilities, lending institutions, building design and construction practitioners, and energy service providers. Adequate awareness and skill-building among such institutions can create supporting market conditions to promote and scale up the adoption of sustainable urban cooling solutions and services.

Cities should explore and leverage existing capacity-building programmes and resources made available by state or national governments, or development organizations. For example, the URBACT programme has been the European Territorial Cooperation programme aiming to foster sustainable integrated urban development in cities across Europe.[38] A key objective of the programme is to improve the capacity of cities to manage sustainable urban policies and practices in an integrated and participative way. URBACT does this through customized training events, networks, knowledge exchange and learning as well as through the action planning, implementation and transfer processes. The target participants include city managers, elected representatives and stakeholders from other public agencies, practitioners, the private sector and civil society.

Generally, a shared pool of skilled professionals can be a resource-efficient way to boost capacities across multiple cities. An example of this model is in the state of California in the United States, where local governments are pressed to expand capacity to meet state-mandated ambitious climate change goals. To address this capacity need, CivicSpark – administered by the Local Government Commission in partnership with the Governor's Office of Planning and Research – provides trained professionals ("Fellows") to build local public agency capacity in cities across California for one service year (CivicSpark n.d.). CivicSpark Fellows implement a needed sustainability and resilience project, while also building long-term capacity within the public agency to ensure that the work is sustained after their service year is completed.

WORKFORCE DEVELOPMENT

City governments alone or in partnership can lead workforce development programmes to develop the technical capacity for workers to implement sustainable urban cooling solutions. Workforce development programmes are highly useful for areas where new skills are needed to implement cooling solutions. These programmes can cover a wide range of topics, such as: training on how to install green or cool roofs, green façades, district cooling, and other infrastructure; training for efficient operations and maintenance of building systems; and training for health-care professionals to better address the health impacts of heat.

New York City runs multiple workforce development programmes as part of its urban cooling strategy, including a cool roofs training programme that provides 300 hours of paid work experience and job placement for similar construction projects and a training programme for health-care professionals (Pereira 2017). The city also runs a NYC Building Operator Training programme (in partnership with the City University of New York) as part of its commitment to reduce greenhouse gas emissions 80 per cent from 2005 levels by 2050. The training is offered at no cost to all eligible participants and seeks to improve the skills of operations and maintenance staff working in New York City's small to mid-sized residential buildings through an overview of critical building systems (such as HVAC), with an emphasis on preventative maintenance and energy efficiency (City University of New York n.d.).

Additionally, cool roof pilot projects in cities such as !Kheis, South Africa and Washington, D.C. point to the potential for adoption of cool roofs to create jobs (ESMAP 2020a). Local governments can prioritize local job creation and workforce development for marginalized communities when designing urban cooling initiatives. For example, the City of New Haven in Connecticut, United States partners with a local non-profit organization to train youth and adults that face employment barriers, including the formerly incarcerated, to work planting trees and maintaining the city's urban forest (Urban Resources Initiative n.d.).

38 URBACT is an instrument of the Cohesion Policy, co-financed by the European Regional Development Fund, the 28 Member States, Norway and Switzerland. For more information, see https://urbact.eu/urbact-glance.

VOLUNTEER PROGRAMMES

Engaging volunteers can bring needed capacity to implement cooling projects. Volunteer programmes can focus on single-day events or ongoing engagement. Volunteer programmes can support a wide array of cooling initiatives. For example, volunteers can bring additional capacity to local governments for the maintenance of green infrastructure. In Medellín, Colombia, the municipal government is paying for the installation and maintenance of green corridors and training volunteer urban gardeners to help maintain the plantings, particularly during the dry season (ESMAP 2020a). Volunteers can also be engaged as "citizen scientists" to help local governments gather relevant and actionable data on local conditions. Volunteer programmes can be open to the general public or be based in partnership with specific groups. For example, the Ahmedabad Municipal Corporation in India engaged a group of 50 student volunteers from local colleges to help implement a pilot programme to coat 3,000 low-income dwellings with cool roofs (NRDC 2018).

11.3 PARTNERSHIPS AND COLLABORATIONS

Urban cooling strategies will be most successful in the long term if they engage stakeholders – through partnerships and collaboration – to support the development of and champion the implementation of cooling initiatives. Important stakeholders include those who can provide technical, political, financial and public support for cooling strategy implementation. Engaging local actors such as developers, contractors or hospitals can bring important insight to policy development and programme implementation. Partnerships with technical, scientific and academic institutions can bring needed knowledge and bolster public trust in the government's ability to understand and address urban heat. Additionally, engaging non-governmental actors that represent and serve populations that are most vulnerable to heat is important to ensure that cooling benefits are delivered to those who need them most.

PARTNERSHIPS WITH THE SCIENTIFIC AND RESEARCH COMMUNITY

Partnerships with technical, scientific and academic institutions can bring needed knowledge and bolster public trust in the government's ability to understand and address urban heat. Partnerships with universities and other academic institutions connect city governments with the scientific and research community, including experts and students. Universities can bring additional capacity, skills and knowledge to local governments to assist with data collection and analysis, for example of a city's micro-climate, spatial distribution of the urban heat island, or urban forest inventories; identifying the most effective strategies for a particular city; and helping with ongoing monitoring and evaluation of urban cooling initiatives. Partnerships with the scientific and research community lend credibility to a city's actions and should be well advertised where appropriate.

PARTNERSHIPS WITH UTILITIES

Utilities can be an important partner for cities in the drive towards reduced emissions and sustainable urban cooling, by advancing energy efficiency in buildings and building systems and appliances. This can generally be achieved through facilitative interventions in the case of investor-owned utilities, but where a municipal (city-operated) utility exists, even control interventions can be applied. Where utilities have mandatory targets for energy efficiency (such as in many of the US states), such partnerships are a win-win, promoting sustainable cooling in cities and supporting the utility in achieving its targets.

Utility partnerships can manifest in ways including, but not limited to:

- **Reducing peak power demand:** During extreme heat events, increased demand for space cooling can overload electricity supply systems and cause power outages. Demand response programmes, run in partnership with utilities, can address this by offering customers a rebate or lower energy costs for reducing use during specified peak hours or emergencies, such as heat events (US Energy Information Administration 2019).
- **Assisting low-income households and vulnerable communities during heatwaves:** Lack of access to water and electricity during a heat event can greatly increase the risk of exposure to elevated temperatures and heat-related illness. City governments can partner with local utilities or require through policy that local utilities suspend water and electricity shut-offs during heat events (US EPA 2016). The Ahmedabad Heat Action Plan includes communication with the local utility Torrent Power to maintain power for critical facilities and vulnerable groups (NRDC *et al.* 2017).
- **Broadening access to energy-efficient cooling:** Utility-led programmes can facilitate wider adoption of high-efficiency cooling appliances, bringing down the typically higher upfront cost of these appliances through targeted incentive programmes. Mexico's Efficient Lighting and Appliances programme is an example of a partnership between the government and the utility with the objective of increasing the use of energy-efficient technologies in key residential end uses such as lighting, refrigeration and air conditioning (World Bank 2016). Under the programme, customers were provided varying amounts – calibrated by income and consumption levels – of price incentives in the form of vouchers (for low-income households) and credits (for low-income and other qualifying consumers) to replace old air conditioners with a specific energy-efficiency standard. Mexico's utility, the Federal Electricity Commission, administered an on-bill mechanism for repayments of credits through customers' electricity bills. While this was a nationally administered programme – with a single utility serving the entire country – this model can be replicated by a cohort of cities served by regional or municipal utilities.
- **Supporting energy efficiency efforts:** Cities can benefit from synergies where utilities administer nationally or regionally mandated programmes to advance energy efficiency, including skill-building such as Building Operator Certification programmes. Even where regulatory frameworks do not exist for utility-led energy efficiency programmes, utility on-bill financing can be leveraged as a unique lending mechanism since there is a lower risk of credit default with utility bills than other unsecured credit mechanisms. On-bill financing has been successfully used as a means of advancing building energy efficiency retrofit efforts and for encouraging the purchase of efficient room air conditioners. Utilities, through the energy-use data available to them, can also lend significant support to building energy efficiency efforts such as energy-use benchmarking (see case study 8.1).

PARTNERSHIPS WITH NON-GOVERNMENTAL ORGANIZATIONS AND LOCAL BUSINESSES

Engaging non-governmental and community organizations can bring important insights into planning, policy design and programme implementation. Non-governmental and community organizations are important partners to represent community voices in the planning and policy design process. Often, non-governmental and community groups have deeper insights into the conditions of a particular neighbourhood or community and can be used to help encourage community participation in these stages. Non-governmental and community groups are key partners for implementing household- and neighbourhood-scale cooling initiatives. Many cities partner with non-governmental organizations to help implement tree-planting programmes, maintain urban greenery and install cool roofs on low-income housing. Non-governmental and community organizations may be more trusted within marginalized communities than local governments and can be important partners for communicating with and engaging with a city's most heat-vulnerable residents.

Cities can also partner with local businesses on workplace cooling initiatives that reduce energy consumption and heat exposure for workers. This can be especially impactful in industries where manual workers are exposed to extreme heat or work in hot environments, such as construction and agriculture, or where manufacturing workers are around processes generating heat (Xiang *et al.* 2014). Cities can create incentives and requirements for local businesses to provide fans, cool water, shade and rest periods to at-risk workers (NRDC 2013b). Businesses can also be incentivised to shift work hours to cooler times of the day or cancel unessential travel or work on the hottest predicted days (NRDC 2013b).

Additionally, cities can work with businesses that have large cooling loads to adopt energy efficiency measures and install cool roofs to reduce energy demand. Cities may also work with businesses on programmes to shift operations to off-peak times to reduce the amount of peak power demanded during a heatwave. Partnerships with business can also bring needed financial and technological resources for urban cooling initiatives. For example, many Indian cities, including Ahmedabad and Hyderabad, are partnering with local businesses to meet their corporate social responsibility contributions by donating materials for cool roof projects in low-income communities (NRDC 2018).

PARTNERSHIPS WITH OTHER CITIES

Cities can also advance urban cooling solutions through participation in city cohorts and collaboratives with other governments. These include local and regional partnerships, participation in country-led initiatives to support cities, and involvement with city networks. Partnerships with other cities can foster peer learning and create networks of support as cities innovate urban cooling solutions. Local and regional partnerships are an effective way for nearby governments to share knowledge and resources and coordinate joint projects. These include ongoing partnerships and collaboratives to comprehensively address urban cooling and partnership dedicated to specific urban cooling projects. For example, a group of local governments in New South Wales partnered on a design competition for a cooled transit shelter (Penrith City Council n.d.).

Many national governments are leading initiatives to support cities. Smart City Sweden is a state-funded export platform that initiates cooperation between Sweden and other countries within smart and sustainable city solutions (Smart City Sweden n.d.). Additionally, city networks such as the Cool Cities Network, a partnership between C40 and the Global Cool Cities Alliance, are valuable sources for building knowledge, peer learning and networking as cities tackle the challenges of urban heat.

11.4 CONCLUDING NOTE

Local governments can bring strong organization and understanding of underlying goals to support networks and collaborations to address urban heat. They can empower local leadership and support community members to help create the vision of locally appropriate strategies and plans – and ultimately support a diverse set of actors to implement urban cooling strategies. At the same time, community members can do more than just play key roles in implementing urban cooling solutions. With support of local leaders and community organizations, community members and businesses can play important roles participating in networks and collaborations that inform the city's underlying vision for urban cooling.

RECOMMENDED CITY ACTIONS

11

The impact and potential benefits of most urban cooling efforts will be enhanced when supplemented with facilitative strategies that raise awareness, build capacities and enable financing solutions. Partnerships and collaborations are an important underpinning to the facilitative strategies, meaningfully engaging relevant stakeholders to support the city's efforts and advance cohesive action.

NO-REGRETS ACTIONS

- Take action for enhancing mass awareness towards the urgency for, and benefits of, sustainable urban cooling. Cities can utilize multiple means and scales for such programmes, depending on their existing resources, and potentially expand the scope and reach of the programme in phases.
- Assess capacities among city authorities and key actors to enforce and implement urban cooling initiatives (ongoing and planned), and accordingly take measures to develop the requisite workforce and technical capacities for appropriate delivery of sustainable cooling solutions.

CITY INTERVENTIONS CATALYSED BY TRIGGER POINTS

Interventions in this category are generally supportive of other interventions and therefore may be triggered by those. The completion of the cooling landscape assessment or identification of recommended immediate actions to be undertaken may usually be the first triggers, where building awareness of their multiple benefits will help ensure support for moving forward and will enhance the leadership profile of elected officials. Other trigger points will generally be centred around building supply-side capability and capacity in support of the selected interventions. For instance, the need for capacity-building may be triggered by major policy or infrastructure-related interventions such as adoption of building energy codes, or development of a district cooling project.

FURTHER RESOURCES

- ***Primer for Cool Cities: Reducing Excessive Urban Heat – With a Focus on Passive Measures,* Energy Sector Management Assistance Program, World Bank, 2020.** https://openknowledge.worldbank.org/handle/10986/34218
- ***Primer for Space Cooling,* Energy Sector Management Assistance Program, World Bank, 2020.** https://openknowledge.worldbank.org/handle/10986/34567
- ***Global Cool Cities Alliance.* Includes initiative and information on cool roofs and cool surfaces.** https://globalcoolcities.org/key-initiatives
- ***City-Business Climate Alliances: A step-by-step guide for developing successful collaborations,* CDP, 2019.** https://www.c40knowledgehub.org/s/article/City-Business-Climate-Alliances-A-step-by-step-guide-for-developing-successful-collaborations
- ***Better Together: How Cities Can Collaborate for Faster, More Effective Climate Action,* C40 Cities Climate Leadership Group, C40 Knowledge Hub, 2020.** https://www.c40knowledgehub.org/s/article/Better-together-How-cities-can-collaborate-for-faster-more-effective-climate-action

CASE STUDY 11.1 | MILLION TREES NYC – NEW YORK CITY, UNITED STATES

HIGHLIGHTS:

- Municipal giveaways
- Public-private partnership
- Expanding urban tree canopy
- Transforming open space in under-resourced communities
- Community engagement / volunteer programmes
- Partnering with local businesses

In January 2016, New York became the first city in the world to plant 1 million trees. The idea came to life eight years prior with a partnership between New York Restoration Project (NYRP) – a non-profit organization dedicated to transforming open space in under-resourced communities in New York City – and the City of New York. The MillionTreesNYC initiative planted 1 million new trees throughout New York City's five boroughs, resulting in an estimated 20 per cent increase in the city's urban forest, while achieving the many quality-of-life benefits that come with planting trees (MillionTreesNYC n.d.).

An enduring public-private partnership was a key factor in the success of the programme, where NYRP and New York City, by working together, were able to leverage the full range of financial resources, infrastructure, data, expertise and volunteers necessary to set a new global standard for green space access. Some noteworthy aspects that contributed to the success of the initiative were:

- **Committed leadership:** The City was fully committed to the initiative, with two successive mayors regarding the project as a priority. As a non-governmental organization, NYRP provided the continuity necessary to see the programme through its eight-year term.
- **Prioritizing under-resourced neighbourhoods:** Through NYRP's free tree giveaway programme, the largest in the country, and through partnerships with the private sector, NYRP catalysed the planting of trees in neighbourhoods that needed them the most, ensuring that the benefits of high-quality green space reach all citizens. The giveaway events were supplemented with free materials and on-site guidance on how to plant and care for the trees. An online portal provided helpful information on tree care and on community engagement opportunities, such as volunteering programmes to care for the trees. NYRP used data to carefully track and record plantings to ensure that the goals of the programme were met.
- **Public and private funding:** NYRP and New York City jointly devoted the bulk of the resources necessary to ensure the programme was a success. In addition, NYRP leveraged large private sector donors to supplement the programme funds.

Planting trees as part of the Million Trees NYC Project, New York City

CASE STUDY 11.2 | CLIMATE ADAPTED PEOPLE SHELTERS DESIGN COMPETITION – WESTERN SYDNEY, AUSTRALIA

HIGHLIGHTS:

- **Awards and competitions**
- **Partnerships**
- **Community engagement**
- **Cooled transit stations**

Bus riders in Western Sydney, Australia are exposed to a range of environmental hazards including urban heat and poor air quality, and this burden falls unequally on marginalized groups within the community. To address this, in 2016, a collaboration of researchers and local and state governments in Western Sydney launched Climate Adapted People Shelters (CAPS), a design competition to create cooler public bus shelters (Penrith City Council n.d.). CAPS consisted of three stages: an open design innovation competition, construction of a prototype bus shelter, and monitoring of the thermal performance and user experience of the winning design.

Initial workshops were held with four participating city councils to identify eight high-traffic locations, each with site-specific issues, as places for contest entrants to base their design. Thirty teams participated in initial workshops, including architectural and engineering professionals and university and high school students. Ultimately, nine teams submitted 15 designs for the final competition. The winning shelter was designed to prioritize shade protection with a unique roof shape and large overhang, enabled cross-flow ventilation with a perforated rear screen, used rooftop solar PV to power LED lighting at the shelter, and used insulated materials that trap less heat.

Good practices that contribute to the efficacy of the design competition include:

- **Partnerships between researchers and local governments:** CAPS was a partnership between the University of Technology Sydney, NSW Climate Adaptation Research Hub, Western Sydney University, and local and state governments. Researchers contributed technical knowledge and expertise and conducted monitoring at the winning project site. Local governments brought site-specific knowledge about which transit stops had the greatest need. Later, the Penrith City Council played a key role in helping to refine, build and install the winning bus shelter.

▶ Continued

CASE STUDY 11.2
CLIMATE ADAPTED PEOPLE SHELTERS DESIGN COMPETITION – WESTERN SYDNEY, AUSTRALIA

Original bus shelter (left) and the CAPS shelter (right), Western Sydney, Australia

- **Workshops and coaching:** Workshops throughout the design competition brought together city councils, technical experts, designers, engineers, local government staff, industry and contest entrants. Initial workshops identified sites for the contest and explored what the community wanted for climate-adapted public infrastructure. Later, teams shared knowledge and ideas and were provided an opportunity to collaborate and share insights gathered during initial research. While workshops provided some coaching, teams were responsible for research, developing a design and 3-D model, and two video pitches describing the bus shelter design and key features including thermal performance, materials, cost estimates and desirability.

- **Open competition and human-centred design:** CAPS was an open competition and attracted a wide range of participants who could offer creative solutions. The competition teams included designers, architects, landscape architects, engineers, urban planners, inventors and students. Initial workshops focused on user experience and human-centred design to meet transit riders' needs. The winning design was chosen in part because it was tailored to meet the specific needs of transit riders identified at that location.

- **Ongoing research and monitoring:** The winning design was constructed next to an existing bus shelter to allow for monitoring of key outcomes and comparison between the two shelters. Monitoring found that temperatures inside the CAPS shelter were up to 4°C cooler than the existing shelter and roof temperatures were up to 15°C cooler during the day. User feedback was also overwhelmingly positive, and transit riders reported perceiving cooler ambient temperatures and improved thermal comfort (Penrith City Council 2018b). Evaluation of the winning design is facilitating local councils who participated in CAPS to incorporate successful elements into additional transit stops throughout Western Sydney (Jacobs, Cunningham and Boronyak 2018).

12 FUNDING AND FINANCING SUSTAINABLE URBAN COOLING INTERVENTIONS

Financial resources are a critical enabler for the successful execution of any urban cooling intervention. This chapter looks at two aspects of funding and financing sustainable urban cooling interventions: 1) funding sources that support cities in implementing interventions (including financing mechanisms that may defer the need for funding); and 2) financing as a facilitative strategy to support and enable broader access to sustainable space cooling practices for the public at large.

12.1 FUNDING AND FINANCING SOURCES FOR CITIES

The starting point for evaluation of funding and financing options is the development of the benefits case – that is, what is the return for a city and its citizens, and to what extent can this return be associated with a specific investment. While the full range of benefits of sustainable urban cooling practices are typically hard to quantify and are often not individually visible, the benefits case still needs to be developed in order to secure support and ensure that adopted interventions bring a net benefit to the city and its citizens that is greater than the cost of the intervention and the associated cost of capital. Key benefit categories to consider include:

- improved public health including reduction in morbidity and mortality;
- improved air quality – temperature and ground-level ozone formation are positively correlated, meaning that urban passive cooling solutions that reduce air temperatures also reduce hazardous smog;
- increased equity in relation to access to cooling within a city;
- reduction in energy use for mechanical cooling systems and associated energy bill savings;
- reduced grid infrastructure requirements, including generation, transmission and distribution investments from peak load reduction; this is of particular relevance in the case of city-owned or -controlled utilities;
- reduced pollution and carbon emissions from power generation to serve mechanical cooling loads; this is of particular relevance in the case of city-owned or -controlled utilities;
- reduction in stormwater run-off and associated infrastructure as a result of increased vegetation in the city environment; and
- enhanced livability within a city, resulting in enhanced property values and attractiveness to commercial enterprises, corporations and investors, which in turn increase a city's tax base.

Along with the build-out of the expected benefits of a specific intervention under a sustainable urban cooling action plan, cost should be optimized by leveraging other funded projects and trigger points in order to reduce the incremental first-cost of the planned intervention. Simply put, by optimizing the incremental cost of an intervention, the benefits become relatively more attractive and can help build the case for change and enhance the chances of being able to secure the necessary funding or financing to enable implementation.

12.2 FUNDING SOURCES FOR CITY INTERVENTIONS

Once the benefits cases for interventions have been developed, funding from existing city revenue sources would require those interventions to be incorporated into cities' longer-term budgetary processes. Cities should also consider whether it would be appropriate to expand those revenue sources to fund the interventions, and if so which additional revenue source would be most aligned with the benefits of the interventions. The potential funding sources to support sustainable urban cooling projects are identified in figure 12.1.

Figure 12.1 Funding sources potentially available to support urban infrastructure projects

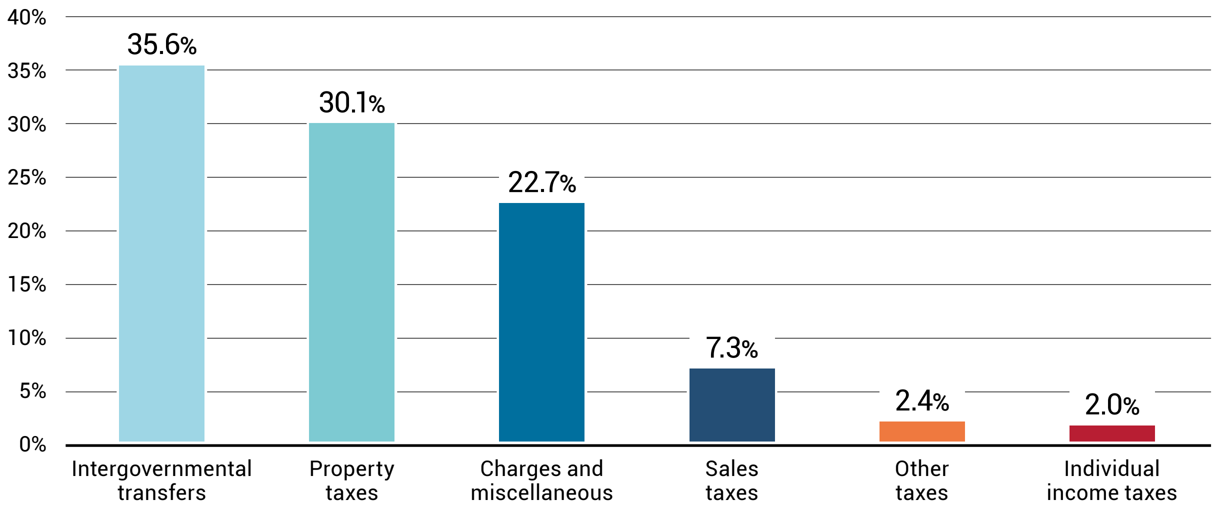
FUNDING SOURCE	DESCRIPTION	COMMENTS
Intergovernmental transfers	Cash transfers of tax revenues or other resources from central government to local authorities for general or specific use	The importance of these transfers in local budgets is generally linked to the level of fiscal decentralization authorized by a national government.
Taxes	May include: ▪ general tax revenues (such as property, sales and income tax) ▪ targeted environmental or location-specific taxes or surcharges linked to access to infrastructure services or other amenities.	Taxation powers at the local level are typically tightly controlled and regulated by national governments. Targeted taxes that seek to internalize the cost of negative externalities are commonly used to support capital expenditures on environment-focused infrastructure.
Land value capture	A mechanism to allow a government to capture some of the development value impact of policy and zoning changes or amenity and infrastructure improvements in a designated area.	Typically targeted at the location-specific beneficiaries of a policy or zoning change or other capital investments. Can be structured as a tax (linked to existing property taxes) or as an auctionable development right. Generally used to support new capital investments.
User fees/tariffs	Directed at the users of a good or service (such as the per unit charges for electricity or water usage; ridership fees for public transport).	Fees/tariffs are usually tightly regulated, balancing equity and cost recovery goals. One benefit is that they can be adjusted relatively quickly and deliver immediate sources of new revenue compared with other financing sources that may be available only once a year or on a one-off basis. Can be used for either operating or capital expenditures.
Fines/penalties redirected for other use	Financial penalties for violation of environmental quality standards or other rules.	Generally considered to be an unstable revenue source. Presumes that a system exists to monitor and levy these fines. Alternatively, penalties may arise from legal proceedings assessing damages for rule violations.
Official development assistance (ODA)	Grants or subsidies	From multilateral and bilateral sources. Generally linked to a framing agreement laying out goals for how resources are to be used. Often comes with an emphasis on environmental and social safeguards designed to protect people and ecosystems. Depending on a country's development status, these funds may or may not include discounted (concessional) rates to ensure affordability.
Dedicated climate funds	May include: ▪ loans/grants from Global Environment Facility, Green Climate Fund, Climate Investment Funds, or country- or region-specific funds ▪ carbon markets or other market-based climate instruments.	▪ May involve entitlement window with guaranteed resource flow to individual countries based on fixed parameters. Also includes project-based applications under certain funding windows. ▪ Access to carbon-focused climate funds is linked to the mitigation outcome achieved, but if done properly projects can also be structured to deliver climate adaptation co-benefits.

Source: Adapted from World Bank 2018

While figure 12.1 presents the typical range of funding sources, the actual sources will be very different for cities in the least developed countries (LDCs) than it is for cities in the high-income developed countries – and across the spectrum between them – where city revenue sources are very different.

In LDCs where a narrower local tax base is available, the primary sources of city revenue are likely to be from inter-governmental transfers and land value capture along with user fees, tariffs and licences. In higher-income countries (figure 12.2), land value capture fees feature less prominently, but taxes (property taxes in particular) are a major revenue source, second only to inter-governmental transfers, and have strong alignment between payment and benefits in relation to sustainable urban cooling, where the burden of payment is borne by the residents of the jurisdiction where the betterment will occur.

Figure 12.2 US breakdown of local government general revenue by category, fiscal year 2017



Source: Tax Policy Center 2020

In LDCs and many low- to middle-income countries, the underpinning property titling and administration system along with immature collection and enforcement mechanisms result in this revenue source being underdeveloped at just 0.03 per cent of national GDP, as compared to 0.89 per cent in high-income countries (United Nations 2017). This typically precludes this potential source of revenue being used for the implementation of sustainable urban cooling interventions – at least in the near to medium term. With respect to LDCs and low- to middle-income countries, opportunities for official development assistance in the form of funding and technical assistance from international bilateral and multinational development aid organizations should be explored as increased funding is made available for climate adaptation projects.

More recently, a number of forward-thinking cities have been innovating at the intersection of climate and social equity. leveraging their local tax-raising authority to raise funding for key priorities. While these examples are not specific to cooling, they provide an insight into future funding opportunities that could be applied towards the sustainable cooling sector.

- **Sales tax approach:** In November 2020, residents of Denver, Colorado, United States voted to pass Ballot Measure 2A, creating a new sales tax that will generate $40 million to fund programmes aimed at eliminating greenhouse gas emissions, reducing air pollution and adapting to climate change. As a result, all Denver residents and visitors will now be subject to an additional 0.25 per cent sales tax on non-essential items. The revenue will fund and benefit a wide range of outcomes, including local clean energy workforce training; neighbourhood-based environmental and climate justice programmes; energy efficiency upgrades to homes and offices; and increased investment in solar power, battery storage and other renewable energy technologies. The measure specifically notes that the funds should "maximize investments in communities of colour, under-resourced communities, and communities most vulnerable to climate change, and endeavour to invest 50 percent of the dedicated funds directly in communities with a strong lens toward equity and race and social justice".
- **Fossil fuel production tax approach:** In November 2020, voters in Long Beach, California, United States approved an increase to a fossil fuel barrel production tax to support climate and community programmes. Long Beach's Barrel Tax effectively serves as a carbon tax, collecting money from oil producers, whose products will result in emissions, and using that funding to support various purposes, including climate initiatives. While the city already taxed oil producers for every barrel produced in Long Beach, the November ballot measure increased the tax by $0.15 per barrel to support general purpose funding, including programmes that address climate change and the environment, community health and youth services.
- **Electricity consumption tax approach:** In November 2020, voters in Albany, California, United States passed Measure DD, an energy consumption tax. All Albany residents except for designated low-income residents will begin paying an increased 9.5 per cent blanket utility service tax that will ultimately fund general city services, including disaster and emergency preparedness, emissions reduction projects, and emergency response and environmental sustainability programmes.

12.3 FINANCING SOURCES FOR CITY INTERVENTIONS

Financing is not a revenue source but a debt obligation that will need to be serviced with returns derived from the underlying investment or from future revenue sources. A brief overview of financing options for supporting control interventions is provided in this section.

The availability and cost of capital will depend on a municipality's fiscal situation, its ability to borrow, its creditworthiness, local legal and regulatory frameworks, and the type of urban cooling measure considered (ESMAP 2020b). For many small to mid-sized cities around the world, establishing their credibility in the global financial marketplace and having projects of sufficient size to warrant substantive investments is a major barrier to getting access to low-cost financing. Some mechanisms through which cities can obtain financing for their urban cooling projects are outlined in figure 12.3.

Figure 12.3 Financing sources potentially available to support urban infrastructure projects

DEDICATED CLIMATE FUNDS	May include: ▪ loans/grants from Global Environment Facility, Green Climate Fund, Climate Investment Funds, or country- or region-specific funds ▪ carbon markets or other market-based climate instruments.	▪ May involve an entitlement window with guaranteed resource flow to individual countries based on fixed parameters. Also includes project-based applications under certain funding windows. ▪ Access to carbon-focused climate funds is linked to the mitigation outcome achieved, but if done properly projects can also be structured to deliver climate adaptation co-benefits.
GOVERNMENT-ISSUED DEBT	May include: ▪ general obligation bonds ▪ special-purpose bonds ▪ green bonds or climate bonds (for dedicated environmental purposes).	Requires basic creditworthiness and an enabling environment that allow a city or system operator to issue bonds. Because of the transaction costs of issuing a bond, they are usually used to finance large capital projects.
PUBLIC-PRIVATE PARTNERSHIPS	Public-private partnerships between the government and a private contractor.	▪ Can take multiple forms, often with a focus on how contracts can be structured to require the private contractor to bring additional resources to maintain or upgrade the infrastructure system. ▪ Can also be structured so risks to system integrity are shared by the government and the contractor, thereby providing the contractor with a greater incentive to ensure that the system is properly maintained or protected against risks (including climate change).

Source: Adapted from World Bank 2018

DEDICATED CLIMATE FUNDS

Dedicated climate funds may offer support through technical assistance, grants and loans. For example, the European Union provides guidelines, technical capacity and financing opportunities to help Member States, regions and local administrations develop and implement comprehensive adaptation strategies and actions.

In 2018, the European Investment Bank signed a €55 million ($65 million) loan to support Athens' 2030 Resilience Strategy via a Natural Capital Finance Facility (Climate Policy Initiative 2021). The Facility's focus is broader than climate change but will include elements that focus on climate change adaptation including €5 million ($5.9 million) in financing from the Facility towards climate adaptation projects to revitalize an urban forest, stabilize water management, create green corridors and squares to reduce temperatures, and improve air quality in the face of rising average temperatures.

GOVERNMENT-ISSUED DEBT

Where municipal governments are sufficiently creditworthy, they can choose to issue bonds directly to investors (bond buyers) to raise the needed capital to support sustainable urban cooling interventions. The issuing government contractually specifies the interest rate or yield ("coupon") that will be paid to the bond holders as well as specifies the time at which the loaned funds ("bond principal") must be returned ("maturity date"). Municipal bonds are often tax-exempt bonds, where the yields that bond holders earn are not subject to income taxes, which makes them a very cost-effective source of financing. Especially for cities in the developing world, prior to issuing a bond, it is important for them to ensure that all the building blocks to accessing this kind of financing are in place, including credible institutions, support from one or more international financial institutions, establishment of their own credit rating where possible, and full buy-in from their national/state government, which may ultimately be held responsible if they default (Kim 2016).

Notably, municipal bonds can vary depending on whether the debt service on the bond is secured, or tied to specific project revenues or special tax assessments. Issuance without identification of revenue or funding sources for debt service could have a detrimental effect on a government's credit standing and would typically require some level of voter approval.

- **General obligation (GO) bond** is an all-purpose debt instrument that cities can use for general purposes. For infrastructure, GO bonds can be issued for projects that do not generate revenues. For fiscally constrained cities, issuing GO bonds to pay for infrastructure could impact their overall debt capacity and credit rating, which could potentially make future borrowing more difficult and expensive. For these and other reasons, GO bonds often require full voter approval. Revenue bonds have historically been the key debt instrument available for cities to finance major infrastructure projects, especially those that generate revenues.

  One such example is the Miami Forever Bond that voters approved in November 2017. This one-time, $400 million general obligation bond is being used to make Miami more resilient to sea-level rise and more frequent and extreme storms. The bond provides an example of how both innovative finance and equity principles can be co-designed, as equity is one of five guiding themes used for selecting projects to fund with this bond. The city has also committed to distributing investment benefits fairly across neighbourhoods and income groups, while emphasizing social cohesion and diversity. Bond funding supports affordable housing as well as green infrastructure projects.

- **Revenue bonds** are a class of municipal bonds issued to fund public projects, which then repay investors from the income created by that project. For instance, a district cooling plant can be financed with municipal bonds with creditors' interest and principal repaid from the fees collected.

- **Special or limited tax bonds** are another debt instrument that can be used successfully in infrastructure. These bonds are secured with the proceeds against a specific tax, which can include a gasoline tax, a special assessment, an incremental sales tax or an ad valorem property tax levied at a fixed level. Unlike GO bonds with unlimited liability, under these bonds, the issuer is limited by the specific tax revenue source.

- **Tax credit bonds** are taxable bonds where the tax subsidy (of the amount equivalent to tax-exempt bonds) is disbursed directly, either to the investors (bond buyers) as a tax credit or to state/local governments (issuers/borrowers) as a direct subsidy.
- **Green bonds** are debt instruments issued by large organizations and public entities to fund large-scale green infrastructure projects. Financial institutions use them to raise capital that is made available to facility owners at more competitive rates for energy efficiency or clean energy projects. They have a set repayment time frame and a set interest rate. Green bonds offer a number of benefits that regular bonds do not, including, for issuers, access to a broader range of investors and, for investors, repayments that are tied to the issuer rather than the "green" project. Green bonds must be used as described in the documentation of the offering to fund specified green projects. The Green Bond Principles are voluntary but widely adopted process guidelines, formulated by the International Capital Market Association, that recommend transparency and disclosure and promote integrity in the development of the green bond market; they explicitly define the eligible categories under which projects can be labelled "green".

- **Climate bonds.** Projects funded by climate bonds typically align with internationally recognized guidelines such as the Climate Bond Standards, which can evoke greater confidence in the outcomes of bond revenue use. Cities and other special purpose authorities have issued these bonds, with proceeds being used exclusively to develop clean energy, transport, water and green building projects.
- **Impact bonds / social impact bonds** are an innovative way to attract private capital as a performance-based contract between an investor, an outcome funder, and a provider of social or environmental services such as water and sanitation or energy services for poor populations. Payments are based on the attainment of agreed performance goals. Once the desired results are achieved, outcome funders, typically a donor or a government, repay the investor at a premium. The investor thus generates a return on its investment, and the outcome funder only pays for success. Some municipalities may leverage private investments in urban cooling through credit lines or risk guarantees (Global Partnership for Results-Based Approaches n.d.). Where energy efficiency funds are in place (*i.e.*, public financing for energy efficiency to public clients with repayments based on estimated energy savings), municipalities may tap into the funds to finance certain urban cooling investments. Individual cities will need to assess their respective situation and potential financing options. The use of impact bonds can also present an opportunity to unlock a large pool of funds from philanthropic organizations, foundations and other non-profit entities.

CREDIT ENHANCEMENTS

Creditworthiness can be a significant challenge for cities, particularly in developing countries, when trying to secure financing. World Bank analysis found that only a small per cent of the 500 largest cities in developing countries are deemed creditworthy – about 4 per cent in international financial markets and 20 per cent in local markets (World Bank 2018).

Credit enhancements can be an effective tool for cities to both enable and lower the cost of government-issued debt. Means for credit enhancement include repayment guarantees, either full or partial, and also pooled financing, sometimes referred to as Local Government Funding Agencies (LGFA). With LGFAs, a state or national entity collects the funding needs of multiple municipalities or utilities and arranges a single instrument to raise the required financing, with the overall credit of the issuance being enhanced by the underlying diversity of the borrowers. Credit under this model can be further enhanced with the establishment of debt service or sinking funds by the borrowers matched to their portion of the overall obligation.

LGFAs exist and operate within the borders of the respective countries where they are based. They are a long-proven concept in Scandinavia and the Netherlands but have limited application outside these countries. Some examples include:

- Municipality Finance of Finland
- Kommuninvest of Sweden
- Kommunekredit of Denmark
- Nederlandse Waterschapsbank of Holland
- Emissionszentrale der Schweizer Gemeinden of Switzerland.

Furthermore, future efforts to quantify the full economic benefits of sustainable urban cooling interventions – including both energy-related as well as non-energy benefits – will enable meaningful cost-benefit assessments and support cities' creditworthiness,[39] increasing the range of available financing options.

PUBLIC-PRIVATE PARTNERSHIPS

Where sustainable urban cooling Interventions are able to generate sufficient revenues to support debt service and risk transfer to the private sector, there are various effective public-private partnership financing options that can be considered, enabling cities to focus on the outcome of a project and not its design and implementation aspects. Typically, under these structures the government entity will be a recipient or partial off-taker of the service being provided.

For example, enabling a district cooling infrastructure project where a city would look to maintain some level of control or is perhaps a primary off-taker (as discussed in chapter 7 of this report) is an example of a design-build-own-operate-maintain (DBOOM) public-private partnership model. Here, a private sector consortium will develop and build the project and own operate and maintain it, often for an initial concessionary period, after which transfer or extension will be negotiated.

Under this model, a city government would procure the lowest levelized cost solution, maintain a level of control of the project, and mobilize private sector finance, which will consider the off-take obligation of the city government – along with its credit standing – in pricing the intrinsic project financing component.

39 Credit rating agencies are now beginning to include municipal climate adaptation and mitigation programmes and climate risk in their credit analysis methodology. Moody's Investment Services acquired Four Twenty Seven in July 2019, a leading provider of data, intelligence and analysis related to physical climate risks, and issued this statement: "The addition of Four Twenty Seven enhances Moody's growing portfolio of risk assessment capabilities and underscores its work to advance global standards for assessing environmental and climate risk factors. Four Twenty Seven will also strengthen Moody's growing thought leadership and research on incorporating climate risk into economic modeling and credit ratings."

Over the last several years, public-private partnerships have also been used to generate revenue for local governments by contracting long-term concessions to private entities to operate existing facilities in exchange for large front-end payments. The private operators also take on the responsibility for maintaining the assets over the life of the concession. Public-private partnerships have been pioneered in Australia, Canada and the United Kingdom and have been increasingly adopted globally. Public-private partnership models can also work on city-owned buildings, both new construction and the deep retrofit / re-purposing of existing buildings, and provide much the same benefits as an enabling structure as the discussion above on district cooling

Besides providing a source of financing, public-private partnership is an innovative business model where city governments can leverage the private sector for the implementation expertise and experience necessary to improve productivity and the service performance outcomes. Public-private partnership as an effective business and partnership model is discussed in more detail in chapter 9 of this report.

The energy services contract (ESCO) model also represents a form of public-private partnership and can be used to implement sustainable cooling and building efficiency measures in city-owned buildings where an active ESCO market exists. Under the ESCO model, financing and repayment are matched to the designed energy savings, and the risk of non-performance is underwritten by the ESCO, which designs and implements the project and ensures that savings provide the cash flow to cover the loan repayments.

12.4 FINANCING AS A FACILITATIVE INTERVENTION

Even when the right policy and regulatory systems are in place, financing access is required to support and enable broader access to sustainable space cooling practices for the public at large. Most markets, in particular in developing economies, see a lack of fit-for-purpose financing that could allow facility owners and consumers to address the usually higher first-cost of sustainable cooling interventions. This lack of fit-for-purpose financing is closely tied to market barriers (as discussed in chapter 3).

Related to, and in parallel with, market barriers, several factors contribute to the lack of access to financing, including the following:

- **Credit risk:** Financiers are generally unable to securitize against assets delivering energy savings because the cooling assets – both the equipment and a building's energy efficiency measures – are usually integrated into the fabric of a building as a whole, which is itself generally indebted and could also be subject to fractional ownership in some cases.
- **Performance risk:** Energy performance is not transparent or immediately visible and is difficult to measure on a normalized basis with precision. The challenge is further compounded by a lack of standardization of measurement and verification practices for savings. Due to the uncertainty of energy savings, financiers are generally unable to securitize financing against sustainable space cooling energy savings.
- **Lack of access to affordable financing:** To address the uncertainty around performance and credit risks associated with sustainable space cooling interventions and resulting structural complexity, financiers will charge higher interest rates. This concern is particularly common in developing countries where experience and expertise in building energy efficiency have yet to be established.

As several of the underlying market barriers – such as awareness, transparency and valuation of efficiency – are effectively addressed by policy and regulatory systems, the risks associated with financing sustainable cooling begin to lessen, creating an environment where financing and enabling mechanisms can be more effectively deployed.

Several financing mechanisms can be enabled by cities to help support private sector adoption of sustainable cooling interventions. These include the following.

- **Revolving loan funds** (ESMAP 2020b): Revolving loan funds are city-enabled financing mechanisms. This pool of capital is typically managed by the government, a government-backed entity or a non-governmental organization rather than by a commercial bank. Revolving loan funds are usually seed funded from governments, with support from multilaterals or other donors, but then operate in a self-sustaining manner with repaid financing as a way to support further loans. These funds typically provide a way to provide financing for projects that may struggle to secure traditional financing at affordable rates. Revolving funds can be used to lend to homeowners and small and medium-sized enterprises, and they are also commonly used to fund energy efficiency projects in the public sector.

Revolving loan funds are by definition restricted to the extent of the initial supporting capital and cannot make more loans until the initial loans are repaid. Also, revolving loan funds will often have high administrative costs due to their relatively small scale and high governance requirements of assuring use in accordance with fund objectives, which can add to the need for subsidies and in turn limit either the scope of operation (such as to public sector buildings where credit and governance risk is low) or the long-term sustainability of the fund. Public sector revolving loan funds are very common in the United States and the United Kingdom. Energy efficiency revolving funds have also been established in other parts of the world, with support from international financial institutions such as the World Bank or from climate finance instruments such as the Global Environment Facility in Armenia and Bulgaria, among other countries. These funds can be targeted specifically towards scaling sustainable cooling projects.

- **Green credit lines** (ESMAP 2020b): Green credit lines are credit lines made available by public finance institutions to support investments in renewable energy and energy efficiency. The credit lines are made available via commercial financial institutions to homeowners and businesses looking to make energy efficiency investments. These credit lines may include features such as reduced interest rates, longer tenors, increased grace periods or incentive payments. Some shortcomings of green credit lines are that they may have high collateral requirements and their interest rates may still be considered too high and their tenors too short for many facility owners and consumers. Green credit lines can be used only by homeowners and businesses with accounts at financial institutions, leaving out 1.7 billion unbanked adults globally. In addition, businesses will generally prioritize investments that they consider to be core to their business over investments in sustainable space cooling.
- **Specialty lending entities and green banks:** Specialty lending entities are corporations set up with a specific purpose, which in this case could be to use innovative financing tools to scale up climate action in sectors with the greatest opportunities and to remove barriers through lending partnerships with like-minded partners. Green banks (or green investment banks) are typically public or quasi-public entities, initially capitalized with public funds. These entities are dedicated to leveraging public funds to attract larger amounts of private capital to invest in green projects. Green banks vary in structure and execution across the world, yet they share some common principles. Foremost are a narrow but flexible mandate focusing on low-carbon, climate-resilient investments; independence in operation and accountability through measurement of impact metrics such as jobs created, private capital mobilized, return on capital and greenhouse gas reductions achieved.

- **Green mortgages:** Also called energy-efficient mortgages, these are similar to typical residential mortgages except they can be used only for energy-efficient buildings or to make energy-efficient upgrades to an existing building. Banks or mortgage lenders may offer lower interest rates and allow borrowers to borrow more compared to a regular mortgage because of the borrower's lower building operating expenses as a result of the energy savings, which enhances their credit status. Green mortgages are available in the United States, parts of Europe and a few developing countries.

  In Europe, the Energy Efficient Mortgages Action Plan is an initiative that aims to create a standard energy-efficient mortgage. It currently has 51 banks and 33 other organizations that have committed to test the implementation of the energy-efficient mortgage framework with their current products and processes, with plans to implement an energy-efficient mortgage product in the future (Energy Efficient Mortgages Initiative 2019). In Mexico, the Sociedad Hipotecaria Federal (Federal Mortgage Society) began offering green mortgages to low-income households through its EcoCasa programme in 2013. The Sociedad Hipotecaria Federal received support from the Inter-American Development Bank and KfW Development Bank to offer mortgages with interest rates up to 3 per cent lower than it typically offered (Monge 2018). About 20 per cent of the Sociedad Hipotecaria Federal's portfolio is through the EcoCasa programme, and by the end of 2016, EcoCasa had provided mortgages for 27,600 homes, which was initially its 2019 goal.

- **PACE financing and EUF:** Property assessed clean energy (PACE) and environmental upgrade financing (EUF) are financing mechanisms whereby financing is provided via the local municipality to building developers (in the case of new construction) and building owners (in the case of existing buildings) to integrate deep efficiency measures in their buildings, secured through a lien as part of the property (or land) tax assessment of the building. By default, the lien is associated with the property and not the owner, with the repayment obligation through property tax payments being the obligation of the current building occupiers. The credit enhancement provided by the use of the municipality's property tax lien and the matching of the obligation to the occupier enjoying the energy savings of the deployed interventions bring significant financing efficiencies to this approach.

The best examples of this financing approach are in the United States and Australia, with new programmes also emerging in municipalities in Canada, South Africa and Europe.

This intervention is particularly suited to new construction and is relevant where significant new districts or cities are planned and there is a strong property or land-based taxation programme within the country.

RECOMMENDED CITY ACTIONS

12

Financial resources are a critical enabler for the successful execution of any urban cooling intervention. Before exploring potential funding and financing resources, however, a categorization of potential interventions needs to be undertaken to identify an optimal mix of measures from a cost, benefit and impact perspective, including inter-related effects. The lower the cost and the greater the benefit and impact of the selected interventions, the greater the likelihood of obtaining the necessary financing resources.

NO-REGRETS ACTIONS

- Undertaking a funding landscape assessment to gain awareness of potential funding sources is a key first step. (Financing is not a revenue source but a debt obligation that will need to be serviced with returns derived from the underlying investment or from future revenue sources.) Beyond this, with funding and financing being a facilitative intervention, the trigger points will be around the activation of the baseline assessment, cooling action plan or individual intervention strategies.

CITY INTERVENTIONS CATALYSED BY TRIGGER POINTS

- The starting point for evaluation of funding and financing options is the development of the benefits case for a single, or combination of, interventions – that is, what is the return for a city and its citizens. The return analysis should be undertaken on a whole-systems basis (as opposed to individual investor basis) to ensure that all benefits are captured, including inter-related benefits occurring in combination with other contemplated interventions.
- Along with the build-out of the benefits of a specific intervention, or combination of interventions, cost should be optimized by leveraging other funded projects and trigger points in order to reduce the incremental first-cost of the planned intervention.
- Once benefits and cost have been optimized, official development assistance, dedicated climate funds, and national- and state-level funding sources should be screened for fit. This is where the whole-system benefits analysis comes to the fore, as, for example, an intervention to expand and restore green space proximate to a waterway may be eligible for funding intended to reduce stormwater run-off, mitigating flooding risk.
- Review opportunities to leverage the city's tax-raising authority to capture new revenues to fund interventions that can demonstrably benefit, and gain the support of, the city's citizenry.

FURTHER RESOURCES

- ***Primer for Space Cooling,* Energy Sector Management Assistance Program, World Bank, 2020.** https://openknowledge.worldbank.org/handle/10986/34567
- **Financing a Resilient Urban Future: A Policy Brief on World Bank and Global Experience on Financing Climate-Resilient Urban Infrastructure, World Bank, 2018.** https://openknowledge.worldbank.org/handle/10986/31068
- **Climate finance: Multilateral and bilateral funding sources, United Nations Climate Change.** https://unfccc.int/topics/climate-finance/resources/multilateral-and-bilateral-funding-sources
- ***Creditworthiness: Good Practice Guide,* C40 Cities Climate Leadership Group, 2016.** https://www.c40.org/networks/creditworthiness

CASE STUDY 12.1 | ISAR-PLAN RIVER RESTORATION PROJECT – MUNICH, GERMANY

HIGHLIGHTS:

- Risk reduction
- Identifying a benefits case through whole-system thinking

ADDITIONAL FEATURES:

- Leveraging a competition approach for innovative ideas
- Collaboration across municipal silos
- Citizen awareness and participation

The Isar-Plan is a river restoration project in Munich, Germany that replaced around 8 kilometres of the monotonous canal-like riverbed – forced into walled river banks in the mid-nineteenth century – with a diverse, rewilding river landscape. This 11-year project (2000-2011) was a joint solution in response to the need for flood protection, improvement of water quality, and increased calls from citizens for green and recreational spaces in the city. The project exemplified a whole-system approach as a key enabler: by harmonizing the project plan across different goals, the project was able to demonstrate a strong case for benefits (Toxopeus 2019).

One of the major challenges related to climate change for the city of Munich is the expected change in rain patterns and a potential increase in floods in the winter months. Heavy rain events in the Alps in the years 1999, 2005 and 2013 already led to major floods and substantial financial damage in the south of Germany (Climate-ADAPT n.d.). The Isar-Plan project is a risk reduction strategy, with upfront investments in urban nature-based solutions to lower future costs from floods. At the same time, the project enables an attractive recreation area for residents and visitors by restoring the river's natural environment and biodiversity.

The expiring of water contracts with local energy plants was a key opportunity for renegotiation of the amount of water flow in the Isar for energy generation. The exemplary level of cooperation achieved between all stakeholders involved in the Isar-Plan was a key success factor for the project. An interdisciplinary project team, headed by the Bavarian Water Management Office, enabled different municipal departments and experts to cooperate successfully across silos. Keeping the multi-dimensional nature of the project in view – that is, the high technical, ecological, societal and urban design requirements – the project included a design competition engaging participation from landscape architects, hydraulics engineers and urban planners. Acceptance from the general public was achieved by strong public participation in the process through multiple mediums to encourage awareness and participation.

The project cost of around €35 million ($41.5 million) was jointly funded by the State of Bavaria and the City of Munich. Multiple benefits of the project have included significant improvement in the flood run-off; considerable improvement in the water quality, enabling swimming in the Isar River; restoring and improving biodiversity; and greatly improved recreational quality for Munich residents.

Isar River in Germany after restoration

CASE STUDY 12.2 | NEW YORK CITY ENERGY EFFICIENCY CORPORATION (NYCEEC) – NEW YORK CITY, UNITED STATES

HIGHLIGHTS:

- **Specialty lending entity/green bank**
- **PACE financing**

Established and endowed by New York City in 2011 with $37.5 million in federal grant funding, New York City Energy Efficiency Corporation (NYCEEC) has financed nearly $100 million in clean energy projects to date across 7.2 million square feet (669,000 square metres) of city building, eliminating more than 629,000 metric tons of greenhouse gases and resulting in the creation of over 1,000 jobs. NYCEEC is a 501(c)3 non-profit specialty finance company. Its design as a highly flexible, mission-focused specialty lender has attracted additional funding from the public sector (federal, city and state), commercial lending institutions and philanthropy.

NYCEEC provides loans and credit enhancement solutions for energy efficiency and clean energy projects that save energy and reduce greenhouse gases. NYCEEC's mission is to innovate and deliver clean energy financing solutions for buildings, and its vision is that clean energy financing markets for buildings will develop and align with the city's long-term environmental goals. As such, NYCEEC works closely with the City of New York to support its environmental policies.

NYCEEC was established with an initial capitalization of $37.5 million provided to New York City through the federal American Recovery and Reinvestment Act (ARRA). NYCEEC has attracted additional capital from the public, private and philanthropic sectors.

To date, NYCEEC's initial $37.5 million capitalization has resulted in debt financing of over $96 million in energy efficiency and clean energy project costs in predominantly multi-family and commercial buildings. This portfolio of projects is projected to eliminate more than 629,000 metric tons of greenhouse gases over the useful life of the equipment. NYCEEC has established several lender partnerships, resulting in greater capital access for efficiency. NYCEEC focuses on building sectors in New York City that have the greatest contribution to greenhouse gas emissions and the toughest challenges in mobilizing energy efficiency investment – namely, privately held, larger commercial and multi-family buildings (including the affordable multi-family housing sector).

NYCEEC's approach is to finance a wide range of technologies that save money and reduce greenhouse gas emissions, ranging from simple, proven approaches to deep multi-measure retrofits. NYCEEC has been active in supporting the development of "passive house" approaches in city buildings by providing attractive financing to this emerging sector.

The Mayor's Office of Sustainability, in partnership with NYCEEC, has developed a PACE financing programme for commercial and multi-family building owners. The programme offers affordable, long-term financing that allows property owners to pay for upgrades that improve energy efficiency, harness renewable energy, and conserve water (NYCEEC n.d.).

SUSTAINABLE URBAN COOLING HANDBOOK

BIBLIOGRAPHY

Acquisition.gov (2019). "Part 23 – Environment, Energy and Water Efficiency, Renewable Energy Technologies, Occupational Safety, and Drug-Free Workplace". https://www.acquisition.gov/content/part-23-environment-energy-and-water-efficiency-renewable-energy-technologies-occupational. Accessed 19 December 2019.

Akbari, H., Menon. S. and Rosenfeld, A. (2009). "Global cooling: increasing world-wide urban albedos to offset CO2". *Climatic Change* 94, 275-286. https://doi.org/10.1007/s10584-008-9515-9.

Ali-Toudert, F. and Mayer, H. (2007). Effects of asymmetry, galleries, overhanging façades and vegetation on thermal comfort in urban street canyons. *Solar Energy* 81(6), 742-754. http://dx.doi.org/10.1016/j.solener.2006.10.007.

ANSI/ASHRAE (2013). Thermal Environmental Conditions for Human Occupancy, standard 55-2013, Atlanta, Georgia. https://www.ashrae.org/technical-resources/bookstore/thermal-environmental-conditions-for-human-occupancy.

Arizona Department of Health Services (2020). "Arizona Heat Season 2020 Recap Webinar". 3 December. https://www.azdhs.gov/documents/preparedness/epidemiology-disease-control/extreme-weather/pubs/arizona-heat-season-2020-recap-webinar-slides.pdf.

Asian Development Bank (2017). *District Cooling in the People's Republic of China: Status and Development Potential*. Manila, Philippines. https://www.adb.org/sites/default/files/publication/222626/district-cooling-prc.pdf.

Bailey, G., Nicholass, A., Gillie, H. and Stewart, E. (2020). *Five Key Steps for Electric Bus Success.* Eunomia. https://www.transportenvironment.org/sites/te/files/publications/Five%20key%20steps%20for%20electric%20bus%20success.pdf.

Barbosa, T. (2021). 2020 ties 2016 as hottest year on record, even without warming boost from El Niño. *Los Angeles Times*. Updated 14 January. https://www.latimes.com/environment/story/2021-01-14/2020-hottest-year-on-record-el-nino-climate-change.

Barcelona City Council (n.d.a). Superilles. https://ajuntament.barcelona.cat/superilles/en. Accessed 24 May 2021.

Barcelona City Council (n.d.b). Results of the Barcelona Superblocks design competition. https://ajuntament.barcelona.cat/superilles/en/content/en-resoluci-dels-concursos-d-idees-de-superilla-barcelona. Accessed 24 May 2021.

Barcelona City Council (2021). Superblock Barcelona: Towards the city we want. Presentation. https://ajuntament.barcelona.cat/superilles/sites/default/files/20210202_Superblock_Barcelona_web.pdf.

Bartesaghi-Koc, C., Osmond, P. and Peters, A. (2020). Quantifying the seasonal cooling capacity of "green infrastructure types" (GITs): An approach to assess and mitigate surface urban heat island in Sydney, Australia. *Landscape and Urban Planning* 203, 103893. http://dx.doi.org/10.1016/j.landurbplan.2020.103893.

Bay Area Regional Energy Network (BayREN) (n.d.). Codes & standards. https://www.bayren.org/codes-standards. Accessed 6 July 2021.

Berkeley Prize (2011). Supernormal of the void deck. http://berkeleyprize.org/endowment/the-reserve?id=73. Accessed 24 May 2021.

Berlin, A., Zhang, X. and Chen, Y. (2020). *Case Study: Electric Buses in Shenzhen*, China. https://iea.blob.core.windows.net/assets/db408b53-276c-47d6-8b05-52e53b1208e1/e-bus-case-study-Shenzhen.pdf.

Bouchama, A., Dehbi, M., Mohamed, G., Matthies, F., Shoukri, M. and Menne, B. (2007). Prognostic factors in heat wave related deaths: a meta-analysis. *Archives of Internal Medicine* 167(20), 2170-76. https://doi.org/10.1001/archinte.167.20.ira70009.

C40 Cities (n.d.). For cities, the heat is on. https://www.c40.org/other/the-future-we-don-t-want-for-cities-the-heat-is-on. Accessed 30 June 2021.

C40 Cities (2016). *Case Study: C40 Good Practice Guides: New York City – New York City Energy Efficiency Corporation.* https://www.c40.org/case_studies/c40-good-practice-guides-new-york-city-new-york-city-energy-efficiency-corporation.

C40 Cities (2017). *Case Study: Cities100: Los Angeles – Demand Aggregation for EV Proliferation Plan.* https://www.c40.org/case_studies/cities100-los-angeles-demand-aggregation-for-ev-proliferation-plan.

C40 Knowledge Hub (2019a). How to set energy efficiency standards for new buildings. April. https://www.c40knowledgehub.org/s/article/How-to-set-energy-efficiency-standards-for-new-buildings.

C40 Knowledge Hub (2019b). How to use reporting and disclosure to drive building energy efficiency. April. https://www.c40knowledgehub.org/s/article/How-to-use-reporting-and-disclosure-to-drive-building-energy-efficiency.

C40 Knowledge Hub (2019c). How to adapt your city to extreme heat. August. https://www.c40knowledgehub.org/s/article/How-to-adapt-your-city-to-extreme-heat.

C40 Knowledge Hub (2021). Heat Resilient Cities: Measuring benefits of urban heat adaptation. March. https://www.c40knowledgehub.org/s/article/Heat-Resilient-Cities-Measuring-benefits-of-urban-heat-adaptation.

Canadian Architect (2018). Toronto raises new development standards, targets zero emissions by 2030. 19 January. https://www.canadianarchitect.cmperento-raises-new-development-standards-targets-zero-emissions-2030.

Carvalho, S., Maranion, B. and Polonara, F. (2018). *Report of the Technology and Economic Assessment Panel. Volume 5. Decision XXIX/10 Task Force Report on Issues Related to Energy Efficiency While Phasing Down Hydrofluorocarbons*. https://ozone.unep.org/sites/default/files/2019-04/TEAP_DecisionXXIX-10_Task_Force_EE_September2018.pdf.

Centers for Disease Control and Prevention (2017a). *The Use of Cooling Centers to Prevent Heat-Related Illness: Summary of Evidence and Strategies for Implementation*. Climate and Health Program. https://www.cdc.gov/climateandhealth/docs/UseOfCoolingCenters.pdf.

Centers for Disease Control and Prevention (2017b). Tips for preventing heat-related illness. Reviewed 19 June. https://www.cdc.gov/disasters/extremeheat/heattips.html.

Chakraborty, T., Hsu, A., Manya, D. and Sheriff, G (2019). Disproportionately higher exposure to urban heat in lower-income neighborhoods: a multi-city perspective. *Environmental Research Letters* 14, 105003. https://iopscience.iop.org/article/10.1088/1748-9326/ab3b99.

Chau, P.H., Chan, K.C. and Woo, J. (2009). Hot weather warming might help to reduce elderly mortality in Hong Kong. *International Journal of Biometeorology* 53(5), 461-68. https://doi.org/10.1007/s00484-009-0232-5.

Chen, W.Y., Hu, F.Z.Y., Li, X. and Hua, J. (2017). Strategic interaction in municipal governments' provision of public green spaces: A dynamic spatial panel data analysis in transitional China. *Cities* 71, 1-10. http://dx.doi.org/10.1016/j.cities.2017.07.003.

Chew, L.W. and Norford, L. (2019). Pedestrian-level wind speed enhancement with void decks in three-dimensional urban street canyons. *Building and Environment* 155 (15 May), 395-407. https://doi.org/10.1016/j.buildenv.2019.03.058.

City University of New York (n.d.). NYC Building Operator Training Program. https://www.cunybpl.org/opstraining. Accessed 29 June 2021.

City of Boulder (2020). Energy Conservation Code. https://bouldercolorado.gov/services/energy-conservation-code. Accessed 30 June 2021.

City of Ljubljana (n.d.a). Ljubljana 2025 Vision. https://www.ljubljana.si/en/ljubljana-for-you/urban-planning/ljubljana-2025-vision. Accessed 30 September 2021.

City of Ljubljana (n.d.b). Ljubljana Urban Region. https://www.ljubljana.si/en/ljubljana-for-you/urban-planning/ljubljana-urban-region-lur. Accessed 30 September 2021.

City of Paris (2020). Les coers Oasis. 19 November. https://www.paris.fr/pages/les-cours-oasis-7389.

City of Paris (2021a). Paris ville du quart d'heure, ou le pari de la proximité. 30 August. https://www.paris.fr/dossiers/paris-ville-du-quart-d-heure-ou-le-pari-de-la-proximite-37.

City of Paris (2021b). Paris expérimente l'ouverture des cours d'école au public le samedi. 22 January. https://mairieparisscentre.paris.fr/pages/paris-experimente-l-ouverture-des-cours-d-ecole-au-public-le-samedi-16519.

City of Toronto (2017). Zero Emissions Buildings Framework. https://www.toronto.ca/wp-content/uploads/2017/11/9875-Zero-Emissions-Buildings-Framework-Report.pdf.

CivicSpark (n.d.). Our impact. https://civicspark.lgc.org/our-impact. Accessed 24 June 2021.

Climate-ADAPT (n.d.). Isar-Plan – Water management plan and restoration of the Isar river, Munich (Germany). https://climate-adapt.eea.europa.eu/metadata/case-studies/isar-plan-2013-water-management-plan-and-restoration-of-the-isar-river-munich-germany. Accessed 5 July 2021.

Climate Policy Initiative (2021). *Multilateral DFI and Tracking Urban Adaptation Finance Report*. https://www.climatepolicyinitiative.org/publication/an-analysis-of-urban-climate-adaptation-finance.

Coalition for Urban Transitions (2019). Climate Emergency – Urban Opportunity: How national governments can secure economic prosperity and avert climate catastrophe by transforming cities. https://urbantransitions.global/en/publication/climate-emergency-urban-opportunity.

Contessa, M., van Vliet, B.J.M. and Lenhart, J. (2018). Is urban agriculture urban green space? A comparison of policy arrangements for urban green space and urban agriculture in Santiago de Chile. *Land Use Policy* 71 (February), 566-577. https://doi.org/10.1016/j.landusepol.2017.11.006.

Cooling Singapore (n.d.). https://www.coolingsingapore.sg. Accessed 30 June 2021.

Cooling Singapore (2020). Outdoor thermal comfort. https://www.coolingsingapore.sg/outdoor-thermal-comfort.

Crook, L. (2020). Barcelona to convert a third of central streets into car-free green spaces. Dezeen. 19 November. https://www.dezeen.com/2020/11/19/barcelona-eixample-masterplan-streets-green-space.

de Guzman, E., Kalkstein, L.S., Sailor, D., Eisenman, D., Sheridan, S., Kirner, K. et al. (2020). *RX for Hot Cities: Climate Resilience Through Urban Greening and Cooling in Los Angeles*. Los Angeles Urban Cooling Collaborative. https://www.treepeople.org/wp-content/uploads/2020/09/RX-for-hot-cities-report.pdf.

de Guzman, E., Malarich, R., Large, L. and Danoff-Burg, S. (2018). Inspiring resident engagement: Identifying street tree stewardship participation strategies in environmental justice communities using a community-based social marketing approach. *Arboriculture & Urban Forestry* 44(6), 291-306. https://www.ioes.ucla.edu/wp-content/uploads/291_306_AUFNov2018.pdf.

Department of Resources Energy and Tourism (2013). *Energy Use in the Australian Government's Operations 2011–12. Australian Government, Canberra*. https://www.energy.gov.au/sites/default/files/energy-use-in-australian-govt-ops_2011-12-report-2013_0.pdf.

Di Cecca, A., Benassis, F. and Poeuf, P. (2019). Energy storage: The Parisian district cooling system. Energy Learning. Climespace – GDF Suez, Paris. https://www.energy-learning.com/index.php/archive/94-energy-storage-the-parisian-district-cooling-system. Accessed 19 December 2019.

Dinçer, İ. and Zamfirescu, C. (2011). *Sustainable Energy Systems and Applications*. Springer International Publishing: New York, USA. ISBN 9780387958606.

Duany, A. and Steuteville, R. (2021). Designing the 15-minute city. Congress for the New Urbanism. 8 February. https://www.cnu.org/publicsquare/2021/02/08/defining-15-minute-city.

Ebi, K.L., Teisberg, T.J., Kalkstein, L.S., Robinson, L. and Weiher, R.F. (2004). Heat watch/warning systems save lives: estimated costs and benefits for Philadelphia 1995-98. *Bulletin of the American Meteorological Society* 85(8), 1067-1074. https://doi.org/10.1175/BAMS-85-8-1067.

Eder, M., Cortes, F., Teixeira de Siqueira Filha, N., Araújo de França, G.V., Degroote, S., Braga, C. et al. (2018). Scoping review on vector-borne diseases in urban areas: transmission dynamics, vectorial capacity and co-infection. *Infectious Diseases of Poverty* 7(1), 90. https://doi.org/10.1186/s40249-018-0475-7.

Eldridge, M., Burrowes, K. and Spauster, P. (2019), *Investing in Equitable Urban Park Systems: Emerging Funding Strategies and Tools*. The Urban Institute. https://cityparksalliance.org/wp-content/uploads/2019/07/Equity_and_Parks_Funding_7.16.19.pdf.

Emery, J.J., Guo, P., Stolle, D.F.E., Hernandez, J. and Zhang, L. (2014). Light-coloured grey asphalt pavements: from theory to practice. *International Journal of Pavement Engineering* 15(1), 23-35. https://doi.org/10.1080/10298436.2013.782402.

EMSD (2012). *Code of Practice for Building Energy Audit*. Hong Kong. https://www.emsd.gov.hk/beeo/en/pee/EAC_2012.pdf.

Enerdata (2021). *Global Energy Statistical Yearbook 2021*. https://yearbook.enerdata.net/electricity/electricity-domestic-consumption-data.html.

Energy Efficient Mortgages Initiative (2019). Pioneers. https://eemap.energyefficientmortgages.eu/pioneers-2/#tab-id-1. Accessed 5 December 2019.

Energy Sector Management Assistance Program (2018). *Regulatory Indicators for Sustainable Energy*. Washington, D.C.: World Bank. https://www.worldbank.org/en/topic/energy/publication/rise-2018.

Energy Sector Management Assistance Program (2020a). *Primer for Cool Cities: Reducing Excessive Urban Heat.* Energy Sector Management Assistance Program Knowledge Series 028/19. Washington, D.C.: World Bank.

Energy Sector Management Assistance Program (2020b). *Primer for Space Cooling.* Energy Sector Management Assistance Program Knowledge Series 030/20. Washington, D.C.: World Bank.

Estrada, F., Wouter Botzen, W.J. and Tol, R.S.J. (2017). A global economic assessment of city policies to reduce climate change impacts. Nature Climate Change 7(6), 403-406. http://dx.doi.org/10.1038/nclimate3301.

European Commission (2018). Industrial Symbiosis. https://ec.europa.eu/environment/europeangreencapital/wp-content/uploads/2018/05/Industrial_Symbiosis.pdf.

Evans, M., Roshchanka, V. and Graham, P. (2017). An international survey of building energy codes and their implementation. *Journal of Cleaner Production* 158, 382-389. https://doi.org/10.1016/j.jclepro.2017.01.007.

Fecther-Leggett, E.D., Vaidyanathan, A. and Choudhary, E. (2016). Heat stress illness emergency department visits in national environmental public health tracking states, 2005-2010. *Journal of Health* 41(1), 57-69. https://doi.org/10.1007/s10900-015-0064-7.

Feng, H. and Hewage, K. (2017). Economic benefits and life cycle costs of green roofs. In Pérez, G. and Perini, K. *Nature Based Strategies for Urban and Building Sustainability*. Oxford, UK: Butterworth-Heinemann.

Fleming, A. *et al.* (2018). Heat: the next big inequality issue. *The Guardian (UK).* 13 August. https://www.theguardian.com/cities/2018/aug/13/heat-next-big-inequality-issue-heatwaves-world.

Gago, E.J., Roldan, J., Pacheco-Torres, R. and Ordóñez, J. (2013). The city and urban heat islands: A review of strategies to mitigate adverse effects. *Renewable and Sustainable Energy Reviews* 25 (September), 749-758. http://dx.doi.org/10.1016/j.rser.2013.05.057.

Geletič, J., Lehnert, M. and Dobrovolný, P. (2016). Land surface temperature differences within local climate zones, based on two central European cities. *Remote Sensing* 8(10), 788. https://doi.org/10.3390/rs8100788.

Georgescu, M., Morefield, P.E., Bierwagen, B.G. and Weaver, C.P. (2014). Twenty-first century megapolitan expansion. Proceedings of the National Academy of Sciences 111(8), 2909-2914. https://doi.org/10.1073/pnas.1322280111.

Gerish, E. and Watkins, S.L. (2018). The relationship between urban forests and income: A meta-analysis. *Landscape and Urban Planning* 170 (February), 293-308. https://doi.org/10.1016/j.landurbplan.2017.09.005.

Gilbert, H.E., Rosado, P.J., Ban-Weiss, G., Harvey, J.T., Li, H., Mandel, B.H. et al. (2017). Energy and environmental consequences of a cool pavement campaign. *Energy and Buildings* 157 (15 December), 53-77. https://doi.org/10.1016/j.enbuild.2017.03.051.

Global Cool Cities Alliance (2012). *Cool Roofs and Pavements Toolkit*. https://www.coolrooftoolkit.org/wp-content/pdfs/ CoolRoofToolkit_Full.pdf.

Global Cool Cities Alliance (n.d.). Cool Roadways Partnership to reduce urban heat. https://globalcoolcities.org/cool-roadways-partnership-to-reduce-urban-heat. Accessed 24 May 2021.

Global Partnership for Results-Based Approaches (n.d.). Who we are. https://www.gprba.org/who-we-are.

Green Purchasing Network. About GPN. https://www.gpn.jp/english. Accessed 19 December 2019.

Gu, K., Fang, Y., Qian, Z., Sun, Z. and Wang, A. (2020). Spatial planning for urban ventilation corridors by urban climatology. *Ecosystem Health and Sustainability* 6(1). https://doi.org/10.1080/20964129.2020.1747946.

Guardaro, M., Messerschmidt, M., Hondula, D.M., Grimm, N.B. and Redman, C.L. (2020). Building community heat action plans story by story: A three neighborhood case study. Cities 107 (December), 102886. https://doi.org/10.1016/j.cities.2020.102886.

Gujarat International (2019). Concept. http://www.giftgujarat.in/concept. Accessed 19 December 2019.

Harmon, E. (2017). Beat the heat this summer with Keep Cool. Metropolitan Area Planning Council. 21 June. https://www.mapc.org/planning101/beat-the-heat-this-summer-with-keep-cool.

Health Canada (2012). *Heat Alert and Response Systems to Protect Health: Best Practices Guidebook.* https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/pdf/pubs/climat/response-intervention/response-intervention-eng.pdf.

Hernández-Pérez, I., Xamán, J., Macias-Melo, E.V. and Castro, K.M.A. (2017). Reflective materials for cost-effective energy-efficient retrofitting of roofs. In Pacheco-Torgal, F., Granqvist, C.-G., Jelle, B.P., Vanoli, G.P., Bianco, N. and Kurnitski, J. *Cost-effective Energy Efficient Building Retrofitting: Materials, Technologies, Optimization and Case Studies.* 119-139. Sawston, UK: Woodhead Publishing. http://dx.doi.org/10.1016/B978-0-08-101128-7.00004-6.

Hess, J.J., Sathish, L.M., Knowlton, K., Saha, S., Dutta, P., Ganguly, P. et al. (2018). Building resilience to climate change: Pilot evaluation of the impact of India's first Heat Action Plan on all-cause mortality. *Journal of Environmental and Public Health*, 1 November. https://doi.org/10.1155/2018/7973519.

Hoffman, J.S., Shandas, V. and Pendleton, N. (2020). The effects of historical housing policies on resident exposure to intra-urban heat: A study of 108 US urban areas. *Climate* 8(1), 12. https://doi.org/10.3390/cli8010012.

Institute for Market Transformation (2020). *Building Performance Standards: A powerful new tool in the fight against climate change*. https://www.imt.org/resources/building-performance-standards-are-a-powerful-new-tool-in-the-fight-against-climate-change.

International Energy Agency (2017). Heat Island Reduction Initiative (HIRI). https://www.iea.org/policies/459-heat-island-reduction-initiative-hiri.

International Energy Agency (2018). *The Future of Cooling*. https://www.iea.org/reports/the-future-of-cooling.

International Energy Agency (2019). *Sustainable District Cooling Guidelines*. Paris. https://iea.blob.core.windows.net/assets/a5da464f-8310-4e0d-8385-0d3647b46e30/2020_IEA_DHC_Sustainable_District_Cooling_Guidelines_new_design.pdf.

Intergovernmental Panel on Climate Change (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, et al. (Eds.)]. Cambridge University Press. In Press.

International Green Roof Association (n.d.). *A Quick Guide to Green Roofs*. https://www.yumpu.com/en/document/read/21845403/a-quick-guide-to-green-roofs-international-green-roof-association. Accessed 30 June 2021.

International Labour Organization (2019). Increase in heat stress predicted to bring productivity loss equivalent to 80 million jobs. 1 July. https://www.ilo.org/global/about-the-ilo/newsroom/news/WCMS_711917/lang--en/index.htm.

IOR (n.d.). Refrigerant containment. https://ior.org.uk/careers/real-zero-refrigerant-emissions-and-leakage-reduct. Accessed 30 June 2021.

IUCN (n.d.). Nature-based solutions. https://www.iucn.org/theme/nature-based-solutions/about. Accessed 24 May 2021.

Jacobs, B., Cunningham, R. and Boronyak, L. (2018). *Climate Adapted People Shelters: Field Assessment. UTS: ISF*, Australia. https://ntropy.blob.core.windows.net/file-uploads/ntpyausPCC30/midwayfiles/9b356d8b-65ec-47a6-af2d-679fb6716c85.pdf.

Jamei, E., Ossen, D.R., Seyedmahmoudian, M., Sandanayake, M., Stojcevski, A. and Horan, B. (2020). Urban design parameters for heat mitigation in tropics. *Renewable and Sustainable Energy Reviews* 134 (December), 110362. https://doi.org/10.1016/j.rser.2020.110362.

Junta, N. and Shin-ichi, T. (2020). Thermal adaptation and comfort zones in urban semi-outdoor environments. *Frontiers in Built Environment* 6 (31 March). https://doi.org/10.3389/fbuil.2020.00034.

Kalkstein, L.S., Sailor, D.S., Shickman, K., Sheridan, S.C. and Vanos, J.K. (2013). Assessing the health impacts of urban heat island reduction strategies in the district of Columbia. Global Cool Cities Alliance / District Department of the Environment. September.

Katili, A., Boukhanouf, R. and Wilson, R. (2015). Space cooling in buildings in hot and humid climates: A review of the effect of humidity on the applicability of existing cooling techniques. *Proceedings of the 14th International Conference on Sustainable Energy Technologies (SET 2015), Nottingham, UK.* http://dx.doi.org/10.13140/RG.2.1.3011.5287.

Kats, G. and Glassbrook, K. (2018). *Delivering Urban Resilience.* Smart Surfaces Coalition. https://smartsurfacescoalition.org/analysis/delivering-urban-resilience-full-report.

Keegan, M. (2018). Shenzhen's silent revolution: world's first fully electric bus fleet quietens Chinese megacity. *The Guardian* (UK). 12 December. https://www.theguardian.com/cities/2018/dec/12/silence-shenzhen-world-first-electric-bus-fleet.

Kim, J. (2016). *Handbook on Urban Infrastructure Finance.* New Cities Foundation. http://bit.ly/NCFUrbanFinance.

King, M. (2012). *Community Energy: Planning, Development and Delivery.* International District Energy Association. https://higherlogicdownload.s3.amazonaws.com/DISTRICTENERGY/998638d1-8c22-4b53-960c-286248642360/UploadedImages/Documents/Publications/USCommunityEnergyGuidelo.pdf.

Kjellstrom, T., Maître, N., Saget, C., Otto, M. and Karimova, T. (2019). *Working on a Warmer Planet: The Effect of Heat Stress on Productivity and Decent Work.* International Labour Organization.

Krayenhoff, E.S., Broadbent, A.M., Zhao, L., Georgescu, M., Middel, A., Voogt, J.A. *et al.* (2021). Cooling hot cities: a systematic and critical review of the numerical modelling literature. *Environmental Research Letters* 16(5), 053007. https://doi.org/10.1088/1748-9326/abdcf1.

Kubota, T., Lee, H.S., Trihamdani, A.R., Phuong, T.T.T., Tanaka, T. and Matsuo, K. (2017). Impacts of land use changes from the Hanoi Master Plan 2030 on urban heat islands: Part 1. Cooling effects of proposed green strategies. *Sustainable Cities and Society* 32 (July), 295-317. https://doi.org/10.1016/j.scs.2017.04.001.

Kubota, T., Rijal, H.B. and Takaguchi, H., Eds. (2018). *Sustainable Houses and Living in the Hot-Humid Climates of Asia.* Springer. https://link.springer.com/book/10.1007%2F978-981-10-8465-2.

Kumar, V., Jolli, V. and Babu, C.R. (2019). Avenue plantations in Delhi and their efficacy in mitigating air pollution. *Arboricultural Journal* 41(1), 1-13. http://dx.doi.org/10.1080/03071375.2019.1562800.

Landscape Performance Series (n.d.). Cheonggyecheon Stream Restoration Project. https://www.landscapeperformance.org/case-study-briefs/cheonggyecheon-stream-restoration#/challenge-solution. Accessed 30 June 2021.

Levinson, R., Pan, H., Ban-Weiss, G., Rosado, P., Paolini, R. and Akbari, H. (2011). Potential benefits of solar reflective car shells: Cooler cabins, fuel savings, and emission reductions. *Applied Energy* 88(12), 4343-4357. https://doi.org/10.1016/j.apenergy.2011.05.006.

Li, T., Hao, Y., Wang, M. and Guo, C. (2021). *Zero-Carbon Targeted Integrated Energy Planning: An Innovative District-Level Pathway to Support Carbon Neutrality by 2060.* RMI. https://rmi.org/insight/zero-carbon-targeted-integrated-energy-planning.

Lim, X.Z. (2019). The super-cool materials that send heat to space. *Nature* 577(7788), 18-20. https://doi.org/10.1038/d41586-019-03911-8.

Liou, Y.-A., Nguyen, K.-A. and Ho, L.-T. (2021). Altering urban greenspace patterns and heat stress risk in Hanoi city during Master Plan 2030 implementation. *Land Use Policy* 105 (June), 05405. https://doi.org/10.1016/j.landusepol.2021.105405.

Living Roofs (2016). Green roof bylaws – from Argentina to San Francisco. https://livingroofs.org/argentina-san-francisco-bylaw.

Louisville Energy Alliance (n.d.). Kilowatt Crackdown. http://www.louisvilleenergyalliance.org/kilowatt-crackdown.html. Accessed 15 June 2021.

Luber, G. and McGeehin, M. (2008). Climate change and extreme heat events. *American Journal of Preventive Medicine* 35(5), 429-435. https://doi.org/10.1016/j.amepre.2008.08.021.

Mahendra, A. and Seto, K. (2019), *Upward and Outward Growth: Managing Urban Expansion for More Equitable Cities in the Global South.* World Resources Institute. https://wri.org/wri-citiesforall/publication/upward-and-outward-growth-managing-urban-expansion-more-equitable.

Matthies, F., Bickler, G., Cardenosa Marin, N. and Hales, S. (Eds.) (2008). *Heat-Health Action Plans – Guidance.* World Health Organization – Europe. https://www.euro.who.int/__data/assets/pdf_file/0006/95919/E91347.pdf.

McDonald, R., Kroeger, T., Boucher, T., Longzhu, W. and Salem., R (2016). *Planting Healthy Air: A Global Analysis of the Role of Urban Trees in Addressing Particulate Matter Pollution and Extreme Heat.* The Nature Conservancy, https://www.nature.org/content/dam/tnc/nature/en/documents/20160825_PHA_Report_Final.pdf.

McDonald, R.I., Kroeger, T., Zhang, P. and Hamel, P. (2020). The value of US urban tree cover for reducing heat-related health impacts and electricity consumption. *Ecosystems* 23, 137-150. https://doi.org/10.1007/s10021-019-00395-5.

Miller, A. (2019). Local governments can lead by example in climate action, starting with the buildings they own. New Buildings Institute. 27 February. https://newbuildings.org/local-governments-can-lead-by-example-in-climate-action.

MillionTreesNYC (n.d.). About MillionTrees NYC. https://www.milliontreesnyc.org/html/about/about.shtml. Accessed 17 June 2021.

Miner, M.J., Taylor, R.A., Jones, C. and Phelan, P.E. (2016). Efficiency, economics, and the urban heat island. *Environment & Urbanization* 29(1), 183-194. https://doi.org/10.1177/0956247816655676.

Ministry of Environment, Forest and Climate Change (2019). *India Cooling Action Plan. Government of India,* New Delhi. http://ozonecell.in/wp-content/uploads/2019/03/INDIA-COOLING-ACTION-PLAN-e-circulation-version080319.pdf.

Monge, C. (2018). EcoCasa Program outperforms its green building goals. Clean Energy Finance Forum. 20 February. https://cleanenergyfinanceforum.com/2018/02/20/ecocasa-program-outperforms-its-green-building-goals.

Municipality of Ljubljana (2015). Ljubljana Green Capital – before and after. YouTube video. 18 March. https://youtu.be/JDLGMItEC40.

Nadel, S. and Hinge, A. (2020). *Mandatory Building Performance Standards: A Key Policy for Achieving Climate Goals.* American Council for an Energy-Efficient Economy. https://www.aceee.org/white-paper/2020/06/mandatory-building-performance-standards-key-policy-achieving-climate-goals.

Natural Resources Defense Council (2013a). *Rising Temperatures, Deadly Threat: Recommendations for Slum Communities in Ahmedabad*. https://www.nrdc.org/sites/default/files/india-heat-slum-communities-IB.pdf.

Natural Resources Defense Council (2013b). *Rising Temperatures, Deadly Threat: Recommendations to Prepare Outdoor Workers in Ahmedabad*. https://www.nrdc.org/sites/default/files/india-heat-outdoor-workers-IB.pdf.

Natural Resources Defense Council (2013c). *Rising Temperatures, Deadly Threat: Recommendations for Health Professionals in Ahmedabad*. https://www.nrdc.org/sites/default/files/india-heat-health-professionals-IB.pdf.

Natural Resources Defense Council (2013d). *Rising Temperatures, Deadly Threat: Recommendations for Ahmedabad's Government Officials.* https://www.nrdc.org/sites/default/files/india-heat-government-officials-IB.pdf.

Natural Resources Defense Council (2018). *Cool Roofs: Protecting Local Communities and Saving Energy.* Issue Brief. May. https://nrdc.org/sites/default/files/ib_-_cool_roofs_-_hyd_workshop.pdf.

Natural Resources Defense Council (2019). *Expanding Heat Resilience Across India*. https://ghhin.org/wp-content/uploads/NRDC.pdf.

Natural Resources Defense Council, Ahmedabad Municipal Corporation, India Meteorological Department, Indian Institute of Public Health, Gandhinagar Public Health Foundation of India, Mount Sinai School of Medicine et al. (2017). *Ahmedabad Heat Action Plan 2017*. https://www.nrdc.org/sites/default/files/ahmedabad-heat-action-plan-2017.pdf.

Natural Resources Defense Council et al. (2018). *Ahmedabad Heat Action Plan, 2019 Update*. https://www.nrdc.org/sites/default/files/ahmedabad-heat-action-plan-2018.pdf.

Nayek, S.G., Shrestha, S., Sheridan, S.C., Hsu, W.-H., Muscatiello, N.A., Panteaa, C.I. et al. (2019). Accessibility to cooling centers for heat vulnerable populations in New York State. *Journal of Transport & Health*. 14 (September), 100563. https://doi.org/10.1016/j.jth.2019.05.002.

Nesta Challenges (n.d.). Climate Smart Cities Challenge open call. https://challenges.org/climate-smart-cities/#applycities. Accessed 24 May 2021.

NYCEEC (n.d.). About C-PACE. https://nyceec.com/nyc-c-pace-administration. Accessed 30 June 2021.

Oke, T. (1987). *Boundary Layer Climates*, 2nd ed. Methuen, London and New York.

Oppla (n.d.). Ljubljana: NBS for Urban Regeneration and Wellbeing. https://oppla.eu/casestudy/19461. Accessed 30 June 2021.

Othman, L. (2016). World's biggest underground district cooling network now at Marina Bay. 3 March. Today Online. https://www.todayonline.com/singapore/plant-underground-district-cooling-network-marina-bay-commissioned.

Patel, G. (2018). India's first district cooling system at GIFT City. REHVA Federation of European Heating, Ventilation and Air Conditioning Association. https://www.rehva.eu/rehva-journal/chapter/indias-first-district-cooling-system-at-gift-city.

Penrith City Council (n.d.). New Cool Bus Shelter at Derby Street, Kingswood. https://www.yoursaypenrith.com.au/project/CAPS. Accessed 12 July 2021.

Penrith City Council (2018a). *Climate Adapted People Shelters (CAPS).* https://ehq-production-australia.s3.ap-southeast-2.amazonaws.com/1451f819293e7948c83e5e5a4a824dd4af5fbc27/documents/attachments/000/072/131/original/CAPS_Case_Study_Feb_2018.pdf.

Penrith City Council (2018b). *Climate Adapted People Shelters (CAPS): What is CAPS?* https://ntropy.blob.core.windows.net/file-uploads/ntpyausPCC30/midwayfiles/7f0e1170-9699-4dab-bad2-bb7eb123c603.pdf.

Pereira, I. (2017). NYC hiring workers for CoolRoofs energy saving program. AMNY. 3 April. https://www.amny.com/news/nyc-hiring-workers-for-coolroofs-energy-saving-program-1.13353595.

Perkins Eastman (n.d.). *Hanoi Capital Master Plan to 2030.* https://www.perkinseastman.com/projects/hanoi-capital-master-plan-to-2030. Accessed 24 May 2021.

Pless, S., Polly, B., Houssainy, S., Torcellini, P., Livingood, W., Zaleski, S. et al. (2020). *A Guide to Energy Master Planning of High-Performance Districts and Communities.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5500-78495. https://www.nrel.gov/docs/fy21osti/78495.pdf.

Power Engineering International (2015). District cooling heats up. 17 September. https://www.powerengineeringint.com/decentralized-energy/district-energy/district-cooling-heats-up.

Qaid, A., Bin Lamit, H., Remaz Ossen, D. and Nafida Raja Shahminan, R. (2016). Urban heat island and thermal comfort conditions at micro-climate scale in a tropical planned city. *Energy and Buildings* 133 (1 December), 577-595. https://doi.org/10.1016/j.enbuild.2016.10.006.

Rajagopalan, P., Lim, K.C. and Jamei, E. (2014). Urban heat island and wind flow characteristics of a tropical city. *Solar Energy* 107 (September), 159-170. https://doi.org/10.1016/j.solener.2014.05.042.

Raven, J., Stone, B., Mills, G., Towers, J., Katzschner, L., Leone, M. *et al.* (2018). Urban planning and design. In Rosenzweig, C., Solecki, W., Romero-Lankao, P., Mehrotra, S., Dhakal, S. and Ali Ibrahim, S. (Eds.). *Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network.* Cambridge University Press. New York. 139-172.

Riahi, L. (2015), *District Energy in Cities: Paris Case Study.* United Nations Environment Programme, Paris. https://www.districtenergy.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=b7d8029e-fb30-d023-a362-50f251a39458&forceDialog=1.

Rim, R. (2018). Green Infrastructure Best Practices & Stakeholder Engagement. Presented at the Cool Cities Network 2018 workshop.

Roberts, V. (2015), The demand for cooling in Singapore's buildings. Energy Ramblings. 5 September. http://www.energyramblings.com/2015/09/05/the-demand-for-cooling-in-singapores-buildings.

Rosenfeld, A., Romm, J. Akbari, H. and Lloyd, L. (1997). Painting the town white – and green. *MIT Technology Review.* February-March. Archived from the original on 14 July 2007. https://web.archive.org/web/20070714173907/http:/eetd.lbl.gov/HeatIsland/PUBS/PAINTING.

Rosenzweig, C., Gaffi, D. and Parshall, L. (Eds.) (2006). *Green Roofs in the New York Metropolitan Region: Research Report.* Columbia University Center for Climate Systems Research and NASA Goddard Institute for Space Studies. https://pubs.giss.nasa.gov/docs/2006/2006_Rosenzweig_ro05800e.pdf.

Sachar, S., Campbell, I. and Kalanki, A. (2018). Solving the Global Cooling Challenge: How to Counter the Climate Threat from Room Air Conditioners. Boulder, Colorado: RMI.

Sailor, D.J., Georgescu, M., Milne, J.M. and Hart, M.A. (2015). Development of a national anthropogenic heating database with an extrapolation for international cities. *Atmospheric Environment* 118 (October), 7-18. https://doi.org/10.1016/j.atmosenv.2015.07.016.

Santamouris, M. (2019). Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change. *Energy and Buildings* 207 (15 January), 109482. https://doi.org/10.1016/j.enbuild.2019.109482.

Santamouris, M., Ding, L., Fiorito, F., Oldfield, P., Osmond, P., Paolini, R. *et al.* (2016). Passive and active cooling for the outdoor built environment: Analysis and assessment of the cooling potential of mitigation technologies using performance data from 220 large scale projects. *Solar Energy* 154 (15 September), 14-33. https://doi.org/10.1016/j.solener.2016.12.006.

Schäffler, A. *et al.* (2013). *State of Green Infrastructure in the Gauteng City-Region.* Gauteng City-Region Observatory (GCRO). https://cdn.gcro.ac.za/media/documents/sogi_final_IKwf0r7.pdf.

Schinasi, L.H., Benmarhnia, T. and De Roos, A.J. (2018). Modification of the association between high ambient temperature and health by urban microclimate indicators: A systematic review and meta-analysis. *Environmental Research* 161 (February), 168-180. https://doi.org/10.1016/j.envres.2017.11.004.

Seattle Planning Commission (2013). *Seattle Transit Communities.* March. http://www.seattle.gov/documents/Departments/SeattlePlanningCommission/SeattleTransitCommunities/STC_report_to_Council_vers3.pdf.

Semenza, J.C., Rubin, C.H., Falter, K.H., Selanikio, J.D., Flanders, W.D., Howe, H.L. *et al.* (1996). Heat-related deaths during the July 1995 heat wave in Chicago. *New England Journal of Medicine* 335(2), 84-90. https://doi.org/10.1056/nejm199607113350203.

Shah Azhar, G., Mavalankar, D., Nori-Sarma, A., Rajiva, A., Dutta, P., Jaiswal, A. *et al.* (2014). Heat-related mortality in India: Excess all-cause mortality associated with the 2010 Ahmedabad heat wave. *PLOS ONE* (14 March). https://doi.org/10.1371/journal.pone.0091831.

Shih, W.-Y. (2017). *The impact of urban development patterns on thermal distribution in Taipei. 2017 Joint Urban Remote Sensing Event (JURSE), Dubai (March).* http://dx.doi.org/10.1109/JURSE.2017.7924634.

Singh, J., Culver, A. and Bitlis, M. (2012). *Public Procurement of Energy Efficient Products: Lessons from Around the World.* Energy Sector Management Assistance Program. World Bank, Washington, D.C. https://openknowledge.worldbank.org/bitstream/handle/10986/17485/735070ESM0P12700EEProducts0TR003012.pdf.

Singh, V.K., Acero, J.A. and Martilli, A. (2020). Evaluation of the Impact of Anthropogenic Heat Emissions Generated from Road Transportation and Power Plants on the UHI Intensity of Singapore. Singapore-ETH Centre, Cooling Singapore. https://doi.org/10.3929/ethz-b-000452434.

Smart City Sweden (n.d.). About Smart City Sweden. https://smartcitysweden.com/about. Accessed 12 July 2021.

Smart Energy International (2018). Smart bus stop promises Singapore commuters cooler waiting time. 12 March. https://www.smart-energy.com/industry-sectors/data_analytics/smart-bus-stop-promises-singapore-commuters-cooler-waiting-time.

Somanathan, E., Somanathan, R., Sudarshan, A. and Tewari, M. (2018). *The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing.* Energy Policy Institute at the University of Chicago. https://bfi.uchicago.edu/wp-content/uploads/UCH-110116_IndianManufacturingResearchSummary_v04.pdf.

Stewart, I.D., Oke, T.R. and Krayenhoff, E.S. (2014), Evaluation of the 'local climate zone' scheme using temperature observations and model simulations. *International Journal of Climatology* 34(4), 1062-1080. https://doi.org/10.1002/joc.3746.

Stone, B., Jr., Mallen, E., Rajput, M., Gronlund, C.J., Broadbent, A.M., Krayenhoff, E.S. *et al.* (2021). Compound climate and infrastructure events: How electrical grid failure alters heat wave risk. *Environmental Science and Technology* 55(10), 6957-6964. https://doi.org/10.1021/acs.est.1c00024.

Stone, L. and Jungclaus, M. (2020). Combating climate change through high-performance districts. RMI. 16 December. https://rmi.org/combating-climate-change-through-high-performance-districts.

Su, W., Gu, C. and Yang, G. (2010). Assessing the impact of land use / land cover on urban heat island pattern in Nanjing City, China. *Journal of Urban Planning and Development* 136(4), 365-372. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000033.

Sustain Europe (n.d.). Going green. https://www.sustaineurope.com/going-green.html. Accessed 24 May 2021.

Sustainable Energy for All (2018). *Chilling Prospects: Providing Sustainable Cooling for All.* Washington, D.C. https://www.seforall.org/sites/default/files/SEforALL_CoolingForAll-Report.pdf.

Takane, Y., Kikegawa, Y., Hara, M. and Grimmond, C.S.B. (2019). Urban warming and future air-conditioning use in an Asian megacity: Importance of positive feedback. *Climate and Atmospheric Science* 2 (25 October). http://dx.doi.org/10.1038/s41612-019-0096-2.

Tax Policy Center (2020). Briefing Book: The state of state (and local) tax Policy. https://www.taxpolicycenter.org/briefing-book/what-are-sources-revenue-local-governments. Accessed 24 May 2021.

The Nature Conservancy (2019). *Heat Action Planning Guide for Neighborhoods of Greater Phoenix.* https://repository.asu.edu/attachments/220853/content/Greater%20Phoenix%20Heat%20Action%20Planning%20Guide.pdf.

The Nature Conservancy (2020). Addressing heat and air quality in Phoenix. 15 July. https://www.nature.org/en-us/about-us/where-we-work/united-states/arizona/stories-in-arizona/city-heat-air-quality.

Toloo, G., FitzGerald, G., Aitken, P., Verrall, K. and Tong, S. (2013). Are heat warning systems effective? *Environmental Health* 12 (5 April). https://doi.org/10.1186/1476-069X-12-27.

Towey, H. (2021). Cities including Miami and Athens are hiring "Chief Heat Officers" to help businesses and residents survive extreme heat. Business Insider. 23 August. https://www.businessinsider.com/heatwave-miami-athens-chief-heat-officers-climate-crisis-extreme-temperatures-2021-8.

Toxopeus, H. (2019). *Taking Action for Urban Nature: Business Model Catalogue.* NATURVATION. https://naturvation.eu/sites/default/files/results/content/files/business_model_catalogue.pdf.

Tran, K.V., Azhar, G.S., Nair, R., Knowlton, K., Jaiswal, A., Sheffield, P. *et al.* **(2013).** A cross-sectional, randomized cluster sample survey of household vulnerability to extreme heat among slum dwellers in Ahmedabad, India. *International Journal of Environmental Research and Public Health* 10(6), 2515-2543. https://doi.org/10.3390/ijerph10062515.

Transit Oriented Development Institute (n.d.). Transit Oriented Development. http://www.tod.org. Accessed 30 June 2021.

Trust for Public Land (n.d.). The ParkScore® index: Methodology and FAQ. https://www.tpl.org/parkscore/about. Accessed 30 June 2021.

Trust for Public Land (2016). The benefits of green infrastructure for heat mitigation and emissions reductions in cities. https://www.tpl.org/benefits-green-infrastructure-heat-mitigation-and-emissions-reductions-cities.

Trust for Public Land (2020a). The heat is on. https://www.tpl.org/the-heat-is-on.

Trust for Public Land (2020b). *School's Out: In a Time of Compounding Crises, America's Schoolyards Are Packed with Potential.* San Francisco. https://www.tpl.org/sites/default/files/Schools-Out_A-Trust-for-Public-Land-Special-Report.pdf.

United Nations (2017). *Financing Sustainable Urban Development in the Least Developed Countries.* https://www.un.org/esa/ffd/wp-content/uploads/2016/09/Financing-Sustainable-Urban-Development-in-LDCs.pdf.

United Nations (2018). 68% of the world population projected to live in urban areas by 2050, says UN. 16 May. https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html.

United Nations (2019). 11: Sustainable Cities and Communities. https://unstats.un.org/sdgs/report/2019/goal-11.

United Nations Department of Economic and Social Affairs (2018), *2018 Revision of World Urbanization Prospects.* United Nations Population Division. https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html.

United Nations Environment Programme (2015). *District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy.* Paris. https://wedocs.unep.org/handle/20.500.11822/9317

United Nations Environment Programme and International Energy Agency (2020). *Cooling Emissions and Policy Synthesis Report.* Nairobi and Paris. https://wedocs.unep.org/bitstream/handle/20.500.11822/33094/CoolRep.pdf?sequence=1&isAllowed=y.

University of Sussex (2017). "Heat island" effect could double climate change costs for world's cities. ScienceDaily. 29 May. https://www.sciencedaily.com/releases/2017/05/170529133714.htm.

Urban Land Institute (n.d.). Seattle Green Factor. https://developingresilience.uli.org/case/seattle-green-factor. Accessed 24 May 2021.

Urban Resources Initiative (n.d.). GreenSkills. Yale School of the Environment. https://uri.yale.edu/programs/greenskills. Accessed 30 June 2021.

US Department of Energy (n.d.). Why building energy codes? Office of Energy Efficiency & Renewable Energy, Building Technologies Office. https://www.energycodes.gov/why-building-energy-codes. Accessed 26 April 2021.

US Department of Energy (2011). Going Beyond Code. Washington, D.C. https://www.energycodes.gov/resource-center/ACE/overview/beyondCode.

US Department of Energy (2017). Waste Heat Recovery Resource Page. https://www.energy.gov/eere/amo/articles/waste-heat-recovery-resource-page.

US Department of Energy (2019). Standard Energy Efficiency Data (SEED) Platform. https://www.energy.gov/eere/buildings/standard-energy-efficiency-data-seed-platform. Accessed 19 December 2019.

US Energy Information Administration (2019). Demand-side management programs save energy and reduce peak demand. Today in Energy. 29 March. https://www.eia.gov/todayinenergy/detail.php?id=38872.

US Environmental Protection Agency (n.d.). Adapting to heat. https://www.epa.gov/heatislands/adapting-heat. Accessed 12 March 2021.

US Environmental Protection Agency (2008). Heat island reduction activities. *In: Reducing Urban Heat Islands: Compendium of Strategies.* https://www.epa.gov/heat-islands/heatisland-compendium.

US Environmental Protection Agency (2016). *Excessive Heat Events Guidebook.* https://www.epa.gov/sites/production/files/2016-03/documents/eheguide_final.pdf.

US Environmental Protection Agency (2021). Using trees and vegetation to reduce heat islands. Updated 15 July. https://www.epa.gov/heatislands/using-trees-and-vegetation-reduce-heat-islands.

Vandentorren, S., Bretin, P., Zeghnoun, A., Mandereau-Bruno, L., Croisier, A., Cochet, C. *et al.* (2006). August 2003 heat wave in France: Risk factors for death of elderly people living at home. *European Journal of Public Health* 16(6): 583-91. https://doi.org/10.1093/eurpub/ckl063.

Vanos, J.K., Kalkstein, L. S., Sailor, D. S., Shickman K. and Sheridan, S.C. (2014). *Assessing the Health Impacts of Urban Heat Island Reduction Strategies in the Cities of Baltimore, Los Angeles, and New York.* https://www.coolrooftoolkit.org/wp-content/uploads/2014/07/Three-City-Heat-Health-Report-FINAL-adj.pdf.

Vijayawada (2018). Slums in Indian cities most vulnerable to heat wave. *The Hindu.* Updated 23 February. https://www.thehindu.com/news/cities/Vijayawada/slums-in-indian-cities-most-vulnerable-to-heat-wave/article22822096.ece.

Vyawahare, M. (2018). One Lakh old ACs to be replaced in govt buildings in bid to conserve energy. *Hindustan Times.* 24 January. https://www.hindustantimes.com/india-news/one-lakh-old-acs-to-be-replaced-in-govt-buildings-in-bid-to-conserve-energy/story-wVv76qwLBCkUIMmxxpLM5O.html.

Walker, A. (2019). Splash pads are the new public pools. Curbed. 12 July. https://archive.curbed.com/2016/8/25/12613140/summer-swimming-pool-fountains-splash-pads-cities.

Wang, C., Wang, C. and Kaloush, K. (2020). *Critical Review and Gap Analysis of Impacts from Pavements on Urban Heat Island.* National Center of Excellence for Smart Innovations, Arizona State University. https://ncesmart.asu.edu/wp-content/uploads/2020/12/NAPA-20120-ASU-UHI-Report..pdf.

Western Sydney Regional Organisation of Councils (WSROC) (n.d.). Turn Down the Heat. https://wsroc.com.au/projects/project-turn-down-the-heat. Accessed 17 May 2021.

Western Sydney Regional Organisation of Councils (WSROC) (2018). *Turn Down the Heat: Strategy and Action Plan*. https://wsroc.com.au/media-a-resources/reports/send/3-reports/286-turn-down-the-heat-strategy-and-action-plan-2018.

White-Newsom, J.L., McCormick, S., Sampson, N., Buxton, M.A., O'Neill, M.S, Gronlund, C.J. *et al.* (2014). Strategies to reduce the harmful effects of extreme heat events: A four city case study. *International Journal of Environmental Research and Public Health* 11(2): 1960-1988. https://dx.doi.org/10.3390%2Fijerph110201960.

Wicht, M., Wicht, A. and Osińska-Skotak, K. (2017). Detection of ventilation corridors using a spatio-temporal approach aided by remote sensing data. *European Journal of Remote Sensing* 50(1), 254-267. https://doi.org/10.1080/22797254.2017.1318672.

World Bank (2016). *Mexico – Efficient Lighting and Appliances Project (English)*. Washington, D.C. http://documents.worldbank.org/curated/en/770671469672145946/Mexico-Efficient-Lighting-and-Appliances-Project.

World Bank (2018). Financing a Resilient Urban Future: A Policy Brief on World Bank and Global Experience on Financing Climate-Resilient Urban Infrastructure. Washington, D.C. http://documents1.worldbank.org/curated/en/370831544454490426/pdf/132822-WP-PUBLIC-8-12-2018-3-26-37-FRUFFinalDec.pdf.

World Bank (2021). *Electrification of Public Transport: A Case Study of the Shenzhen Bus Group.* Washington, D.C. https://openknowledge.worldbank.org/handle/10986/35935.

World Health Organization (n.d.a). Heatwaves. https://www.who.int/health-topics/heatwaves. Accessed 23 April 2021.

World Health Organization (n.d.b). Vector-borne disease. https://www.who.int/heli/risks/vectors/en. Accessed 23 April 2021.

World Health Organization (2008). Heat-health action plans guidance. https://www.euro.who.int/en/publications/abstracts/heathealth-action-plans.

World Health Organization (2014). *Quantitative Risk Assessment of the Effects of Climate Change on Selected Causes of Death, 2030s and 2050s*. Geneva. http://apps.who.int/iris/bitstream/handle/10665/134014/9789241507691_eng.pdf.

Xiang, J., Bi, P., Pisaniello, D. and Hansen, A. (2014). Health impacts of workplace heat exposure: An epidemiological review. Industrial Health 52(2), 91-101. https://dx.doi.org/10.2486%2Findhealth.2012-0145.

Xu, C., Kohler, T.A., Lenton, T.M., Svenning, J.-C. and Scheffer, M. (2020). Future of the human climate niche. *Proceedings of the National Academy of Sciences* 117(21), 11350-11355. https://doi.org/10.1073/pnas.1910114117.

Yadav, N. and Sharma, C. (2018). Spatial variations of intra-city urban heat island in megacity Delhi. *Sustainable Cities and Society* 37 (February), 298-306. https://doi.org/10.1016/j.scs.2017.11.026.

Yin, C., Yuan, M., Lu, Y., Huang, Y. and Liu, Y. (2018). Effects of urban form on the urban heat island effect based on spatial regression model. *Science of the Total Environment* 634 (1 September), 696-704. https://doi.org/10.1016/j.scitotenv.2018.03.350.

Yin, X., Yang, R., Tan, G. and Fan, S. (2020). Terrestrial radiative cooling: Using the cold universe as a renewable and sustainable energy source. *Science* 370(6518), 786-791. https://doi.org/10.1126/science.abb0971.

York, D., Neubauer, M., Nowak, S. and Molina, M. (2015). *Expanding the Energy Efficiency Pie: Serving More Customers, Saving More Energy Through High Program Participation.* Washington, D.C.: American Council for an Energy-Efficient Economy. https://www.aceee.org/sites/default/files/publications/researchreports/u1501.pdf.

Zagyi, N. (2013). Traditional energy-free solutions for ventilation and air-cooling in arid tropical areas of Asia. *Geographical Locality Studies* 1(1), 58-79. https://www.yumpu.com/en/document/read/56822930/nandor-zagyi-traditional-energy-free-solutions-for-ventilation-and-air-cooling-in-arid-tropical-areas-of-asia.

Zhang, H., Arens, E. and Pasut, W. (2011). Air temperature thresholds for indoor comfort and perceived air quality. *Building Research & Information* 39(2), 134-144. https://doi.org/10.1080/09613218.2011.552703.

Zhang, J., Zhang, K., Liu, J. and Ban-Weiss, G. (2016). Revisiting the climate impacts of cool roofs around the globe using an Earth system model. *Environmental Research Letters* 11(8), 084014. https://doi.org/10.1088/1748-9326/11/8/084014.

Zhao, L., Oleson, K., Bou-Zeid, E., Krayenhoff, E.S., Bray, A., Zhu, Q. *et al.* (2021). Global multi-model projections of local urban climates. *Nature Climate Change* 11, 152-157. https://doi.org/10.1038/s41558-020-00958-8.

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