ESMAP

Global Platform for Sustainable Cities

Knowledge Series 031/20

# PRIMER FOR COOL CITIES: REDUCING EXCESSIVE URBAN HEAT

## WITH A FOCUS ON PASSIVE MEASURES

KIGALI
COOLING EFFICIENCY PROGRAM

The International Bank for Reconstruction
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# ABBREVIATIONS

| | |
|---|---|
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| BEE | Indian Bureau of Energy Efficiency |
| BREEAM | Building Research Establishment Environmental Assessment Method |
| °C | Celsius |
| $CO_2$ | Carbon dioxide |
| DESA | United Nations Department of Economic and Social Affairs |
| EERE | United States Office of Energy Efficiency and Renewable Energy |
| EPA | United States Environmental Protection Agency |
| EPM | Medellin, Colombia, municipal utility |
| ESMAP | Energy Sector Management Assistance Program |
| FAO | United Nations Food and Agriculture Organization |
| $PM_{2.5}$ | Fine particulate matter |
| GHG | Greenhouse gas |
| GPSC | Global Platform for Sustainable Cities |
| GSA | United States General Services Administration |
| HFC | Hydrofluorocarbon |
| Hg | Mercury |
| IEA | International Energy Agency |
| ICT | Information and communication technologies |
| IPPC | Intergovernmental Panel on Climate Change |
| km | Kilometer |
| kWh | Kilowatt hour |
| LBNL | Lawrence Berkeley National Laboratory |
| LEED | Leadership in Energy and Environmental Design |
| LUSH | Landscaping for Urban Spaces and High-Rises |
| MEPS | Minimum energy performance standards |
| NDCs | Nationally determined contributions |
| NRDC | National Resources Defense Council |
| $m^2$ | Square meter |
| MW | Megawatt |
| MWh | Megawatt hour |
| NOx | Nitrogen oxides |
| NYC | New York City |
| ODS | Ozone-depleting substances |
| PV | Photovoltaic |
| RFI | Request for information |
| SANEDI | South African National Energy Development Institute |
| SDG | Sustainable development goal |
| SECO | Swiss State Secretariat of Economic Affairs |
| SE4All | United Nations Sustainable Energy for All |
| $SO_2$ | Sulfur dioxide |
| TMG | Tokyo Municipal Government |
| UDZ | Urban development zones |
| UHI | Urban Heat Island |
| UNEP | United Nations Environment Program |
| UTIA | University of Tennessee Institute for Agriculture |
| WHO | World Health Organization |
| ZAMG | Austrian Central Institute for Meteorology and Geodynamics |

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# EXECUTIVE SUMMARY

## WHY COOL CITIES?

Cities are getting hotter as a result of growing urbanization and global climate change. The negative impacts of temperature increases are significant and touch nearly every aspect of urban life. Protecting populations from extreme heat is one of the key resiliency and sustainability challenges of the twenty-first century. Successfully implementing measures to cool cities will lead to many benefits, including for health, well-being, productivity, air quality, and energy systems.

Urban cooling solutions can be deployed in the short term to help mitigate the risk of rising urban air temperatures. This primer and its Annex, *Cool City Case Studies: Reducing Urban Heat,* provide practical, actionable guidance and examples for implementers, policy makers, and planners tasked with mitigating urban heat impacts. The report covers:

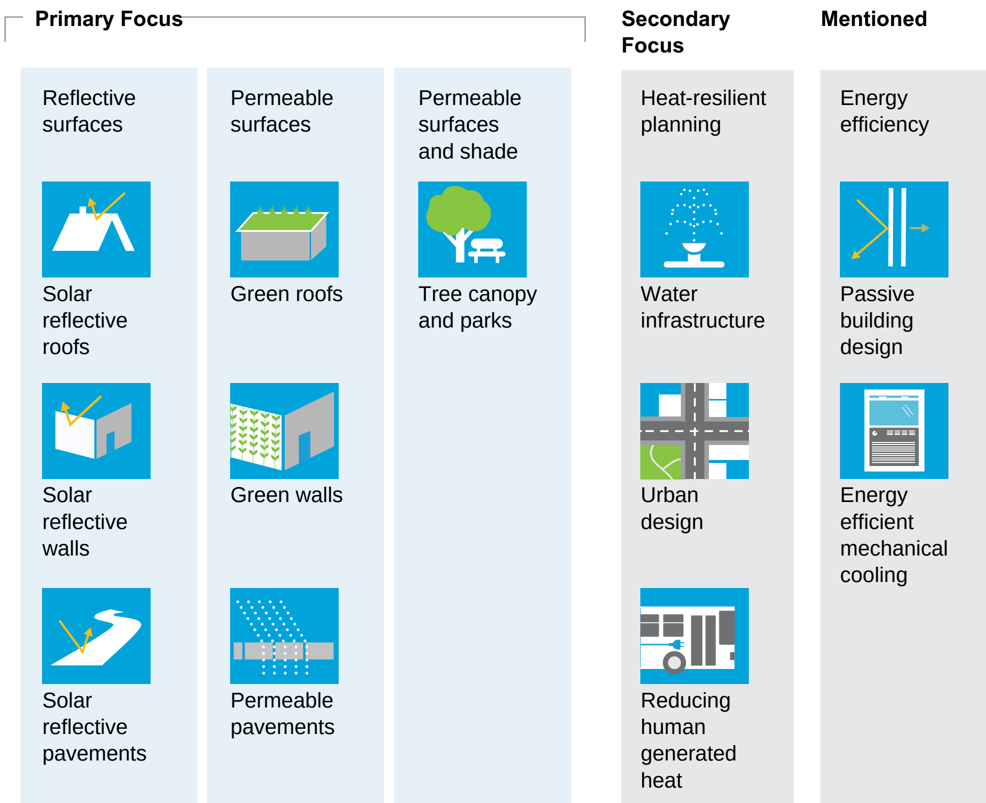
- the challenges of rising temperatures for cities, and for urban design more broadly
- actions and solutions that can be deployed at the building, community, and city levels to reduce excess heat and promote thermal comfort
- the benefits of an integrated deployment of urban cooling solutions at scale
- a framework for an inclusive process to develop urban cooling strategies
- the benefits of heat action plans to protect residents from periods of extreme temperatures
- examples, results, and recommendations from urban cooling policies and actions implemented around the world.

### Solutions Exist to Help Cities Address Rising Temperatures

Just as rising heat creates substantial and varied challenges to urban life, there are broad societal benefits that accrue from adopting measures to cool down urban temperatures. Cooler cities result in positive impacts on human health, air quality, productivity, student learning, tourism, public safety, energy use and expenditures, and quality of life. Cities can address rising air temperatures by adopting a mix of urban cooling solutions covered in detail in Section 3 of the primer.

There is an urgency to transition away from the technologies, materials, and designs that currently define our cities toward the cooling solutions described in Figure ES-1. The choices cities make when deciding where and how to develop their urban areas and the technologies and materials they employ can be locked in for years (for building infrastructure, for example) and as long as centuries (for urban design and planning).

**FIGURE ES-1: URBAN COOLING SOLUTIONS**




*Source:* Authors.

## Urban Cooling Solutions Can Reduce Indoor and Outdoor Air Temperatures in Cities

Every urban area will experience the effects of excess heat and urban heat islands in a unique way, based on location, the size and shape of the city, building types and construction practices, existing land cover, climate and meteorological conditions, and other factors. The unique conditions will, in turn, lead cities to pursue a unique mix of cooling solutions. For example, a combination of solutions that is highly effective in a temperate, humid climate will not be as effective in a desert (hot and dry) climate.

**Effect on outdoor temperatures:** The body of existing scientific and observational research indicates that adopting an integrated combination of the urban cooling solutions presented in this primer will reduce outdoor air temperatures. Research finds that:

- Average outdoor air temperatures could be reduced by 0.3°C per 0.10 increase in solar reflectivity across a city. Peak outdoor air temperature decreases by up to 0.9°C per each 0.10 increase in solar reflectivity (Santamouris 2014).
- The deployment of green roofs at a city-scale could reduce air temperatures by 0.3°C to 3°C (Santamouris 2014).

- Street tree deployment at scale would have a cooling effect of between 0.4°C and 3°C, with the greatest cooling effect occurring within 30 meters of the tree (McDonald et al. 2016).
- Waste heat from active mechanical cooling (particularly vapor compression technologies) adds between 1°C and 2°C to nighttime air temperatures in cities where mechanical cooling is common (Salamanca et al. 2014). Thus, efforts to improve efficiency and reduce the need to operate mechanical cooling equipment can have a direct effect on urban air temperatures.
- Urban design choices that maximize natural wind flows and minimize trapped heat can help cities stay cooler.[1] For example, an increase in windspeed of 1.5 meters/second was determined to reduce air temperatures in Singapore by 2°C (Erell et al. 2011).

**Effect on indoor air temperatures:** Indoor air temperatures can also be lowered by adopting these urban cooling strategies. A pilot outside of Ahmedabad, India, found that air temperatures inside a small home with a solar reflective metal roof were 2.5°C–3.5°C lower than an identical home with an uncoated metal roof (Sahoo and Mittal 2013). Passive, nonmechanical cooling in buildings (for example, improved natural ventilation and good shading devices combined with a green roof acting as insulation) can deliver thermal comfort while significantly reducing a building's cooling load and waste heat generated by active mechanical cooling. A study in Dubai, United Arab Emirates, which has a subtropical desert climate, found that passive cooling in buildings could reduce energy consumption by up to 23.6 percent (Hanam 2014).

## Synergies and Co-Benefits

As cities evaluate and plan their approaches to urban cooling, it is important to keep in mind how cooling can contribute to many other urban and national goals, such as improved human health, enhanced productivity (especially for outdoor workers), better stormwater management, improved air quality, reduced pressure on the city's electricity system, and lower GHGs emissions. A growing body of analysis supports the importance of cooling for achieving most of the Sustainable Development Goals (Sustainable Energy for All 2019). The beneficial effects of urban passive cooling solutions could also play an important role in helping countries achieve their Nationally Determined Contributions (NDCs) under the Paris Climate Accord.

In addition to contributing to broader policy goals, there are also a number of synergistic relationships between urban passive cooling solutions that further reinforce the need for an integrated cooling strategy. Air temperature reductions occur when strategies are deployed at scale, so a combination of strategies is often needed to change enough of the urban landscape to produce the deployment scale needed for meaningful urban cooling.

## The Economics of Urban Cooling Solutions

Combinations of urban passive cooling solutions (primarily solar reflective and permeable surface solutions) can generate between US$1.50 and US$15.20 in net benefits for each US$1.00 invested, in a study covering 1,692 cities worldwide (Estrada, Botzen, and Tol 2017), although figures vary both by location and by individual use case.

1 Urban design could include, among other examples, wind lanes or building designs that "step back" from sidewalks and roadways to allow heat to be shed more quickly and promote wind flow.

The primer includes detailed information on costs (up-front and ongoing) and benefits of different technical cooling options insofar as available, recognizing that they may be difficult to generalize. As awareness in urban cooling issues has increased in recent years, more experience is being gained and accordingly more documentation of urban cooling economics. However, to date much of this experience has been from cities in the United States and other developed countries and thus may not be fully comparable to developing countries. The primer gives practitioners information on (1) the relative costs between different urban cooling technologies and (2) some efficient market pricing from which to base negotiations on product costs in practitioners' local markets. The relative merits of different approaches may vary with factors that distinguish costs across countries; for example, higher material costs and lower labor costs for paving materials could favor lower-cost options that may need to be replaced more frequently.

## Practical Considerations When Implementing Urban Cooling Solutions

Each urban passive cooling technical solution presents a unique set of benefits, costs, and usage considerations to factor in when planning a city's cooling strategy. As noted above, costs to implement these solutions may differ in different cities due, for example, to differences in material costs, labor costs, the availability of contractors with relevant experience in the measures proposed, and other local circumstances as described in the review of the technical cooling solution. Table ES-1 briefly summarizes the characteristics of the main technical urban cooling solutions covered in Section 3 of the primer.

## Barriers to Urban Cooling

Though the potential benefits of urban cooling strategies are great, a number of substantial barriers have slowed the transformation to cooler cities worldwide. Limited budgets and multiple competing priorities are very common situations that work to impede the uptake of urban cooling in cities. Many of the barriers associated with implementing energy efficiency in buildings are also factors for slow progress in implementing urban cooling. For example, both urban cooling and building energy efficiency face challenges due to differences between who pays for and who benefits from the measures (also referred to as the "principal-agent" or "split-incentive problem). Urban cooling implementation also faces some unique barriers to progress such as:

**No one owns the problem of urban heat:** There is no central authority in cities responsible for policy making, funding, and implementing solutions to address the challenges of heat on urban systems.

**Lack of awareness and availability of urban cooling solutions:** Particularly in developing countries, there remains a lack of information about which urban passive cooling solutions exist, how they perform in a local context, and the potential benefits of adopting them. This is also a challenge for highly efficient active cooling solutions.

**Lack of comprehensive policy guidance or regulatory frameworks:** There is a need to incorporate urban cooling into broader urban design, planning, zoning, regulatory, procurement, and building code evaluation processes.

**Limited financing/incentives for cities and building owners:** To date, there have been insufficient financial resources dedicated to supporting and sustaining municipal cooling efforts from within city and national budgets, or mobilized from the private sector or non-government sources, such as development banks or foundations.

## Establishing an Integrated Approach to Designing Urban Cooling Solutions

Excess urban heat is a uniquely complicated challenge dealt with by a wide array of city agencies, departments, private sector actors, the public, research institutions, and other stakeholders. Policy makers and practitioners should consider several overarching questions when planning and taking action on urban heat, including the following:

- How can cities help individuals and households adapt to higher temperatures and provide a livable and resilient urban environment?
- What are the technical and policy solutions available to cities to help mitigate urban heat?
- How do cities manage the negative side effects of individual cooling actions (such as temperature increases from waste heat generated by mechanical cooling and vehicles)?
- How do cities catalyze and organize collective action?

Table ES-2 proposes a framework for an inclusive, integrated approach to help cities develop locally appropriate cooling strategies to address these core questions. This framework seeks to inform efforts to understand and characterize the local challenges of heat, identify existing activities and policies that support or hinder progress toward urban cooling, identify data needed to make informed decisions, engage relevant stakeholders, and evaluate policy options.

Going through Table ES-3 leads to a checklist of deeper questions to be considered and helpful information to gather when using the framework that is covered in Section 5 of the primer. Cities will need to work closely with stakeholders to gather key information and resources necessary for policy responses. This work will help inform cities' decisions on their cooling strategy and the specific cooling measures to pursue.

In addition to proposing a process to address the unique nature of designing a locally effective urban cooling strategy, Section 6 of the primer includes a suite of over 20 specific policies and programs that cities could consider implementing as part of their strategy. These policies are presented as part of a menu of options that have been pursued by various cities, some of which are described in Table ES-3. The actions and measures are grouped into four categories.

1. **Awareness raising** activities engage and inform the public and other stakeholders about urban heat mitigation and how to take action.
2. **Leading by example** activities can be implemented by city governments on assets, processes, and spaces over which they have direct control.
3. **Incentives** encourage the adoption of urban cooling measures, passive design, and building energy efficiency in both the public and private sector and may be either financial or nonfinancial in nature.
4. **Mandatory activities** are requirements (e.g., codes or regulations) enforced by government to compel implementation of urban cooling strategies.

## TABLE ES-1: URBAN COOLING STRATEGY SUMMARY

| SMART SURFACE STRATEGY | WHERE TO USE | BENEFITS SUMMARY |
|---|---|---|
| **Cool roofs** | • Globally applicable, with most benefits accruing in warmer climates<br>• Highest efficiency gains in single story structures with high roof to wall area ratio | • Net energy savings<br>• Improved indoor comfort<br>• Air temperature reductions (at scale*)<br>• Cancels warming effect of atmospheric GHGs<br>• Does not interfere with occupants' use of the roof (e.g., sleeping space)<br>• Compatible with rooftop solar PV installations. |
| **Cool walls** | • Globally applicable with additional evaluation when applied to buildings that are close together and unshaded<br>• More benefit on buildings with low roof to wall area and wall to window area ratios | • Net energy savings<br>• Improved indoor comfort<br>• Air temperature reductions (at scale*) |
| **Cool pavements** | • Location-specific, with a focus on low-traffic and pedestrian areas<br>• Highest thermal comfort benefit when applied to urban paved surfaces | • Net energy savings<br>• Air temperature reductions (at scale*)<br>• Improved pavement life<br>• Reduced outdoor lighting needs/improved nighttime visibility<br>• Cancels warming effect of atmospheric GHGs |
| **Green roofs** | • Primarily applicable in areas with sufficient precipitation to support vegetation, on structures with sufficient support to bear the weight, and in areas where stormwater mitigation is a priority | • Net energy savings<br>• Improved indoor comfort<br>• Air temperature reductions (at scale*)<br>• Extended roof life<br>• Better stormwater management<br>• Improved biodiversity and habitats<br>• Potential for urban agriculture<br>• Tends to increase property values<br>• Compatible with solar PV installation |
| **Green walls** | • Similar to green roofs | • Net energy savings<br>• Improved indoor comfort<br>• Air temperature reductions (at scale*)<br>• Aesthetic value |
| **Permeable pavement** | • Lower traffic areas such as parking lots, alleys, or curb lanes | • Better stormwater management<br>• Cooler surface tempertures<br>• Local cooling (if moisture is present)<br>• Reduced traffic noise<br>• Reduced ponding/surface water on roadways |
| **Tree canopy and parks** | • Globally applicable where adequate water is available and appropriate local species that are suited to future climate conditions | • Energy savings (when properly positioned)<br>• Improved indoor comfort (if shading buildings)<br>• Air temperature reductions (at scale*)<br>• Improved air quality<br>• Improved thermal comfort for pedestrians<br>• Improved biodiversity and habitats<br>• Aesthetic and recreational value |

*Source:* Authors.
**When solution is deployed at a neighborhood scale or broader.*

| CONSIDERATIONS FOR USE (SIGNIFICANCE) | ECONOMICS |
|---|---|
| • Net energy savings reduced by increased heating energy requirements in very cold climates (minor effect)<br>• Loss of some surface reflectivity over time (minor effect)<br>• Potential for moisture buildup in certain types of retrofits in cold climates (minor effect) | • Cool roofs generate a net economic benefit from their energy savings alone in all but the coldest climates. First costs for cool roofs are comparable to a dark option on flat roofs, and the cost premium for cool colored steep slope roofing options is narrowing rapidly. |
| • Potential for increased reflected solar energy onto buildings and people in close proximity. (minor effect)<br>• Since walls are highly visible, aesthetic value may be an issue. (minor effect)<br>• Evaluations of the effects of cool walls should be undertaken when deploying in dense areas (medium) | • Choosing lighter colored coatings will be cost neutral to dark color options. Cool colored options have some cost premiums over traditional dark options. |
| • The effect of cool pavements on energy consumption and thermal comfort is site specific. Depending on vintage, quality, window to wall ratios and proximity to the cool pavements, buildings may experience higher cooling energy demands due to reflected sunlight. Buildings may also experience reduced energy demands due to increased daylighting (medium effect)<br>• Lifecycle GHG effects should be evaluated on a product by product basis (medium effect)<br>• Shade reduces the heat mitigation effect of cool pavements (minor effect)<br>• Potential for reduced pedestrian thermal comfort when walking/working on surface for a lengthy period (minor effect) | • Cool pavements still have a medium to high cost premium over an untreated surface. The market for cool pavement products is nascent, with market demand not yet sufficient to achieve large economies of scale. |
| • Buildings must have sufficient structure to support weight (medium effect)<br>• Water requirements, particularly during establishment period, heat events, or droughts (medium effect)<br>• Negative effects on thermal comfort from increases in humidity (minor effect)<br>• Selection of appropriate plant types is important to roof performance and maintenance requirements (medium effect) | • Green roofs tend to have a moderate cost premium over other roof options. In cases where stormwater management is highly valued, green roofs can have a net economic benefit. Longer roof life of green roofs also improves the cost/benefit calculation. |
| • First cost can be high (medium effect)<br>• Regular maintenance is necessary (medium effect)<br>• Water requirements, particularly during establishment period, heat events, or droughts (medium effect) | • Green exterior walls have a substantial cost premium (first and ongoing) over tradtional exterior walls. |
| • Cooling benefit reduced when pavement is dry (medium effect)<br>• Reduced durability if installation is not done properly (medium/high effect)<br>• Potential to overtax drainage capacity (minor effect with proper design)<br>• Potential to allow unfiltered pollutants into water bodies (minor effect with proper design) | • Permeable pavements have a higher first cost than standard pavements. Regular maintenance is needed to retain permeability and should be included in operating budgets. Capital budgets may also be affected if municipality buys specialty cleaning equipment. |
| • Heat may be slower to shed at night (minor effect)<br>• Selection of noninvasive and climate hardy species (medium/high effect) | • The ecosystem services provided by trees substantially outweigh first and ongoing maintenance costs. |

## TABLE ES-2: A FRAMEWORK FOR DEVELOPING AN URBAN COOLING STRATEGY

| | |
|---|---|
| **Taking stock** | • What is the evidence of urban heat islands in the city? What kind of problem(s) do urban heat islands cause in the city?<br>• How can urban cooling contribute to existing priorities, strategies, and plans?<br>• What existing policies, programs, partnerships, developments, projects, or research would advance cooling efforts? |
| **Gather and analyze data** | • Where do urban heat islands exist in my city?<br>• Where do most vulnerable people live and work?<br>• Are there data on health impacts of urban heat islands?<br>• What data already exist that characterize climate, resource availability, and other unique aspects of my city? What data exist that support action on urban cooling?<br>• Are there already urban cooling measures in place? How are they performing? Is there information on costs and benefits?<br>• Are there other cities with similar characteristics/situations taking action to address urban heat islands? What is their experience? |
| **Stakeholder engagement** | • Which organizations/constituencies should be a part of the policy design process? Which can support the effort directly?<br>• Which groups would serve as effective champions for cooling? What capacity and support do they need to be successful? |
| **Policy development** | • What mix of cooling strategies delivers the most immediate, high-impact results while minimizing negative consequences? What organization, agencies, or other stakeholders are needed to implement these cooling strategies? |

## Financing Urban Cooling Programs and Policies

There are different types of municipal financing mechanisms that can be used for urban cooling efforts. The availability and cost of financing will depend on each municipality's fiscal situation, its ability to borrow, its creditworthiness, local legal and regulatory frameworks, and the type of urban cooling measure considered. For example, municipalities may use public finances such as taxes and intergovernmental transfers, as well as permits or licenses to fund urban cooling measures. A city that has not reached its borrowing limit and has a good credit rating may be able to access commercial financing through the issuance of municipal and/or green bonds. Investments in urban cooling measures that lead to energy cost savings to the municipality, e.g., measures that lead to reduced cooling loads in municipally-operated facilities, will free up municipal financial resources otherwise used to pay the electricity bill and can be used to repay borrowed money for the investments, and continue to generate budgetary savings over a longer period. One innovative way of attracting private capital being promoted by the World Bank Group is an "impact bond," an innovative performance-based contract between an investor, an outcome funder, and a provider of social or environmental services like 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

## TABLE ES-3: MEASURES AND ACTIONS TO REDUCE EXCESS HEAT IN CITIES

| CATEGORY | POLICIES & PROGRAMS | EXAMPLE CITIES/COUNTRIES |
|---|---|---|
| **Awareness raising** | Guidelines, toolkits, design guides, and handbooks | Bogota, New York, Melbourne |
| | Heat health alerts | Seoul, Paris, Athens |
| | Demonstrations in heat vulnerable areas | Nairobi, Pretoria, Hyderabad |
| | Media campaigns | Guadalajara |
| **Leading by example** | Strategic planning | Washington D.C., Singapore |
| | Heat action planning | Ahmedebad |
| | Tree planting and maintenance | Singapore |
| | Park development | Seoul |
| | Heat-sensitive urban planning | Tokyo, Singapore |
| | Municipal government procurement specifications | Los Angeles, Toronto |
| | Enhanced public transportation access policy | Medellin |
| | Vehicle fleet electrification | Shenzhen |
| **Incentives** | Cool roof rebates | Austin, Athens, Toronto |
| | Property tax reductions* | France, Mexico City, Portugal |
| | Tree giveaways | Durban |
| | Increased floor area ratios for green space provision | Seattle |
| | Fast tracking for permit approvals | Chicago, New York |
| | Planning fee waiver | Austin |
| | Stormwater fee discounts | Philadelphia |
| **Mandatory** | Stormwater credits | Washington D.C. |
| | Urban cooling/passive design regulations | Los Angeles, Paris, Tokyo, New Delhi, Chicago |
| | Tree ordinances | Melbourne |
| | Vehicle access restrictions | London |

* Indicates an activity that may involve/require regional or national authority.

for success (Global Partnership for Results-Based Approach 2019).[2] Some municipalities may leverage private investments in urban cooling through credit lines or risk guarantees (Global Partnership for Results-Based Approach 2020). 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.[3]

## Recommendations to Cities

Cities can differ greatly from one another in terms of climates, weather patterns, building types, design, development patterns, financial situation, population, density, proximity to water, growth forecasts, and many other factors. As such, even if all cities seeking to mitigate urban heat followed the same cooling strategy framework proposed in Table ES-3, the resulting mix of policies and programs to be implemented would likely vary widely. Table ES-4 highlights case studies included in the primer of real-world examples of these policies in practice. While each city will determine the best mix of policies, measures, and actions given its own circumstances, there are a number of actions that will be broadly applicable to most cities including:

- **Develop a cooling action plan:** Having an overarching cooling action plan (or urban heat mitigation plan) to articulate the rationale for urban cooling, set targets and goals, and establish a means to measure progress can be a helpful way to organize strategies and actions toward cooler cities.
- **Identify heat vulnerable areas and populations:** Knowing where cities are hot and where residents are at greatest risk of heat stress can form the basis for a variety of targeted interventions, including outreach and communication efforts, incentive programs, programs providing enhanced access to cooling, and concentrations of shelters from extreme heat.
- **Demonstrate urban cooling strategies with pilot projects:** Pilot projects serve to test solutions for a broader urban cooling approach, develop local performance data, and raise awareness of urban cooling
- **Engage the public:** Creating an environment where the public plays a meaningful role in the policy development process is essential, especially for poor or marginalized communities where the need for urban cooling is greatest but where trust in government may be low.
- **Lead by example:** Municipal procurement that benefits urban cooling, efficiency, and broader resiliency improvements will help create local markets for these solutions, provide test cases for the general public and the private sector, and build capacity for implementing and evaluating the measures.
- **Make urban cooling measures the standard:** Establish passive design principles (e.g., solar reflective surfaces, vegetated surfaces, natural ventilation, and shade) and energy efficiency in buildings within building energy codes.

2 Some 28 impact bonds are in the implementation and design stages in developing countries. The most popular sectors are health, employment, agriculture, education, and social welfare. For a more detailed explanation and examples, see Global Partnership on Results-Based Approaches (2020).

3 See ESMAP (2018) for a description of categories of municipal financing mechanisms applied to municipal energy efficiency projects. The Basel Agency for Sustainable Energy (2019) discusses financing mechanisms in the public and residential, as well as commercial sectors. Sustainable Energy for All (SEforAll) (2020) reviews the current status and challenges to the many cooling needs that are not being met through commercial products, including heat extremes in urban slums.

- **Consider incentives: Properly designed and well targeted incentives can encourage adoption** of urban cooling measures, passive design, and energy efficiency in both the public and private sector.
- **Expand urban forestry efforts:** Revitalizing urban tree canopy and park space with native species that are appropriate to expected future local climate conditions can provide substantial cooling and other benefits to most locations, although suitability depends on water availability (e.g., they may not be appropriate in desert and highly water constrained climates).
- **Work with other cities and city networks:** Sharing experiences with peers in other cities can (i) help others learn from challenges, (ii) identify innovative approaches to replicate, and (iii) offer opportunities for coordinated activities. Global networks of cities, such as the C40 Cool Cities Network and ICLEI—Local Governments for Sustainability, are already focused on urban cooling issues.

## A Note on the Novel Coronavirus (COVID-19) Pandemic

The primer was being published during the global outbreak of the COVID-19 pandemic, which has taken the world into uncharted territory and disrupted billions of lives. This is particularly important for cities where more than half of the world's population lives, posing unprecedented threats on human health, economic activity, fiscal resources, and nearly every aspect of urban life. The COVID-19 epidemic has presented cities with an added crisis—the possibility of millions of people, including groups particularly vulnerable to both infection and heat—self-isolating in homes they can't keep cool. Cities will, rightly, be focusing on the immediate health impacts of the pandemic and may not have the capacity and bandwidth to consider urban heat in the very short term. This unique situation presents the need to identify options and solutions that could manage the combined risks of extreme heat and COVID-19. In fact, cities are at the forefront of recovery efforts and have an opportunity to consider how to build a more resilient and greener recovery for their cities. The urban cooling solutions outlined in this primer, and their multiple benefits for heath and quality of life, can help make cities more livable for the millions of people that call them home.

## TABLE ES-4: SUMMARY OF CASE STUDIES

| CITY | COOLING SOLUTIONS | RESULTS |
|---|---|---|
| Ahmedabad, India | Cool roofs on 3,000 low-income houses | Houses with the cool roofs experienced indoor temperature reductions of 2–3°C. |
| Shanghai, China | A goal, set in 2014, to add 400,000 $m^2$ of green roofs and walls by 2016 and 2 million $m^2$ by 2020. | Authorities estimate the green roofs can reduce power consumption by 6 million kwh, prevent 920,000 tons of rainfall from entering the sewer system, and absorb 170 tons of air pollutants annually in the city. |
| Hyderabad, India | Cool roof pilots | Indoor air temperatures fell by an average of 2°C in the homes with cool roofs; surface temperature of the cool roofs in the pilot were 15°C lower than surface temperatures of asbestos roofs and 10°C lower than surface temperatures of cement roofs. |
| Guadalajara, Mexico | *Ciudad Fresca*—Cooling program including mapping, awareness raising, and tree planting | The city estimates the environmental value of pollution reductions, reduced runoff, GHG emissions avoided, and improved buildings total approximately US$21 million per year, plus a one-time benefit of nearly US$8 million from carbon storage. |
| Washington, D.C. | Smart roof program for city buildings | At current deployment rates, the Smart Roof program will reduce estimated lifecycle GHG emissions by 20,000 metric tons and save the District US$33 million over 20 years. The use of coatings to restore and extend the life of functioning roofs reduced capital requirements by 75 percent and generated 224 new local jobs. |
| Tokyo, Japan | Cool pavements | Research in 2004 showed that new lightweight green roofs applied to existing buildings could lower the roof surface temperature by 25°C and the temperature on the ceiling of rooms below the roof by 1°C to 3°C even with thermal insulation. |
| Singapore | Consortium of research institutions *Cooling Singapore* developed a road map to reduce the country's temperature and improve thermal comfort | Technical support to track the effect the city-state's integrated cooling efforts have on excess heat and thermal comfort. The initiative produced a map correlating urban form with air temperature and used data collected from 14 weather stations to validate its findings. |
| Paris, France | Four related programs to create pockets of heat resiliency throughout the city—*Cool Islands*, *Cool Pathways*, *Urban Oases*, and *Extrema* | *Cool Islands*—an initiative to ensure every Parisian is within a 7-minute walk of a "cool island" by 2020. *Urban Oasis*—retrofits schoolyards to demonstrate passive cooling options. *Extrema*—a mobile application to help Parisians stay cool during extreme heat events. |
| Melbourne, Australia | Growing Green Guide adopted in 2014 | Currently 50 green walls, 100 green roofs, and many green façades have been installed. |
| Los Angeles, California | Cool pavements and an integrated approach to implementing passive cooling solutions | The city has undertaken a large, multiyear pilot of cool coatings for urban roadways, in partnership with the private sector. The city is now deploying these technologies, along with water infrastructure and shade, at major public transit hubs. |
| New York | Urban Heat Island Task Force and Cool Neighborhoods NYC | New York convened a multi-stakeholder effort to identify urban heat data needs and to evaluate responses to rising heat in the city. The result was Cool Neighborhoods, a US$100 million commitment to transforming three of its most heat vulnerable neighborhoods. |

# 1. WHY COOL CITIES?

The need to protect populations from extreme heat is one of the key resiliency and sustainability challenges of the twenty-first century. The combined trends of urbanization in developing countries, global climate change, and rapid growth in urban temperatures mean that billions of people need to find ways to access cooling solutions to live and thrive. The negative effects of excess heat on urban systems are significant and impact nearly every aspect of urban life. Successfully implementing measures to cool urban air temperatures will lead to many benefits, including for health, well-being, productivity, air quality, and energy systems.

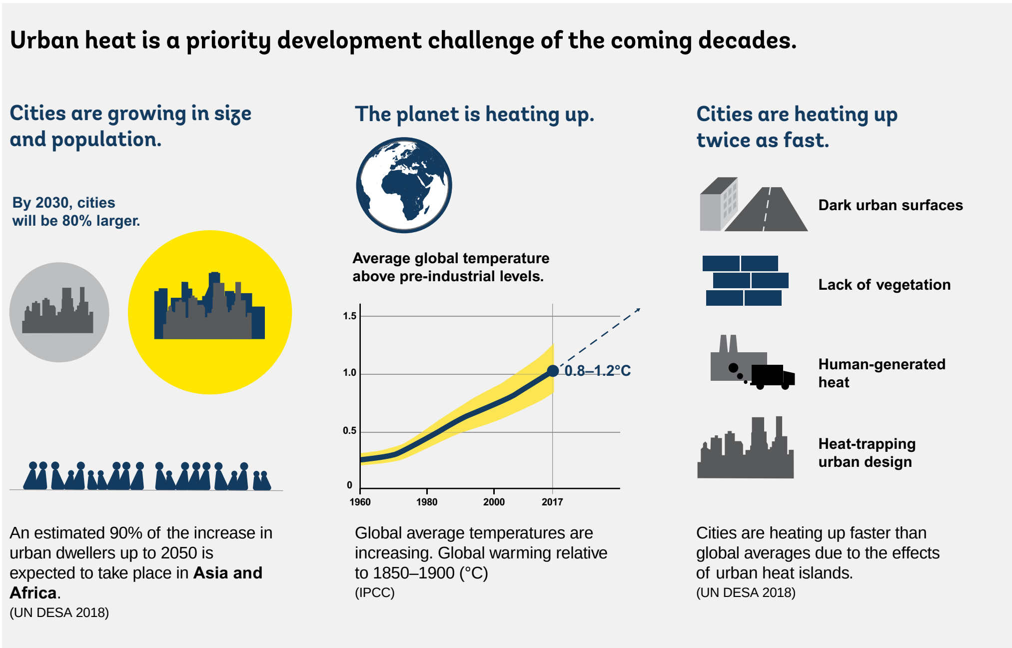
Urban cooling solutions can be deployed in the short term to help mitigate the risk of rising urban air temperatures. This primer provides practical, actionable guidance and examples for implementers, policy makers, and planners tasked with mitigating urban heat impacts. The report covers:

- the challenges of rising temperatures for cities and for urban design more broadly
- actions and solutions that can be deployed at the building, community, and city levels to reduce excess heat and promote thermal comfort
- the benefits of an integrated deployment of urban cooling solutions at scale
- a framework for an inclusive process to develop urban cooling strategies
- the benefits of heat action plans to protect residents from periods of extreme temperatures
- examples, results, and recommendations from urban cooling policies and actions implemented around the world.

This report reviews a wide range of options for reducing urban heat that can be tailored to various city contexts and take into account local specificities, including climate. There is no one-size-fits-all solution. While some cities are already advanced in recognizing the issues, taking stock, and implementing actions, others, particularly in many of the poorest cities with some of the most vulnerable populations, are still at early planning stages. Some elements relevant to all cities include:

- Current and projected future climate, including number of days above different temperature thresholds relevant for public health and labor productivity.
- Existing institutional capacity and resources with a focus on heat management and options for cooling solutions. Often the departments that deal most directly with excess heat, such as sustainability offices, have few resources and wield advisory power only.
- The status of new construction practices and consideration of cooling needs, including awareness and practice of passive design.
- Measures that require public financing and/or implementation, versus those that can be achieved through regulation and investment by private parties.
- The share of population in urban slums with the greatest vulnerability to extreme temperatures.
- Legal and budgetary authority for regulations and investments required for urban cooling solutions.

FIGURE 1: TRENDS DRIVING INCREASED TEMPERATURES AND EXPOSURE TO HEAT




*Source:* Authors.

Three trends, highlighted in Figure 1, combine to make excess urban heat one of the priority development challenges of the next several decades:

1. **Cities are growing rapidly in physical size and population:** Urban migration trends will result in two out of every three people living in an urbanized area by 2050, up from one in two today (UNDESA 2018). An estimated 90 percent of that increase in urban dwellers is expected to take place in developing countries in Asia and Africa. Assuming current trends continue, urban areas will increase in size by 80 percent between 2018 and 2030 (Mahendra and Seto 2019). Rapid urbanization is happening in populous countries with warm climates such as India, Pakistan, and Nigeria. Their cities are growing and experiencing dramatic land-use changes; vegetated areas are being replaced by large, impermeable pavement; high-rise buildings are being constructed that block wind flows; and dark, heat-trapping materials are being used in construction.

2. **Global average temperatures are increasing:** The Intergovernmental Panel on Climate Change (IPCC) found that global average temperatures[4] were between 0.8–1.2°C above preindustrial levels in 2017, with increases of 0.2°C per decade. For most of human history, humans have lived in climates characterized by mean annual temperatures of 11–15°C. By 2070, one out of every three people worldwide will live in far hotter conditions, with mean annual temperatures of more than 29°C. These conditions currently exist in under 1 percent of the Earth today (Xu et al. 2020).

4 Combined air and sea-surface temperatures.

3. **Cities are already hotter than rural areas and heating up at twice the global average rate due to urban heat island effects:**[5] Cities tend to be hotter than surrounding rural areas because they absorb more solar radiation,[6] have less vegetation, release built-up heat more slowly, and generate more waste heat from vehicles and mechanical (or active)[7] cooling. These factors contribute to a phenomenon called the "urban heat island (UHI)" wherein the annual mean air temperature of a city with 1 million people or more can be 1–3°C warmer than its surroundings. On a clear, calm night, however, the temperature difference can be as much as 12°C (Oke 1997). The urbanization and development trends described above exacerbate the effects and have led urban areas to heat up at twice the global average rate (McCarthy, Best, and Betts 2010). The world's largest cities are forecasted to see additional warming of over 2°C by 2050. Medium-sized cities will experience nearly 1°C of additional warming. One study of 1,692 cities found that 20 percent of the cities studied would experience temperature increases of 4°C by 2050 and 7°C by 2100 (Estrada, Botzen, and Tol 2017).

5 The observation that cities are hotter than surrounding rural areas was first recorded in scientific literature as early as the 1800s.
6 Solar radiation and sunlight are used interchangeably in this report.
7 Mechanical cooling refers to meeting the cooling load through a mechanical system such as air-conditioning. This report distinguishes between mechanical cooling via vapor compression systems and non-refrigerant–based technologies such as fans and swamp coolers. The former set of technologies tends to produce more waste heat than the latter.

Credit: Baloncici. Purchased from Shutterstock. https://www.shutterstock.com/image-photo/cairo-egypt-februar-25-traffic-jam-70086049

# 2. EFFECTS OF EXCESS HEAT ON CITIES

Rising urban temperatures have serious negative implications for nearly every aspect of urban life. This section captures some of the main negative effects of excess heat including on:

- human health
- resiliency of health, transportation, and energy systems
- air and water quality
- energy use and peak electricity demand
- crime
- social equity and justice
- economic productivity and prosperity.

## 2.1 HEALTH

### 2.1.1 Heat Mortality

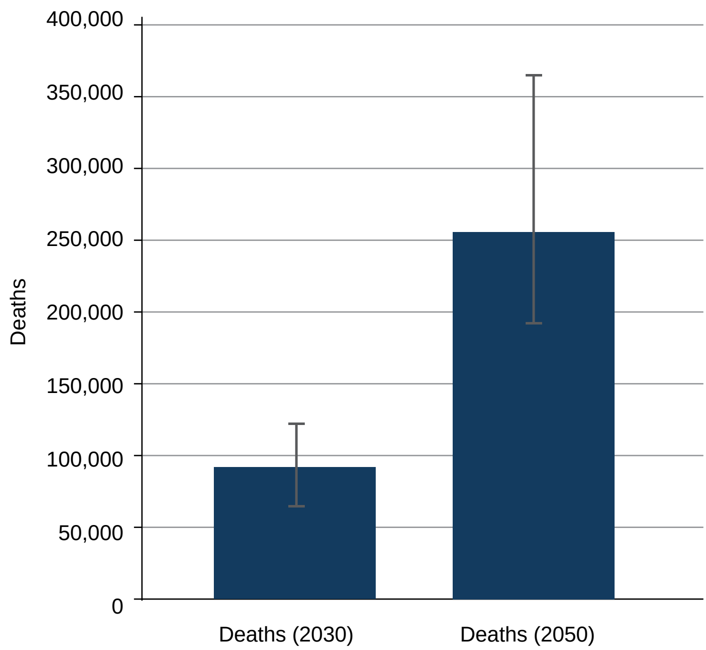
In an average year, heat is the world's deadliest natural disaster, but its effects are often not as visible as the physical destruction of typhoons, tornadoes, or other disasters. Heat mortality is expected to dramatically worsen in the coming decades. The World Health Organization estimates that annual heat-related deaths will rise from 100,000 in 2030 to 250,000 by 2050 (Figure 2) as extreme heat events grow in frequency, duration, and intensity (The World Health Organization 2018).

### 2.1.2 Heat-Related Illnesses

Heat stress starts to occur when the human body reaches a temperature above 38°C (or 1°C above its normal temperature of 37°C) (Steffan, Hughes, and Perkins 2014). Heat stress on humans (and animals) is a combination of extended exposure to high air temperatures, direct and indirect solar radiation on the body, wind speed, and humidity. High levels of humidity raise the "apparent" temperature—the temperature the body actually experiences—and thus further worsens the impact of heat.

Exposure to these conditions can result in dehydration, heat exhaustion, heat stroke, and other direct heat-related medical emergencies. Excess heat conditions, along with poor air quality, also exacerbate a

**FIGURE 2: HEAT-RELATED DEATHS PER YEAR, ASSUMING NO ADAPTATION**




*Source:* The World Health Organization (2018), "Health and Sustainable Development: Air Pollution." http://www.who.int/sustainable-development/cities/health-risks/air-pollution/en/

number of common health conditions caused by diseases of the heart, lungs, and kidneys, and diabetes (Perera et al. 2012). Sensitive populations, such as children, the elderly, and those with existing health conditions, are at particular risk from excess heat (United States Environmental Protection Agency 2008). Uncooled indoor environments are often even hotter and more oppressive than outdoor environments in warm climates. A study found that ambient indoor temperatures above a threshold temperature of 27°C lead to increased mental stress and difficulty sleeping (van Ralte et al. 2012). These stressors have far-ranging effects on urban populations. For example, studies find that an increased frequency of heat waves also reduces student performance (Goodman et al. 2018).

### 2.1.3 Emergency Room Visits

Extreme heat events, particularly those that last multiple days, tend to increase the number of people treated in emergency rooms (Zhang, Chen, and Begley 2015; Josseran et al. 2009; Sun et al. 2014). The increase in emergency room visits due to heat varies by illness, with visits due to complications from renal diseases showing the most sensitivity. Some studies also found an increase in emergency room admissions during heat waves for dysentery and other gastrointestinal ailments (Zhang, Bi, and Hiller 2008).

## 2.2 AIR QUALITY

Energy demand for cooling is increasing rapidly to meet the thermal comfort needs of warming cities. Supplying that demand will lead to greater volumes of pollutants emitted from power plants, as fossil-fuel power plants generate the largest share of electricity supply globally, including in many developing countries. Air pollutants emitted from power plants contribute to global warming and ground-level ozone (smog), and may include sulfur dioxide ($SO^2$), nitrogen oxides (NOx), carbon monoxide, carbon dioxide ($CO_2$), fine particulate matter ($PM_{2.5}$), and mercury (Hg). Fossil fuel–based power plants that are located near urban areas will have a larger effect on urban air quality than those located in rural locations.

Smog is a major air quality concern that significantly contributes to respiratory illness in cities.[8] Smog increases as temperatures rise (Burrows 2016). Currently, over 1 million deaths per year are attributed to extended exposure to ozone pollution, the majority of which occurs in India and China (Malley et al. 2017). While air quality improvement efforts have traditionally focused on reducing the emission of the precursor chemicals that lead to the formation of smog, lowering urban air temperatures could also play an important role. There is a clear and positive relationship between high air temperatures and smog formation; therefore urban cooling strategies that lower air temperatures on warm days can help reduce the formation of smog (Kenwood 2014). Similarly, as cooling units (e.g., room air conditioners) exhaust heat and raise urban temperatures, measures that reduce the need for air-conditioning via ambient cooling or energy efficiency will contribute to lower heat-related air pollution. Airborne $PM_{2.5}$ is another major health challenge. A review of the literature from the last 30 years on the health effects of $PM_{2.5}$ finds that the particles have a “consistent and significant” effect on human health, most prominently through their link to cardiovascular disease, that results in a “large global public health burden” (Anderson, Thundiyil, and Stolbach 2012).

## 2.3 WATER QUALITY

Hard, dark urban surfaces degrade water quality, mainly with thermal pollution. One study covering the central United States found that the temperature of stormwater runoff from urban areas was as high as 35°C, posing risks to warmwater plants and animals (Zeiger and Hubbart 2015). Researchers found that stormwater entering urban waterways during the summer was hotter than allowable water emissions from water-cooled power plants in the United States. Heat is considered a pollutant of concern by the U.S. Environmental Protection Agency due its negative effect on flora and fauna in urban waterways. In addition to heat pollution, urban land choices that exacerbate heat also have a negative effect on water quality. Substituting natural land cover for impermeable surfaces reduces the ability of the city to filter pollutants from stormwater runoff before they reach waterways.

8 Air-conditioning units that leak refrigerant containing ozone-depleting substances (ODS) and hydrofluorocarbons (HFCs) will have an additional negative effect.

## 2.4 ENERGY DEMAND

Rising temperatures, and trends of global economic growth, are leading to an increase in the use of active mechanical cooling (e.g., air-conditioning) that is expected to result in a significant increase, perhaps as much as 58 percent, in energy demand by 2050 (van Ruijiven, Cian, and Wing 2019). On average, Indian cities demand 11 percent more electricity when temperatures rise between 21–24°C. Delhi experiences a 30 percent increase in electricity above 30°C (Harish, Singh, and Tongia 2020). A study of several U.S. cities found that an urban heat island effect was responsible for a 5–10 percent increase in energy demand (Akbari 2005). These increases in demand may have a substantial economic impact. London's urban heat island and rising temperature trends may result in a 30 percent increase in the cost to cool the city by 2050 (Kolokotroni 2012).

In developing countries, there is a growing lower-middle-income population (estimated at 2.2 billion people) that is on the brink of purchasing room air conditioners—often the least efficient and cheapest models available. Globally, the number of room air conditioners is projected to more than triple by 2050 (Campbell, Kolanki, and Sachar 2018). Developing countries will see their demand for room air conditioners increase five-fold. While providing critical thermal comfort indoors, the use of air conditioners increases electricity demand, generates greenhouse gas (GHG) emissions that contribute to climate change, and generates waste heat that has the perverse effect of raising urban air temperatures, exacerbating the impact of heat on cities' most vulnerable populations (including outdoor workers).

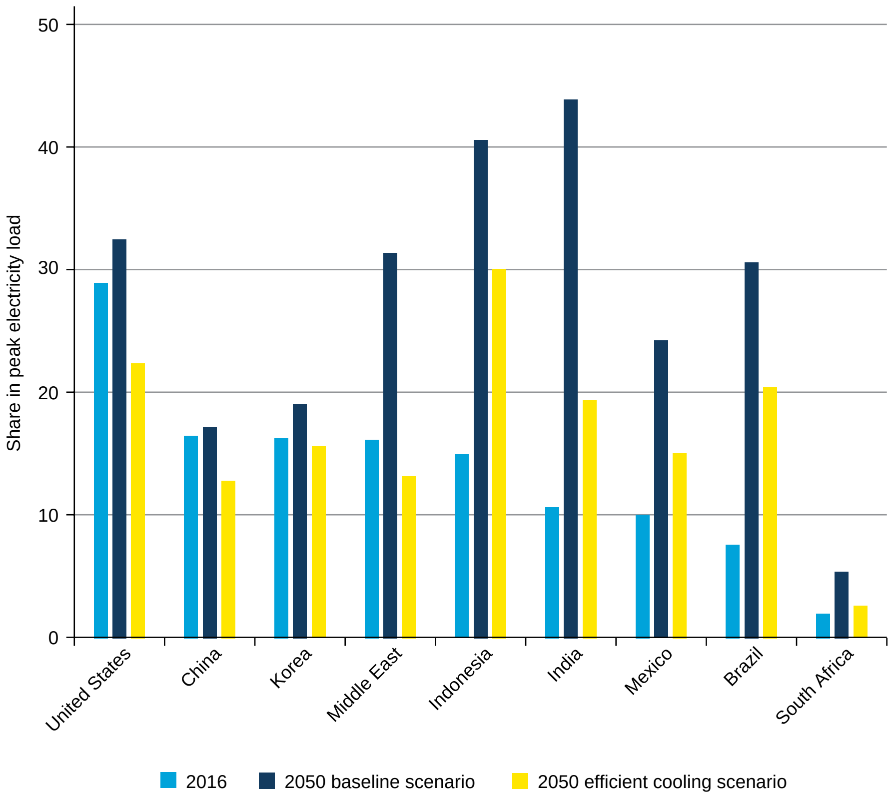
### 2.4.1 Peak Energy Demand

During extreme heat events, excess demand for space cooling can overload electricity supply systems and cause power outages (Añel et al.; United States Environmental Protection Agency 2008). Every 0.6°C of an air temperature increase is associated with a 0.25–2.5 percent increase in peak electricity demand (Santamouris 2014). Demand for electricity tends to peak during the day in business areas and during the evening hours in residential areas. In most temperate and warm regions, electricity demand peaks during the summer months when households and businesses run their space-cooling units. Average daily demand for electricity in the summer typically rises in the early afternoon and peaks in the late afternoon or evening. Peak demand is more sensitive to rising temperatures than average demand. Rising heat is increasing the amount of peak power demanded, the frequency of days where peak power is needed to meet cooling demand, and the length of time a region remains in a period of peak demand (Auffhammer, Baylis, and Hausman 2017).

### 2.4.2 Energy System Resiliency

As excess urban heat increases in the coming decades, electricity demand in cities will grow and affect electricity costs and system efficiency. Figure 3 shows that by 2050, cooling will make up over 40 percent of peak load in developing economies like India and Indonesia (International Energy Agency 2018). Moreover, transmission and distribution systems are less efficient when air temperatures are high. As metal electrical resistance increases, electric flow decreases due to lower hanging transmission lines and other factors.

FIGURE 3: CONTRIBUTION OF SPACE COOLING TO PEAK ELECTRICITY DEMAND




*Source:* International Energy Agency (2018), "The Future of Cooling," https://www.iea.org/reports/the-future-of-cooling

## 2.5 ECONOMY AND PRODUCTIVITY

The negative effects of excess heat described above have substantial implications for urban economies. Table 1 illustrates how excess urban heat increases the cost of active mechanical cooling, just one economic effect of heat, by hundreds of millions of dollars annually per city. A study of 1,692 cities worldwide finds that the effects of excess urban heat and local climate change will reduce economic output of the median city by 5.6 percent by 2100 and by up to 11 percent in the worst-affected cities (Estrada et al. 2017). Other studies examine the negative economic effects of heat, including reduced productivity, power outages, and transport disruptions (Zander et al. 2013). Financial losses from a 2009 heatwave in southeast Australia were estimated to be US$521 million, largely from disruptions to the power grid and transportation system (Chhetri et al. 2012). A productivity analysis of manufacturing plants throughout India found that a 1°C increase in air temperatures above a threshold temperature reduced output by 2 percent, a clear, economically significant impact. Heat-related productivity losses were greatest in industrial and manufacturing facilities where the worker value-add was high (Sudarshan and Tewari 2014).

## TABLE 1: TWO COMMON COSTS OF UHI FOR CITIES (ESTIMATED ANNUAL)

| CITY | GDP (billion US$) | EXCESS COST AIR CONDITIONING REPAIR (million US$) | EXCESS COST AIR CONDITIONING OPERATION (million US$) | COST OF BOTH AS % OF GDP |
|---|---|---|---|---|
| Ottawa | 40 | 4 | 6 | 0.02 |
| London | 452 | 174 | 4.1 | 0.04 |
| Dallas–Fort Worth | 268 | 24 | 238 | 0.10 |
| New York | 1133 | 58 | 31 | 0.01 |
| Phoenix | 156 | 60 | 376 | 0.28 |
| Paris | 460 | 100 | 18 | 0.03 |
| Athens | 73 | 50 | 62 | 0.15 |
| Tokyo | 1191 | 720 | 147 | 0.07 |
| Seoul | 218 | 364 | 83 | 0.21 |
| Moscow | 181 | 3 | 2 | 0.003 |
| Delhi | 93 | 29 | 186 | 0.23 |
| Sydney | 172 | 75 | 57 | 0.08 |
| Beijing | 99 | 77 | 89 | 0.17 |
| Shanghai | 139 | 44 | 99 | 0.10 |

*Source:* Miner, M. J., R. A. Taylor, and C. Jones (2017), “Efficiency, economics, and the urban heat island,” *Environment and Urbanization International Institute for Environment and Development* Vol 29(1): 183–194. https://journals.sagepub.com/doi/pdf/10.1177/0956247816655676 (accessed June 9, 2020).

# 2.6 OTHER EFFECTS OF HEAT

## 2.6.1 Transportation Disruptions

Extreme heat can cause asphalt roads to soften and melt, which can lead to dangerous driving conditions similar to ice on roadways, roads that are impassable, or premature pavement failure due to rutting. Heat can also cause rail lines to buckle (Photo 1), which has major implications for public transit and freight transport.

**Photo 1: Rails buckled due to heat**

Source: Railsystem.net.

### 2.6.2 Violence and Crime

Rates of violent crime go up as temperatures rise, primarily because hot weather increases mental stress and the number of people outside. An increase in annual temperatures of 1°C is associated with a 6 percent average increase in homicides (Mares and Moffett 2015). While there may be several factors at play, including more teens and youth who typically account for a disproportionate share of violent crime arrests in many cities being outside during summer months, researchers are able to link heat and violence in low-income neighborhoods. This suggests that heat shocks can exacerbate differences in urban quality of life between neighborhoods through their effect on crime (Heilmann and Kahn 2019). Indeed, the negative effects of extreme temperatures are not equally distributed. Those living in sub-standard housing, without access to cool environments, as well as those with mental illnesses, face the greatest risks. Links between heat and aggressive or violent behavior also have implications for domestic violence, with women and children bearing the brunt of such situations (Cooper 2019; Anderson and DeLisi 2011).

### 2.6.3 Social Equity and Justice

Without exception, the negative effects of heat described above are disproportionately borne by poor and marginalized populations. The effect of rising heat is particularly dire for the 680 million people living in hot, economically impoverished, urban areas who lack access to mechanical cooling and must find other solutions to deliver the thermal comfort needed to live and thrive (Sustainable Energy for All 2019). People living in lower-income and less-vegetated areas have a 5 percent greater chance to die due to heat than those living in wealthier, shadier areas (Schinasi, Benmarnhia, and DeRoos 2017).

Cities in developing countries are growing fast as a result of overall population growth and economic opportunities available in urban areas that may be lacking in rural areas. But this growth is often unplanned, leading to the creation of slums. Slums, where housing is below minimum standards for sanitation and comfort (including thermal comfort), are estimated to house about 40 percent of the world's urban expansion. Areas like these, characterized by low vegetation and substandard building construction can be substantially (up to 11°C) hotter than other parts of the city (Morrison 2019). This urban poor population may not have sufficient income to purchase or run a fan, and many must rely entirely on passive cooling measures (e.g., shade, ventilation, and solar reflective roofs and walls) to survive and thrive.


Credit: hecke61. Purchased from Shutterstock. https://www.shutterstock.com/image-photo/facade-air-conditioning-colombo-10-december-1032667708

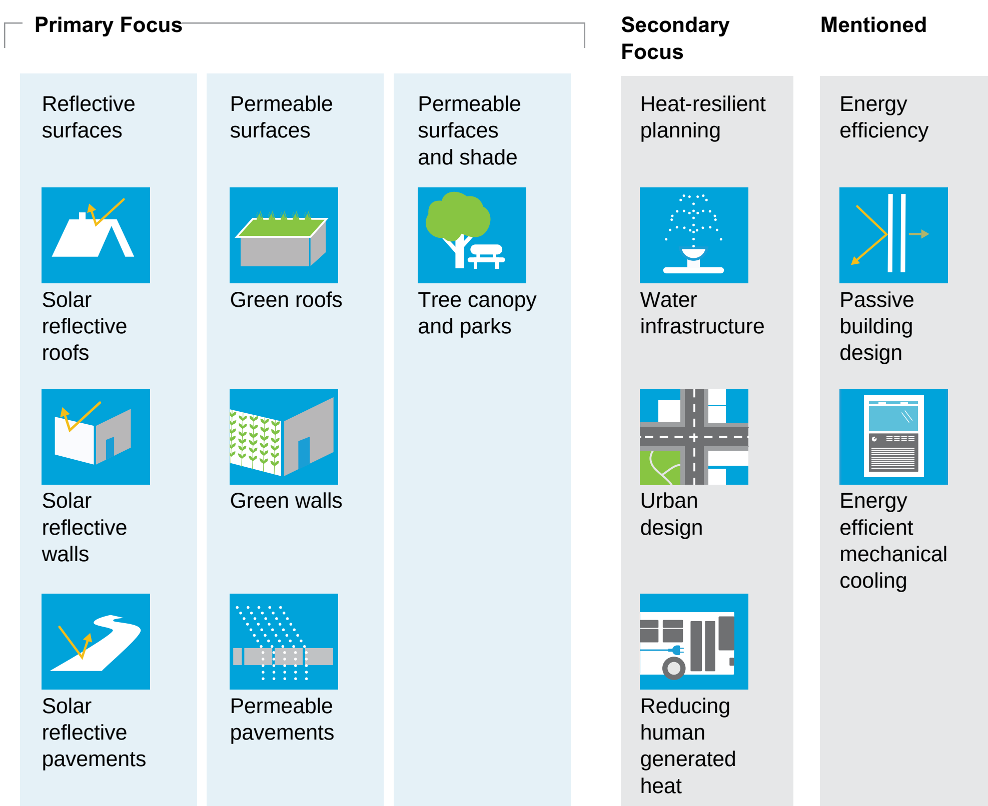
# 3. URBAN COOLING SOLUTIONS

Just as rising heat creates substantial and varied challenges to urban life, there are broad societal benefits that accrue from adopting strategies to cool down urban temperatures. Cooler cities result in positive impacts on human health, air quality, productivity, student learning, tourism, public safety, energy use, energy expenditures, and quality of life. Cities can address rising air temperatures by adopting a package of measures (Figure 4), including:

**Passive, nonmechanical cooling solutions, such as:**

- urban roofs, walls, and pavements that reflect, rather than absorb solar radiation (reflective surfaces)
- expanded vegetated cover and tree canopy (shading, green roofs/walls, and permeable surfaces).

**FIGURE 4: COMMON COOLING SOLUTIONS**




*Source:* Authors.

**Heat-resiliency planning, such as:**

- natural and man-made water features (water infrastructure)
- urban planning that minimizes heat buildup and retention (urban design)
- passive cooling designs for buildings, such as increased thermal insulation (passive building design).

**Energy-efficient cooling solutions, such as:**

- energy-efficient cooling technologies and climate-friendly centralized cooling applications, including district cooling
- fewer polluting vehicles and more public transportation.

This primer primarily focuses on passive, nonmechanical, reflective, permeable, and readily deployable solutions that deliver large cooling benefits to buildings and cities. These solutions include reflective and permeable surfaces, and shading. Some of these solutions have been used in traditional construction and design practices in developing countries but are often now overlooked in favor of more modern building construction relying on cooling technologies.

The primer also touches upon heat resiliency planning measures that are explored in more detail in other World Bank publications (The World Bank 2010; The World Bank 2019) before exploring the important role of energy efficiency in reducing urban heat, a topic examined in greater detail in a complementary ESMAP primer on space cooling (ESMAP 2018).

The primer briefly describes how urban passive cooling and heat resiliency solutions can contribute to cities' efforts to prepare for and respond to extreme heat emergencies. Adding more parks, accessible water infrastructure, and more thermally comfortable buildings offers more areas of respite during heat waves. The complementary aspects of passive cooling and heat emergency preparedness are briefly noted in this primer. More information on responding to heat emergencies is covered in more detail in other resources such as the Red Cross Red Crescent Climate Centre's *Heatwave Guide for Cities* (n.d.).

## 3.1 URBAN PASSIVE COOLING SOLUTIONS

Urban areas will experience excess heat and heat island effects in unique ways depending on location, size, shape, built environment, construction practices, existing land cover, climate and meteorological conditions, and other factors. Cooling solutions should be tailored accordingly. For example, solutions that are highly effective in a temperate, humid climate will not be as effective in a hot and dry desert climate.

**Effect on outdoor temperatures:** A comprehensive review of studies evaluating the effectiveness of urban cooling strategies finds that city-scale solutions meaningfully[9] reduce urban air temperatures (Santamouris 2014). Research finds that:

- Average outdoor air temperatures can be reduced by 0.3°C per 0.10 increase in solar reflectivity (e.g., increasing the number of cool roofs, walls, and pavements) across a city. Peak outdoor air temperature decreases by up to 0.9°C per each 0.10 increase in solar reflectivity (Santamouris

9 The body of existing scientific and observational research allows us to establish an approximate range of temperature impact from each solution.

**BOX 1: THE EFFECT OF SOLAR-REFLECTIVE SURFACES DEPLOYED AT A REGIONAL SCALE: ALMERIA, SPAIN**

Photo 2: Almeria, Spain

Source: Google Earth.

Increasing surface solar reflectance at scale leads to regional air temperature reductions. Almeria, a region in southern Spain and shown in Photo 2, has a unique tradition of white-washing its greenhouses in preparation for summer weather. Almeria has over 27,000 hectares of land area covered by greenhouses, making it one of the largest concentrations of greenhouses in the world. The region reflects substantially more sunlight than neighboring regions that have fewer whitewashed green-houses. A 20-year longitudinal study compar-ing weather-station data in Almeria to similar surrounding climatic regions found that average air temperatures in Almeria have cooled 0.4°C compared to an air temperature increase of 0.3°C in the surrounding regions lacking whitewashed greenhouses (Campra 2011).

2014). Box 1 highlights field research that indicates a reduction in regional air temperatures resulting from the widespread use of highly reflective surfaces.

- The deployment of green roofs at a city-scale can reduce air temperatures by 0.3–3°C (Santamouris 2014).
- Street-tree deployment at scale has a cooling effect of between 0.4–3°C, with the greatest cooling effect occurring within 30 meters of a tree (McDonald et al. 2016).
- Waste heat from active mechanical cooling (particularly vapor compression technologies) adds between 1°C and 2°C to nighttime air temperatures in cities where mechanical cooling is common (Salamanca 2014). Thus, efforts to improve efficiency and reduce the need to operate mechanical cooling equipment can have a direct effect on urban air temperatures.
- Urban design choices that maximize natural wind flows and minimize trapped heat can help cities stay cooler.[10] For example, an increase in windspeed of 1.5 meters per second reduced air tempera-tures in Singapore by 2°C (Erell, Pearlmutter, and Williamson 2011).

**Effects on indoor air temperatures:** Indoor air temperatures can also be lowered by adopting urban cooling strategies. A pilot study outside of Ahmedabad, India, found that air temperatures inside a small home with a solar reflective metal roof were 2.5–3.5°C lower than an identical home with an uncoated metal roof (Sahoo and Mittal 2013). Passive, nonmechanical cooling in buildings (for example, improved natural ventilation, good shading devices, and a green roof for insulation) can deliver thermal comfort while significantly reducing a building's cooling load and the waste heat generated by active mechanical cooling. A study in Dubai, United Arab Emirates, which has a subtropical desert climate, found that pas-sive cooling in buildings could reduce energy consumption by up to 23.6 percent (Hanam 2014).

10 Urban design could include, among other examples, wind lanes or building designs that "step back" from sidewalks and roadways to (i) allow heat to be shed more quickly and (ii) promote wind flow.

## 3.2 BENEFITS OF URBAN COOLING

Just as rising heat creates substantial and varied challenges to urban life, there are broad societal benefits from adopting strategies to cool urban temperatures. These include benefits to:

- **Human health:** Rising average urban surface solar reflectance[11] by 0.10 and vegetated cover by 10 percent results in a 7 percent reduction in mortality during heat events in a study of 4 U.S. cities (Kalkstein et al. 2013). Cooler, more comfortable temperatures promote outdoor activity, social interaction, and enhance quality of life, leading to improved mental health.

- **Air quality:** Urban trees reduce nearby concentrations of $PM_{2.5}$ anywhere from 9–50 percent, with the largest effects within 30 meters of the tree (McDonald et al. 2016). Energy-use reductions from more energy-efficient cooling units and passive design also lower the emission of ozone precursor chemicals.[12] Temperature and ground-ozone formation are positively correlated, meaning that urban passive cooling solutions that reduce air temperatures also reduce hazardous smog.

- **Water quality:** Increased efficiency efforts and deployment of permeable and solar-reflective paving can lower the temperature of stormwater runoff or delay its release into urban waterways until it has cooled. One study found that the water absorbed by trees can reduce direct stormwater runoff by as much as 62 Percent (Armson, Stringer, and Ennos 2013). Green infrastructure may also filter and remove pollutants that would otherwise flow into waterways.

- **Energy use:** Solar reflective roofs can reduce cooling energy demand by between 10–40 percent. In winter, heating penalty may range between 5–10 percent as a function of local climate and building characteristics (Salamanca 2014). Studies have found that green roofs can reduce cooling demand in buildings by 15–39 percent (Spala et al. 2008; Gaffin et al. 2010). Trees that shade buildings and cool the air can deliver energy savings depending on climate. In California, for example, such measures generate an estimated annual energy savings of between 237 kWh and 350 kWh per tree (McPherson and Simpson 2003). A 25 percent increase in tree canopy cover was estimated to reduce cooling energy use by 57 percent in hot, temperate Sacramento, California. In hot, humid Lake Charles, Louisiana, the number was 25 percent compared with 17 percent in hot, dry Phoenix, Arizona (Akbari et al. 2010).

- **Peak energy demand:** Urban cooling strategies are particularly good at reducing summer peak demand because their energy reduction benefits often occur when the sun is strongest, temperatures are highest, and energy demand is the greatest. Cooling strategies such as increased reflectivity for surface roofs and pavements could reduce maximum peak power demand by up to 7 percent (Pomerantz 2018).

The net benefits of urban cooling solutions will depend on climate, building location and orientation, altitude, annual heating load, annual cooling load, peak energy demand, electricity tariffs, occupancy patterns, shading, material availability, market efficiency, urban form, and other factors. While efforts have been made in this publication to provide a range of estimates and effects of different urban cooling strategies, identifying or developing local performance data will be important for making policy decisions.

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11 Solar reflectance refers to the portion of solar energy a surface reflects, rather than absorbs. This concept is explored in greater detail in Section 3.3.

12 As noted earlier, this effect is most pronounced when power plants are located near urban areas and less pronounced when generation assets are further from population centers.

There are a number of factors cities should take into account, including the specific use cases[13] discussed in Sections 3.3–3.7, when designing, tailoring, and prioritizing cooling solutions according to local needs.

Adopting cooling solutions will generate benefits in practically all use cases, including “4-season” climates that experience warm/hot summers and cold winters. The beneficial effects will be most substantially felt in tropical and subtropical climates where many of the rapidly developing country cities are located. Table 2 summarizes the use cases for each strategy and highlights how broadly applicable each of them are.

### 3.2.1 Economic Benefits

Combinations of urban passive cooling solutions, primarily solar reflective and permeable surface solutions, generate between US$1.50 and US$15.20 in net benefits for each US$1.00 invested, according to a study covering 1,692 cities worldwide (Figure 5) (Estrada, Botzen, and Tol 2017). A review of California cities finds that street trees, which were not included in the study referenced above, generate nearly US$6 in benefits (including energy savings, improvements to air quality and stormwater management, and property value increases) for every dollar invested in trees (McPherson, van Doorn, and de Goede 2015). The effect would likely be additive to the results described in (Figure 5), because tree canopy decisions are independent of roof and road choice. The costs (up-front and ongoing) of each urban cooling solution described in this primer range widely, both by location and by individual use case. That said, some of the solutions (such as flat cool roofs) are comparable in costs to traditional options. Other measures, such as green roofs or tree canopy increases, may have higher up-front costs than traditional options. However, those costs are typically more than offset by the direct and social benefits they generate over their lives.

The economics of individual benefits are discussed in more detail in Sections 3.3–3.7. The primer includes detailed information on costs and benefits of options insofar as available. As awareness in urban cooling issues has increased, more experience is being gained and accordingly more details of cooling economics are being documented. To date, however, much of this experience has been from cities in the United States and other developed countries and thus may not be directly comparable for developing countries. The primer gives practitioners valuable information on (1) the relative costs between different urban cooling technologies and (2) efficient market pricing from which to base negotiations on product costs in practitioners’ local markets. The relative merits of different approaches may vary with factors that distinguish costs across countries, e.g., higher material costs and lower labor costs for paving materials could favor options that require more frequent re-application. Up-front costs and higher borrowing costs may also be more important considerations in cash-strapped developing countries; greater emphasis may be needed on short-term returns and less on benefits over the life of an investment.

13 “Use cases” refer to specific situations in which urban cooling solutions could be used and encompass climate, building type, or resource availability characteristics that might affect performance of a specific cooling solution.

## TABLE 2: URBAN COOLING STRATEGY SUMMARY

| SMART SURFACE STRATEGY | WHERE TO USE | BENEFITS SUMMARY |
|---|---|---|
| **Cool roofs** | • Globally applicable, with most benefits accruing in warmer climates<br>• Highest efficiency gains in single story structures with high roof to wall area ratio | • Net energy savings<br>• Improved indoor comfort<br>• Air temperature reductions (at scale*)<br>• Cancels warming effect of atmospheric GHGs<br>• Does not interfere with occupants' use of the roof (e.g., sleeping space)<br>• Compatible with rooftop solar PV installations. |
| **Cool walls** | • Globally applicable with additional evaluation when applied to buildings that are close together and unshaded<br>• More benefit on buildings with low roof to wall area and wall to window area ratios | • Net energy savings<br>• Improved indoor comfort<br>• Air temperature reductions (at scale*) |
| **Cool pavements** | • Location-specific, with a focus on low-traffic and pedestrian areas<br>• Highest thermal comfort benefit when applied to urban paved surfaces | • Net energy savings<br>• Air temperature reductions (at scale*)<br>• Improved pavement life<br>• Reduced outdoor lighting needs/improved nighttime visibility<br>• Cancels warming effect of atmospheric GHGs |
| **Green roofs** | • Primarily applicable in areas with sufficient precipitation to support vegetation, on structures with sufficient support to bear the weight, and in areas where stormwater mitigation is a priority | • Net energy savings<br>• Improved indoor comfort<br>• Air temperature reductions (at scale*)<br>• Extended roof life<br>• Better stormwater management<br>• Improved biodiversity and habitats<br>• Potential for urban agriculture<br>• Tends to increase property values<br>• Compatible with solar PV installation |
| **Green walls** | • Similar to green roofs | • Net energy savings<br>• Improved indoor comfort<br>• Air temperature reductions (at scale*)<br>• Aesthetic value |
| **Permeable pavement** | • Lower traffic areas such as parking lots, alleys, or curb lanes | • Better stormwater management<br>• Cooler surface tempertures<br>• Local cooling (if moisture is present)<br>• Reduced traffic noise<br>• Reduced ponding/surface water on roadways |
| **Tree canopy and parks** | • Globally applicable where adequate water is available and appropriate local species that are suited to future climate conditions | • Energy savings (when properly positioned)<br>• Improved indoor comfort (if shading buildings)<br>• Air temperature reductions (at scale*)<br>• Improved air quality<br>• Improved thermal comfort for pedestrians<br>• Improved biodiversity and habitats<br>• Aesthetic and recreational value |

*Source:* Authors.
**When solution is deployed at a neighborhood scale or broader.*

| CONSIDERATIONS FOR USE (SIGNIFICANCE) | ECONOMICS |
|---|---|
| • Net energy savings reduced by increased heating energy requirements in very cold climates (minor effect)<br>• Loss of some surface reflectivity over time (minor effect)<br>• Potential for moisture buildup in certain types of retrofits in cold climates (minor effect) | • Cool roofs generate a net economic benefit from their energy savings alone in all but the coldest climates. First costs for cool roofs are comparable to a dark option on flat roofs, and the cost premium for cool colored steep slope roofing options is narrowing rapidly. |
| • Potential for increased reflected solar energy onto buildings and people in close proximity. (minor effect)<br>• Since walls are highly visible, aesthetic value may be an issue. (minor effect)<br>• Evaluations of the effects of cool walls should be undertaken when deploying in dense areas (medium) | • Choosing lighter colored coatings will be cost neutral to dark color options. Cool colored options have some cost premiums over traditional dark options. |
| • The effect of cool pavements on energy consumption and thermal comfort is site specific. Depending on vintage, quality, window to wall ratios and proximity to the cool pavements, buildings may experience higher cooling energy demands due to reflected sunlight. Buildings may also experience reduced energy demands due to increased daylighting (medium effect)<br>• Lifecycle GHG effects should be evaluated on a product by product basis (medium effect)<br>• Shade reduces the heat mitigation effect of cool pavements (minor effect)<br>• Potential for reduced pedestrian thermal comfort when walking/working on surface for a lengthy period (minor effect) | • Cool pavements still have a medium to high cost premium over an untreated surface. The market for cool pavement products is nascent, with market demand not yet sufficient to achieve large economies of scale. |
| • Buildings must have sufficient structure to support weight (medium effect)<br>• Water requirements, particularly during establishment period, heat events, or droughts (medium effect)<br>• Negative effects on thermal comfort from increases in humidity (minor effect)<br>• Selection of appropriate plant types is important to roof performance and maintenance requirements (medium effect) | • Green roofs tend to have a moderate cost premium over other roof options. In cases where stormwater management is highly valued, green roofs can have a net economic benefit. Longer roof life of green roofs also improves the cost/benefit calculation. |
| • First cost can be high (medium effect)<br>• Regular maintenance is necessary (medium effect)<br>• Water requirements, particularly during establishment period, heat events, or droughts (medium effect) | • Green exterior walls have a substantial cost premium (first and ongoing) over tradtional exterior walls. |
| • Cooling benefit reduced when pavement is dry (medium effect)<br>• Reduced durability if installation is not done properly (medium/high effect)<br>• Potential to overtax drainage capacity (minor effect with proper design)<br>• Potential to allow unfiltered pollutants into water bodies (minor effect with proper design) | • Permeable pavements have a higher first cost than standard pavements. Regular maintenance is needed to retain permeability and should be included in operating budgets. Capital budgets may also be affected if municipality buys specialty cleaning equipment. |
| • Heat may be slower to shed at night (minor effect)<br>• Selection of noninvasive and climate hardy species (medium/high effect) | • The ecosystem services provided by trees substantially outweigh first and ongoing maintenance costs. |

## FIGURE 5: BENEFIT COST RATIOS FOR FOUR URBAN COOLING SCENARIOS

Scenario: 50% of all roofs and 100% of roads become highly solar reflective

Benefit to cost ratio range
$5.37–$14.50

Scenario: 20% of all roofs and 50% of roads become highly solar reflective

Benefit to cost ratio range
$6.00–$15.20

Scenario: 10% of roofs become green, 25% of roofs become highly solar reflective, 50% of roads become highly solar reflective

Benefit to cost ratio range
$2.35–$6.09

Scenario: 10% of roofs become green, 10% of roofs become highly solar reflective, 20% of roads become highly solar reflective

Benefit to cost ratio range
$1.59–$3.96

- Non-cool surface
- Highly solar reflective surface
- Green roof

*Source:* Developed by GCCA based on Estrada et al. (2017), "A global economic assessment of city policies to reduce climate change impacts," *Journal Nature Climate Change*, https://www.nature.com/articles/nclimate3301

### 3.2.2 Development Benefits

A growing body of analysis supports the importance of cooling for achieving 11 of the 17 Sustainable Development Goals (SEForAll 2018), including a particular benefit for ‘Good Health and Well-Being’ (SDG3), ‘Reduced Inequalities’ (SDG10), ‘Sustainable Cities and Communities’ (SDG11) and ‘Climate Action’ (SDG 13). Moreover, urban passive cooling solutions could help countries achieve their Nationally Determined Contributions (NDCs) under the Paris Climate Accord. The aesthetic and quality-of-life enhancements from trees and vegetation are also important benefits of cooling measures. The Global Platform for Sustainable Cities, led by the World Bank, provides knowledge support to cities that are interested in incorporating cooling options into urban strategy and planning. An integrated approach that balances multiple strategies is key to maximizing urban cooling while minimizing potential unintended consequences.

### Energy Balance Equation

Air temperature and the mechanisms that change it in a particular location are governed by a relatively simple equation for energy balances (Figure 6) (Oke 1982). In a city, energy is generated by solar radiation and waste heat. That energy must go somewhere. It may be stored in building and pavement materials, be blown away by wind, contribute to increases in air temperature, or be used to evaporate water into water vapor. Each of the urban cooling strategies considered in this report affects an element of the equation to reduce urban temperatures.

**FIGURE 6: THE ENERGY BALANCE EQUATION AND ITS IMPLICATIONS FOR HEAT**

| ENERGY INPUTS INTO THE AIR | = | WHAT HAPPENS TO THAT ENERGY |
|---|---|---|
| | | Stored energy |
| + | | + |
| Waste heat from human activity | | Energy carried away by wind |
| | | + |
| | | Energy that heats the air (sensible heat) |

*Source:* Oke, T. R. (1982), “The Energetic Basis of the Urban Heat Island,” *Quarterly Journal of the Royal Meteorological Society,* 1982. 108: pp. 1–24.

## 3.3 REFLECTIVE INFRASTRUCTURE

The concept of creating cooler structures using a surface's ability to reflect sunlight and to efficiently emit absorbed heat dates back to ancient Sumerian and Egyptian construction. Every opaque urban surface (e.g., roofs, walls, pavements) reflects some incoming sunlight and absorbs the rest, turning it into heat. Some of this solar heat contributes to the heat island effect. Reflecting solar radiation into the sky, ideally through the atmosphere and into space, can reduce the amount of solar heat gain in cities. The effectiveness of so-called "cool surfaces" is measured by the fraction of solar radiation reflected versus the fraction absorbed and converted into heat (measured by solar reflectance or SR). The effectiveness of cool surfaces is also measured by how efficiently and quickly heat is shed. A surface absorbing solar radiation becomes hotter and releases some heat by conduction, convection, and radiation (measured by thermal emittance or TE). These concepts are explained in more detail in Figure 7. A cool surface is both highly reflective and highly thermally emissive to minimize the amount of solar radiation converted into heat and to maximize the amount of heat that is lost by the surface. However, solar reflectance is the predominant factor in determining whether a surface is cool. Figure 8 illustrates how sunlight is managed by different colored surfaces and the implications for building and community heat gain. Research undertaken over the last 25 years points to a potential effect associated with reflective infrastructure to facilitate global cooling. This global cooling effect is described in Box 2.

### BOX 2: GLOBAL COOLING: A UNIQUE EFFECT OF INCREASING REFLECTIVE INFRASTRUCTURE

By reducing the electricity needed for air-conditioning, reflective surfaces (roofs, walls, pavements) decrease GHG emissions from power plants and thereby indirectly cool the world. But the larger and more direct cooling benefit of reflective surfaces, described in Table 3, is a product of their most basic properties—they reflect, rather than absorb, most incoming sunlight. So instead of heating up and warming not only the surrounding air but also the atmosphere, reflective surfaces return sunlight back through the atmosphere and out into space, starting from the moment they are installed. A large-scale shift toward reflective surfaces could therefore immediately cool the world by reducing the amount of heat that is transmitted from the earth's surface and trapped in the atmosphere. The use of more reflective surfaces in hot cities around the world could cancel the warming effect of 44–57 billion metric tons of emitted carbon dioxide (Akbari, Menon, and Rosenfeld 2009)—up to 75 percent above current annual global emissions of carbon dioxide (LeQuere et al. 2013).[14] Subsequent long-term modeling of more reflective urban surfaces found a sustained global cooling effect of 0.01–0.07°C (Akbari, Matthews, and Seto 2012). Another study estimated that increasing the reflectance of land surfaces (e.g., by converting to highly reflective roofs only) could offset as much as 30 percent of greenhouse warming and slow climate change (Hamvey 2007).

14 Estimate of 9.5 billion metric tons of carbon emitted (35 billion metric tons of carbon dioxide).

## FIGURE 7: KEY TERMINOLOGY FOR REFLECTIVE INFRASTRUCTURE

### Solar Reflectance (SR or albedo)

The fraction of sunlight (0 to 1, or 0 percent to 100 percent) that is reflected from a surface. SR typically ranges from about 0.04 (or 4 percent) for charcoal to 0.9 (or 90 percent) for fresh snow. High solar reflectance is the most important property of a cool surface.

### Solar Absorptance (SA)

The fraction of sunlight (0 to 1, or 0 percent to 100 percent) that is absorbed by a surface. Surfaces with high solar absorptance tend to get hot in the sun. If the surface is opaque, solar absorptance equals 1 minus solar reflectance.

### Thermal Emittance (TE)

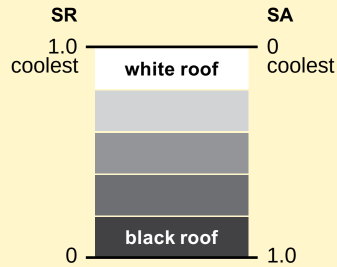
The efficiency (0 to 1) with which a surface emits thermal radiation. High thermal emittance helps a surface cool by radiating heat to its surroundings. Nearly all nonmetallic surfaces have high thermal emittance, usually between 0.80 and 0.95. Uncoated metal has low thermal emittance, which means it will stay warm. An uncoated metal surface that reflects as much sunlight as a white surface will stay warmer in the sun because it emits less thermal radiation. TE is the second most important property of a cool surface.

### Solar Reflective Index (SRI)

A coolness indicator that compares the surface temperature of a roof on a sunny summer afternoon to those of a clean black roof (SRI = 0) and a clean white roof (SRI = 100). SRI is computed from solar reflectance and thermal emittance, and can be less than 0 for an exceptionally hot surface (e.g., a solar collector) or greater than 100 for an exceptionally cool material (e.g., a very bright white roof). An SRI calculator can be found at http://coolcolors.lbl.gov/assets/docs/SRI%20Calculator/SRI-calc10.xls.

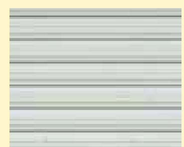
### Thermal Resistance (R-value)

A measure of a material or system's ability to prevent heat from flowing through it. The thermal resistance of a roof can be improved by adding insulation, a radiant barrier, or both.




Solar reflectance (SR) and absorptance (SA) have an inverse relationship. The more heat a surface reflects, the less heat it absorbs.

Uncoated metal
sri = 68
sr = 0.75
te = 0.08
r = low



Coated metal
sri = 92
sr = 0.75
te = 0.83
r = low

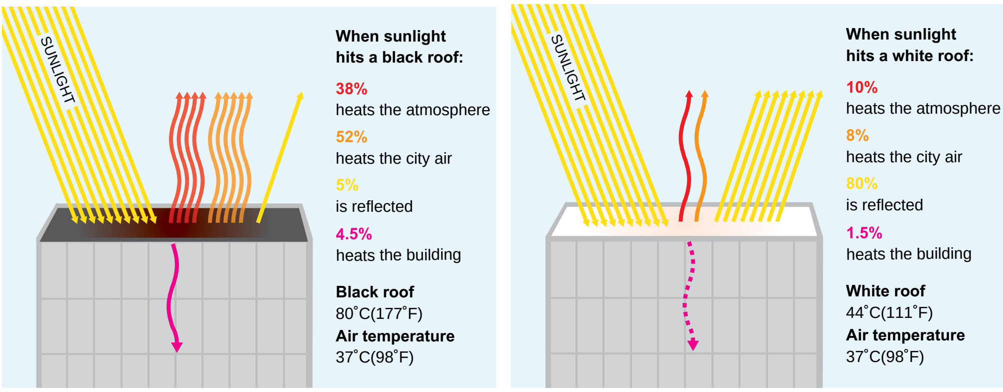
Metal that is painted and coated has a considerably higher thermal emittance than uncoated metal. This raises its SRI to 92, which is much cooler than uncoated metal, whose SRI is 68.

The value in the above examples are estimates. Actual product values may vary. Please consult the Cool Roof Rating Council or a manufacturer for actual values.

*Source:* Global Cool Cities Alliance (2012), "The Cool Roofs and Pavements Toolkit," https://www.coolrooftoolkit.org/wp-content/pdfs/CoolRoofToolkit_Full.pdf

## FIGURE 8: THE EFFECT OF HIGH SOLAR REFLECTIVITY

Comparison of a black and a white flat roof on a summer afternoon with an air temperature of 37˚ Celsius.




*Source:* Global Cool Cities Alliance (2012), "Cool Roofs and Pavements Toolkit," https://www.coolrooftoolkit.org/wp-content/pdfs/CoolRoofToolkit_Full.pdf.
Data for graphic provided by Lawrence Berkeley National Laboratory (LBNL).

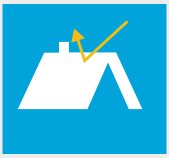
### 3.3.1 Cool Roofs

Roofs typically make up 25–30 percent of an average city's urban surfaces. Roofs may be either steep sloped or nearly flat. There are a wide variety of highly reflective roofing products available today in nearly every roof surface type used worldwide.

Most changes to roof solar reflectance will occur when a new roof or a replacement roof is installed. At these times, it is much easier to design for and choose a cool option. There are also options to use coatings to increase the solar reflectance of an existing, functional roof. Coatings are typically applied to a functional roof to waterproof it or to extend its useful life. Table 4 highlights the coating options currently available and their strengths and weaknesses. The product options in Table 3 are generally ranked in order of their cost (lowest to highest).

Cool surfaces are commonly created by lightening roof color to reflect more solar energy in the visible spectrum (e.g., a white roof rather than a dark roof). However, slightly less than 50 percent of solar energy is contained in the visible spectrum (UTIA n.d.). The vast majority of the remaining solar energy is in the near infrared spectrum that is invisible to the naked eye. Certain pigment technologies known as cool colors take advantage of that fact to allow colored surfaces (i.e., red, green, blue, grey) to be more highly reflective than traditional pigments would allow. Cool colors are most often used on steep-sloped roofs, where the roof is more noticeable and aesthetics are an issue. Cool colored roofing products are available for conventional roofing materials such as tile, asphalt shingle, coatings, and metal.

## TABLE 3: SUMMARY OF COOL ROOF APPLICATIONS, BENEFITS, AND ECONOMICS



**Cooling method:**
Cool roofs cool by reducing the amount of solar energy absorbed by a building's roof.

| | |
|---|---|
| **Applicable use cases** | Cool roofs are globally applicable to all building types, with the most benefits accruing in warmer climates. Highest efficiency gains are in single story structures with a high roof to wall area ratio. |
| **Benefits** | • Net energy savings<br>• Improved indoor thermal comfort<br>• Air temperature reductions (at scale)<br>• Cancels warming effect of atmospheric GHGs already in the atmosphere<br>• Does not interfere with occupants' use of the roof (e.g., sleeping space)<br>• Compatible with rooftop solar PV installations |
| **Considerations (significance of effect)** | • In very cold climates, increased heating energy demand in winter reduces overall net energy savings (minor)<br>• Loss of some surface reflectivity over time (minor)<br>• Potential for moisture buildup in cold climates (minor) |
| **Economics** | Cool roof installations generate a net economic benefit in all but the coldest climates. First costs for new cool flat roofs are approximately comparable to new dark roofs. Some first cost premiums when coating an existing roof. Slight first cost premium for cool steep-sloped roofs. |
| **General recommendation** | Cool roofs should be encouraged/required as part of building and energy codes and prioritized in municipal procurement specifications. |

*Source:* Authors.

### 3.3.1.1 Cool Roof Economic Considerations

Up-front cost premiums will vary, particularly in new markets with fewer product options, but highly reflective roof options are generally cost-competitive with traditional roofs in established markets. The simple economic payback[15] of choosing highly reflective roof options ranges between 0 and 6 years based on building energy-cost savings alone. The labor required to install cool roofs is about the same as for non-cool roofs. Other factors to consider when evaluating cost-effectiveness include changes in expected life of the roof, expected maintenance (i.e., regular roof inspections, repairs, or washing), roof material disposal, and replacement costs. Applying a coating to an otherwise functional roof would have an up-front cost premium (e.g., material and labor costs) but would pay back those costs with energy savings, lengthened roof life, and other benefits. Figure 9 illustrates some of the lifetime costs and benefits to consider when evaluating cool roofing installations.

15 Payback is defined as the amount of time it takes for benefits generated to equal costs incurred.

## TABLE 4: ROOF COATING TYPES AND CHARACTERISTICS

| COATING | STRENGTHS | WEAKNESSES |
|---|---|---|
| Acrylic | • Cost-effective<br>• Good balance of cost to performance<br>• UV resistant<br>• Easy to apply | • Thickness loss with weathering<br>• Applied and cure only above 10°C (day and night temp)<br>• Poor performance in ponding water conditions |
| Elastomeric | • “Rubber” acrylic, but thicker and more flexible<br>• Good for waterproofing | • Long cure in humid conditions<br>• Applied and cure only above 10°C (day and night temperature) |
| Polyurethane (aromatic base, aliphaltic top) | • Stays clean longer than most options<br>• Durable and traffic resistant<br>• Better with ponding water than acrylic | • More expensive than acrylic<br>• Noxious, potentially toxic gassing at application |
| Silicone | • Very durable and long lasting (25+ years)<br>• Good in humid conditions and ponding water<br>• Mold resistant | • Will remain dirty without rain/washing<br>• Cannot recoat over existing silicone<br>• More expensive |

*Source:* Authors.

## FIGURE 9: COOL ROOF LIFE-CYCLE

**Up-front and ongoing costs:**

Materials and labor

Disposal and replacement

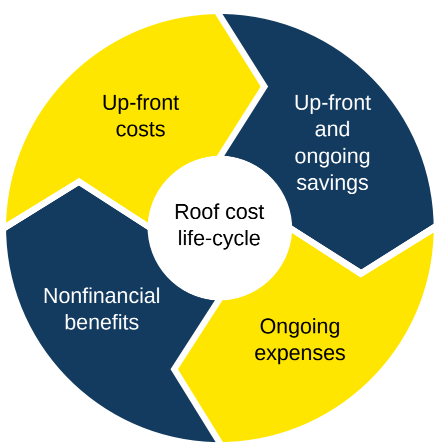
Maintenance (varies)

Cost of capital

**Nonfinancial benefits:**

Indoor comfort (cooler temperatures)

Quality of life improvements from reduced air pollution and cooler ambient temperatures




**Up-front and ongoing benefits:**

Energy savings

Rebates and incentives where available

Savings from potential to downsize HVAC equipment

Extended roof lifetime

Maintenance (varies)

Water management (pavements)

*Source:* Global Cool Cities Alliance (2012), “The Cool Roofs and Pavements Toolkit,” https://www.coolrooftoolkit.org/wp-content/pdfs/CoolRoofToolkit_Full.pdf

Economically, the best time to install cool roofs is when a new roof will be installed or an existing roof needs to be replaced anyway. Repairs to an existing functional roof, especially when waterproofing, can also be a cost-effective time to shift to a highly reflective solar roof.

Table 5 shows approximate cost premiums for cool products by roofing type in the United States. Prices are similar in other mature markets but may vary greatly in less mature markets—a situation prevalent in many developing countries. For example, indigenous products that increase solar reflectivity, such as lime wash commonly used in India, often have much lower first costs, but require more frequent application, than products generally available in mature markets. Alternatively, product types may also be more expensive due to a lack of competition, logistics/importing challenges, tariffs, and other factors.

### 3.3.1.2 Cool Roofs: Other Considerations

Cool roofs make sense in all but the coldest climates. The following are some of the disadvantages of cool roofs:

**Winter heating penalty:** Cool roofs may cause an increase in demand for building heating in the winter. With the exception of extremely cold, polar climates, the additional energy for heating demand in winter is typically more than offset by the cooling energy savings in the summer. A number of factors minimize the "winter heating penalty" of cool roofs in many cases, such as:

- The sun is generally at a lower angle in winter months than it is in summer months, which means that solar radiation is less intense during the winter.
- In some areas, snow cover during the winter makes the underlying roof color irrelevant because it prevents sunlight from reaching the roof surface.
- Heating loads and expenditures are typically more pronounced in evenings and are not aligned with the daytime benefit of a darker roof in winter.
- Many commercial buildings have a low surface area-to-volume-area ratio, so heat losses in winter are often fully offset by interior heat sources from human bodies, electric lighting, and office equipment. Occupancy patterns in some commercial buildings may be such that space cooling is used in all seasons, and in such cases, reducing solar heat gain contributes to building energy savings year-round.

**Changes in solar reflectance over time:** The solar reflectance of roofs declines as they age, weather, and become soiled (from a combination of accumulated soot, dust, salt, and, in some climates, mold and moss growth). Reducing a roof's ability to reflect sunlight increases the potential for heat transfer into buildings. The reduction in solar reflectance due to weathering and aging will vary based on the composition of the accumulated soil and precipitation patterns that help to wash the roof. In general, a roof may lose approximately 25 percent of its initial solar reflectance over the first three years after installation, with minimal additional loss in solar reflectance afterwards. Cool roof products have improved solar reflectance longevity by making products more resistant to water (hydrophobic) and biological growth. Roofs may also be periodically washed to restore their solar reflectivity—this may be most relevant in areas experiencing high levels of air pollution and little rainfall.

**Condensation:** Moisture from indoor air can condense within roof structures/systems. If allowed to accumulate over years, moisture can damage those materials and negatively affect the roof's durability and service life. In consistently hot and dry climates, there is little risk of moisture buildup. In winter months in cooler climates, all roof structures will develop some moisture that will then dry out in warmer summer months. This "self-drying principle" is a long-standing roof design feature. Without proper design

## TABLE 5: PRICE PREMIUMS FOR COOL ROOFS

| ROOF MATERIALS | TYPICAL NON-COOL SURFACE | COOL ALTERNATIVE | US$ PER M² |
|---|---|---|---|
| Built-up roof | Mineral aggregate embedded in flood coat | Light-colored aggregate, like marble chips, gray stag | 0.00 |
| | Asphaltic emulsion | Field-applied coating on top of emulsion | 8.61 to 16.14 |
| | Mineral surfaced cap sheet | White mineral granules | 5.38 |
| Metal | Unpainted metal | May already be cool | 0.00 |
| | | Factory-applied white paint | 2.15 |
| | Painted metal | Cool-colored paint | 0 to 10.76+ |
| Modified bitumen | Mineral surface cap sheet | Factory-applied coating, white mineral granules | 5.38 |
| | Gravel surface in bitumen | Light colored gravel | 0.00 |
| | Metallic foil | May already be cool | 0.00 |
| | | Field-applied coating | 8.61 to 16.14 |
| | Asphalt coating | Field-applied coating on top of asphaltic coating | 8.61 to 16.14 |
| Shingles | Mineral granules | White granules | 0.00 |
| | | Cool-colored granules | 3.77 to 8.07 |
| Sprayed polyurethane foam | Liquid applied coating | Most coatings are already cool to protect the foam | 0.00 |
| | Aggregate | Light colored aggregate | 0.00 |
| Thermoplastic membranes | White, colored, or dark surface | Choose a white or light colored surface | 0.00 |
| Thermoset membranes | Dark membrane, not ballasted (adhered or mechanically attached) | Cool EPDM formulation | 1.08 to 1.61 |
| | | Factory cool ply or coating on dark EPDM | 5.38 |
| Tiles | Nonreflective colors | Clay, slate (naturally cool) | 0.00 |
| | | Cool colored coatings | 0.00 |

*Source:* U.S. Department of Energy (2010), 'Guidelines for Selecting Cool Roofs,' https://www1.eere.energy.gov/buildings/publications/pdfs/corporate/coolroofguide.pdf and installation, both dark and cool roofs can accumulate moisture in colder climates. Solar reflective roofs maintain lower temperatures than dark roofs and will typically take longer to dry out over the course of an annual cycle than a dark roof. In all but the coldest climates, though, the cool roofs reach the same level of dryness as a dark roof over the course of a year (Hosseini and Akbari 2015).

**Effects of insulation:** Roof solar reflectance and insulation in the roof structure reduce heat flow into a building. The similarity in their effect on heat flows has, in some cases, led to policies that allowed increased surface solar reflectance to be traded off for lower insulation levels, given the relative ease of changing roof color compared to adding insulation in an existing structure. Some building codes allow for a reduction in insulation levels when a solar reflective surface is installed. However, recent research in a climate characterized by hot summers and cold winters in the United States finds that insulation and surface reflectance are complementary, not substitute, solutions for building efficiency and comfort. Building heat flows during summertime are driven by roof surface color and heat flows during winter are correlated to insulation level (Ramamurthy 2015). A recent pilot in Ahmedabad, India (Box 3) tracked the indoor temperature benefits of cool roof insulations.

## BOX 3: CASE STUDY: COOL ROOFS IN AHMEDABAD (NATIONAL RESOURCES DEFENSE COUNCIL 2018)

**Photo 3: Ahmedabad, Gujarat State, India**

Credit: Leonid Antonov.

One of India's fastest growing cities, Ahmedabad (Photo 3) is the economic center of the state of Gujarat and home to 7.2 million people. Located in the arid western region of India, Ahmedabad's warm, dry conditions are conducive to heat waves. In 2017, the Ahmedabad Municipal Corporation unveiled an initiative to install 3,000 cool roofs on low-income homes (about 2 percent of all low-income homes in the city) (Ahmadabad Municipal Corporation 2017). The pilot used ModRoof, a light-colored modular roofing product made from packaging and agricultural waste as an alternative to metal or asbestos roofing. The city completed the installations by May 2017. The total cost of the project was US$10,924, at an average cost of US$3.51 per household.[16] Houses with the cool roofs experienced indoor temperature reductions of 2–3°C.

In 2018, the initiative incorporated solar reflective paint coatings (in this case, a locally available white lime coating costing $0.75 per m$^2$), and 25 local real estate developers agreed to expand cool roofs to private buildings in Ahmedabad on a voluntary basis. The city's next steps include adding cool roofs to more municipal buildings, adopting incentive mechanisms for cool roofs on private buildings, incorporating cool roof initiatives into city building codes, and establishing stable budget and financing mechanisms.

For more information, please see the extended case study in the annex, *Cool City Case Studies: Reducing Urban Heat*.

*Case study source:* Adapted from the National Resource Defense Council (2018), "Cool Roofs: Protecting Local Communities and Saving Energy Issue, Brief May 2018," https://nrdc.org/sites/default/files/ib_-_cool_roofs_-_hyd_workshop.pdf

16 Based on a house size of 42m$^2$.

### 3.3.2 Cool Walls

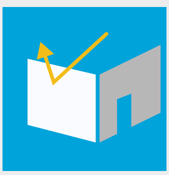
Cool walls are very similar to cool roofs but applied to vertical building surfaces. There are many light-colored, cool wall products available commercially worldwide, and they tend to stay clean and reflective over time (Levinson et al. 2019). Table 6 summarizes the applications and benefits of cool walls. Photo 4 shows cool walls in practice in Santorini, Greece.

Cool walls mitigate urban heat islands like cool roofs. Simulations predict that increasing wall solar reflectance throughout Los Angeles

**Photo 4: White walls in Santorini, Greece**

Source: Hashem Akbari.

**TABLE 6: COOL WALLS APPLICATIONS, BENEFITS, AND ECONOMICS**



**Cooling method:**
Cools by reducing the amount of solar energy absorbed by a building's walls.

| | |
|---|---|
| **Applicable use cases** | Cool walls are applicable in all but the coldest climates. Additional analysis on effect recommended when buildings are close to each other and unshaded. More benefits for buildings with low roof to wall ratios and window to wall ratios. |
| **Benefits** | • Energy savings<br>• Improved indoor thermal comfort<br>• Air temperature reductions (at scale) |
| **Considerations (significance of effect)** | • Increased solar energy reflected into neighboring buildings (minor)<br>• Pedestrian thermal comfort (minor)<br>• Aesthetics (minor)<br>• Evaluations of the effects of cool walls should be undertaken when deploying in dense areas (medium) |
| **Economics** | Choosing lighter colored coatings will be cost neutral to dark color options. Dark colors that increase solar reflectance have some cost premiums, particularly in developing markets. |
| **General recommendation** | Continue study of the effects of cool walls in dense developments and, if positive, cool walls should be encouraged/required as part of building and energy codes and prioritized in municipal procurement specifications. |

*Source:* Authors.

County[17] would lower daily average outside air temperature in the “urban canyon” between buildings by about 0.2°C during the hot summer month of July.

### 3.3.2.1 Cool Wall: Economic Considerations

As with highly solar reflective roofs, there are cool alternatives for most wall material types, including metal cladding, vinyl siding, and exterior paint. In general, color does not appear to affect price. Some advanced cool-color technology, where a product appears dark to the eye but reflects more solar energy than a traditional dark pigment, does carry a cost premium. There is limited market availability for these more advanced products, which may also affect price. In California, the median cost of a dark-colored, solar-reflective wall is 5–130 percent higher than a traditional, solar-absorbing option.[18] Cool walls generate economic value by improving building energy efficiency. In warm U.S. climates, cool walls lowered annual heating/cooling energy costs by up to 8.5 percent, or $1.10/m$^2$, in single-family homes, up to 4.2 percent, or $1.80/m$^2$, in medium offices, and up to 5 percent, or $3.70/m$^2$, in stand-alone retail stores.[19] Energy cost savings would be more substantial in markets with higher energy costs (Levinson et al. 2019).

### 3.3.2.2 Cool Walls: Other Considerations

Cool walls are generally applicable in the same places and cases that are appropriate for cool roofs, i.e., practically everywhere except in very cold climates. The considerations presented here primarily apply when cool walls are installed on buildings that are close together but also receive substantial sun exposure. Generally, the negative effects of these considerations are minor and easily mitigated, and thus should not dissuade the use of cool wall strategies. They include:

- **Increased reflectance into neighboring buildings:** Cool walls reflect more sunlight between urban surfaces than dark walls, potentially leading to increased heat transfer. This effect may increase cooling load, decrease heating load, and reduce the need for artificial lighting in nearby buildings; the size of the effect will vary based on the solar reflectance of wall surfaces (both the wall reflecting the sunlight and the wall absorbing it), the proximity of nearby buildings, and the sky view factor between them.[20]
- **Pedestrian thermal comfort:** Walls are made more reflective to reduce building solar heat gain, but cool walls also affect the thermal environment of pedestrians by (a) increasing the solar radiation striking nearby pedestrians, (b) decreasing longwave (thermal infrared) radiation incident on the pedestrian, and (c) lowering the outside air temperature. The magnitude of these often-opposing effects on pedestrians can be quantified by human comfort models, but research indicates that that the pedestrian thermal comfort change induced by raising wall solar reflectance is small (Levinson et al. 2019).
- **Aesthetics:** Because walls are highly visible, color choices will often be based on aesthetic preference over other benefits. Cool-color products can come in a range of dark colors but still allow for increased solar reflectance.
- **Effects of insulation:** The interaction between wall-surface reflectivity and insulation levels is very similar to that in roof structures (as described in Box 4 and Section 3.3.1.2).

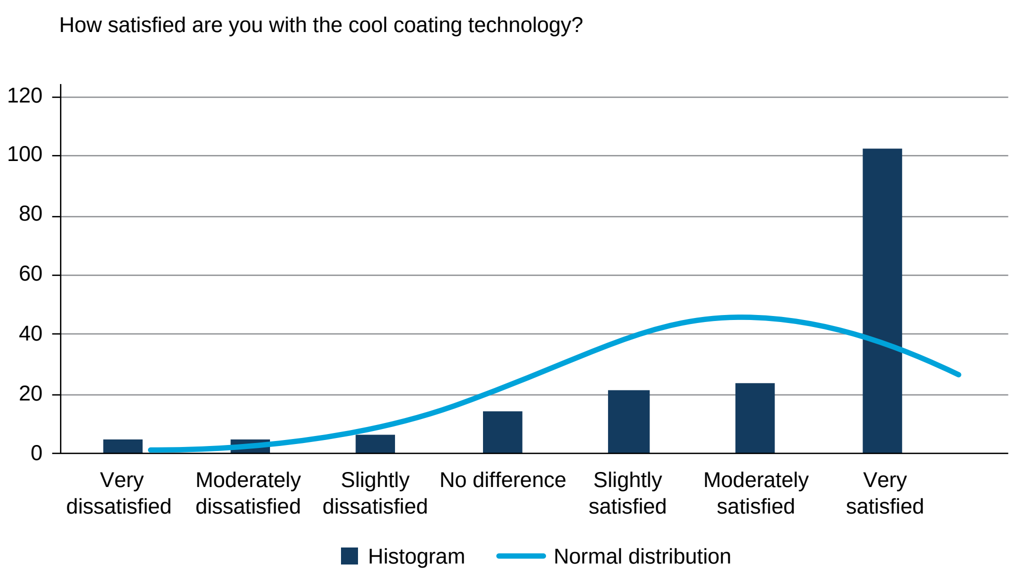
---

17 The study evaluated an increase of 0.4 in wall solar reflectivity. That is roughly equivalent to changing from a black surface to a medium gray surface.
18 Cost premiums per gallon of exterior paint based on assumptions in Appendix P of Levinson R., et al. 2019. Price premium ranges are based on pigment densities in available coatings products, which range from 3–22 percent of total product volume. The end product cost assumed here is $11.87/liter, or $45/gallon and is based on retail prices for top-tier exterior paints available in California as of March 2020.
19 Based on energy costs for Florida (warm, humid climate) and New Mexico (warm, desert climate), residential electricity costs during the analysis period were between $0.12 and $0.13/kWh in both states. Commercial electricity costs were between $0.09 and $0.10/kWh.
20 The sky view factor is explained in Section 3.6 Urban Design.

## BOX 4: CASE STUDY: COOL ROOFS AND WALLS IN !KHEIS, SOUTH AFRICA

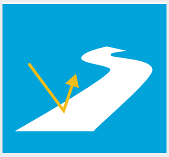
!Kheis is a small town of 10,000 residents located in the hot, arid Northern Cape region of South Africa. Housing is predominantly informal in nature and homes were too hot to enter during summer days. In 2014, a program managed jointly by the U.S. Department of Energy and the South Africa National Energy Development Institute arranged for a limited pilot of cool roofs and walls. In addition to significant improvements to thermal comfort experienced in the demonstration dwellings, the program highlighted the possibility that coating structures could create jobs for local residents. The local municipal manager applied for and received a grant from the national government to expand the pilot to 500 structures. The grant application was the first of its kind and created a template for other municipalities, both small and large, to seek funding for cool roof and wall programs. As of 2019, the larger pilot was nearly complete, and monitoring of thermal comfort and energy savings of subset of the pilot homes was finalized. The project required approximately 15,600 liters of coatings to cover roofs and walls at a cost of US$2.25 per liter, including labor and materials. Additional monitoring and assessment costs incurred as part of the pilot were approximately US$20,000, for a total project cost of US$55,100. Pilot managers measured changes in inside temperatures and interviewed residents to capture their perceptions of their newly coated homes. Air temperatures in coated homes were consistently 3–4°C cooler inside than uncoated structures. The interviews revealed that residents were spending more time indoors than before the pilot and, in general, expressed high levels of satisfaction with the project. Figure 10 shows the results of the satisfaction survey, with numbers of residents on the y-axis (South African National Energy Development Institute 2019).

## FIGURE 10: SATISFACTION SURVEY OF !KHEIS RESIDENTS WHOSE HOUSES WERE COATED




*Source:* SANEDI (2019) and Kausch, Assessment and Verification of Passive Building Technologies—Example: Cool Coating, https://www.saeeconfed.org.za/wp-content/uploads/2019/11/2019SAEEC-Cova-Room-LowExCo-Kausch-Assessment-of-Cool-Coating.pdf

**TABLE 7: SOLAR REFLECTIVE APPLICATIONS, BENEFITS, AND ECONOMICS**



**Cooling method:**
Cools by reducing the amount of solar energy absorbed by a paved surface.

| | |
|---|---|
| **Applicable use cases** | Solar reflective pavements are currently most applicable in pedestrian and low-traffic paved areas in warm climates and should be evaluated on a location by location basis. |
| **Benefits** | • Net energy savings<br>• Improved outdoor lighting performance<br>• Improved pavement life<br>• Air temperature reductions (at scale)<br>• Cancels some of the warming effects of atmospheric GHGs |
| **Considerations (significance of effect)** | • Building/pavement interactions (medium)<br>• Greenhouse gas emissions effect (medium)<br>• Shade effect on heat mitigation benefit (minor)<br>• Pedestrian thermal comfort (medium)<br>• Durability (minor)<br>• Limited installed, long-term experience with cool pavements (medium) |
| **Economics** | Solar reflective pavement options tend to have a moderate to high cost premium over an untreated surface, particularly in high-traffic applications where few products are available on the market. |
| **General recommendation** | Cities should explore the use of solar reflective pavements, particularly in pedestrian areas with shade. Further demonstrations on moderate to high traffic areas are needed to understand local performance. |

*Source:* Authors.

### 3.3.3 Solar Reflective Pavement

Pavements cover approximately 40 percent[21] of a city's surfaces. Of that amount, roads generally cover 45 percent, parking lots 40 percent, and sidewalks 15 percent. Paved space may take up more urban surface than any land use type; thus cool pavements could be a major potential contributor to urban cooling strategies. Solar reflective pavements are summarized in Table 7. Most pavement can be classified into the two basic types:

- **Asphalt cement pavements:** made up of aggregate rock held together by a binder derived from crude oil called bitumen. Asphalt pavements tend to be dark colored but lighten over time depending on the color of the aggregate. Asphalt is a typical pavement choice for urban vehicular roadways and parking lots. Asphalt pavements are cheaper to install and easier to repair than concrete cement, but often have a shorter service life.

21 Studies of urban fabric find that pavements can account for 20–66 percent of total urban area.

- **Concrete:** a mixture of a paste, made of Portland cement, slag, polymers, or other materials mixed with water, and aggregate rock. The paste hardens and cures to form the rock-like mass known as concrete. New concrete is typically light grey in color but will darken as more vehicles drive over it. Concrete may have a number of additional ingredients, some of which have a lightening effect on new concrete. Concrete pavement is typically applied where maximum strength is needed, such as on highways, runways, or on the pavement near bus stops.

Similar to roofs and walls, pavements that are darker in color have higher surface temperatures than lighter colored materials and can also raise air temperatures. Both pavement types have options for lightening the surface color to increase solar reflectance. There are three common methods for lightening a paved surface, including:

- **Transition from dark asphalt to concrete materials:** Switching to concrete will lighten the pavement, though the difference in solar reflectance shrinks as both materials age.
- **Substitute dark aggregate used in the asphalt pavement mix for lighter colored aggregate:** Over time, the dark asphalt binder wears down and reveals more of the aggregate color. Lighter aggregate choices would lighten the color of the aged asphalt surface compared to a darker colored aggregate. The effect of aggregate color can be immediate if a clear binder such as resin is used instead of bitumen.[22]
- **Apply a light-colored, reflective top coat to the pavement:** Cool pavement coatings are light-colored topical surface treatments that increase pavement solar reflectance. Figure 11 summarizes the various reflective surfacing options available on the market today.

There are a number of benefits unique to solar reflective pavements. Lighter-colored pavement surfaces are cooler than dark surfaces. Particularly for asphalt pavements, cooler surface temperatures lengthen pavement life and delay rutting. One study performed a Heavy Vehicle Simulation where a standard axle load was driven back and forth over a surface at 7 km per hour and found that an asphalt pavement surface maintained at 53°C rutted to the point of pavement failure after 20,000 repetitions. A pavement maintained at 42°C rutted to the point of failure after 270,000 repetitions, a more than 10-fold extension of pavement life (Pomerantz, Akbari, and Harvey 2000).

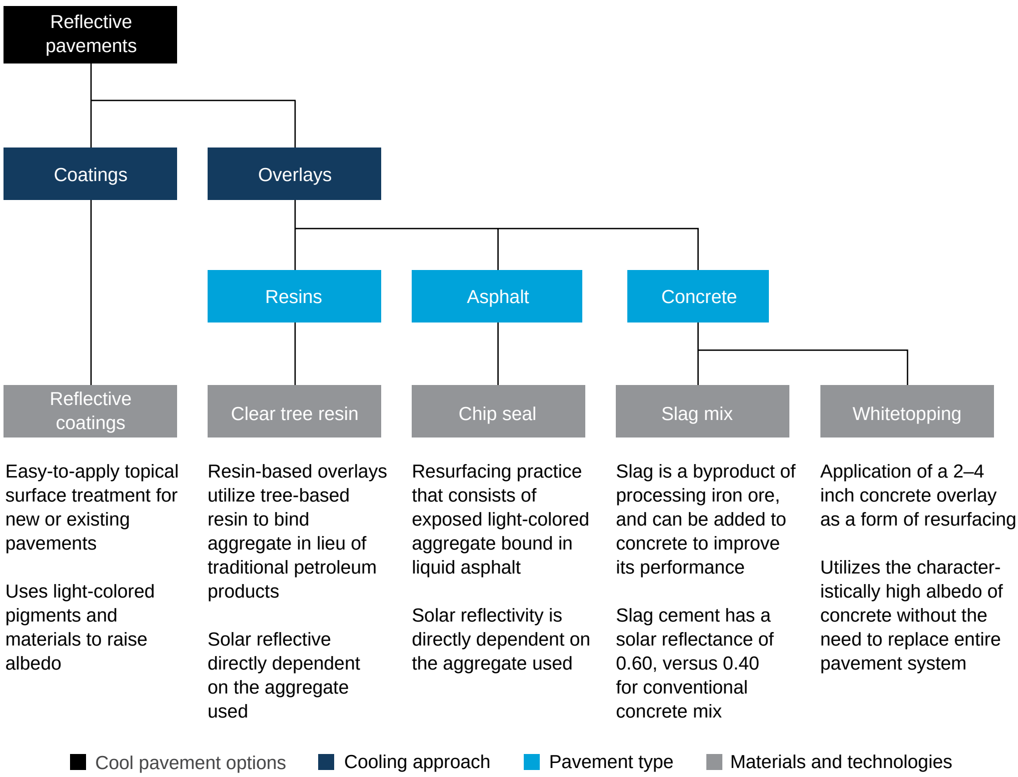
Lighter-colored pavements may reduce energy demand for streetlighting by 30 percent compared to darker pavements (Stark 1986), though the energy saving will be lower in places where already efficient LED lighting is used. Light-colored pavements may also improve safety by improving visibility at night in city streets, especially where there are pedestrians and cyclists.

### 3.3.3.1 Solar Reflective Pavement Economics

Cool pavement options tend to have a higher up-front cost than traditional pavements. Up-front costs for concrete tend to be higher than for asphalt. Cities that have invested in the machinery and facilities to produce and install asphalt may incur additional costs to transition to concrete. Concrete does tend to have a longer service life than asphalt, which should be factored into an economic analysis of pavement switching. The recyclability of both products is also an important consideration. Costs for cool pavement coatings, still a relatively new technology, range from US$1.70 to US$37.75 per $m^2$ (Bloomberg Associates 2019). The wide range in product costs is due to the variety of use cases (from pedestrian only to high-traffic), expected product service life (i.e., durability), and the fact that the technologies are

22 Resin binders are appropriate for pedestrian walkways, driveways, and other low-traffic pavements.

## FIGURE 11: REFLECTIVE PAVEMENT PRODUCT OPTIONS




*Source:* Bloomberg Associates (2019), "Mitigating Urban Heat Island Effects Cool Pavement Interventions," https://www.bbhub.io/dotorg/sites/32/2019/08/20190516_Cool-Pavement-Research-FINAL.pdf

relatively new with limited market availability. A number of factors complicate an easy cost comparison between coating products. First, the number of coats required will vary by location, use, condition, and porosity of the existing pavement. Cities also need to consider shipping costs, service life, amount of material needed for applications, and maintenance/reapplication costs to maintain reflectivity. Product costs and service lives of current cool pavement options are included in Figure 12.

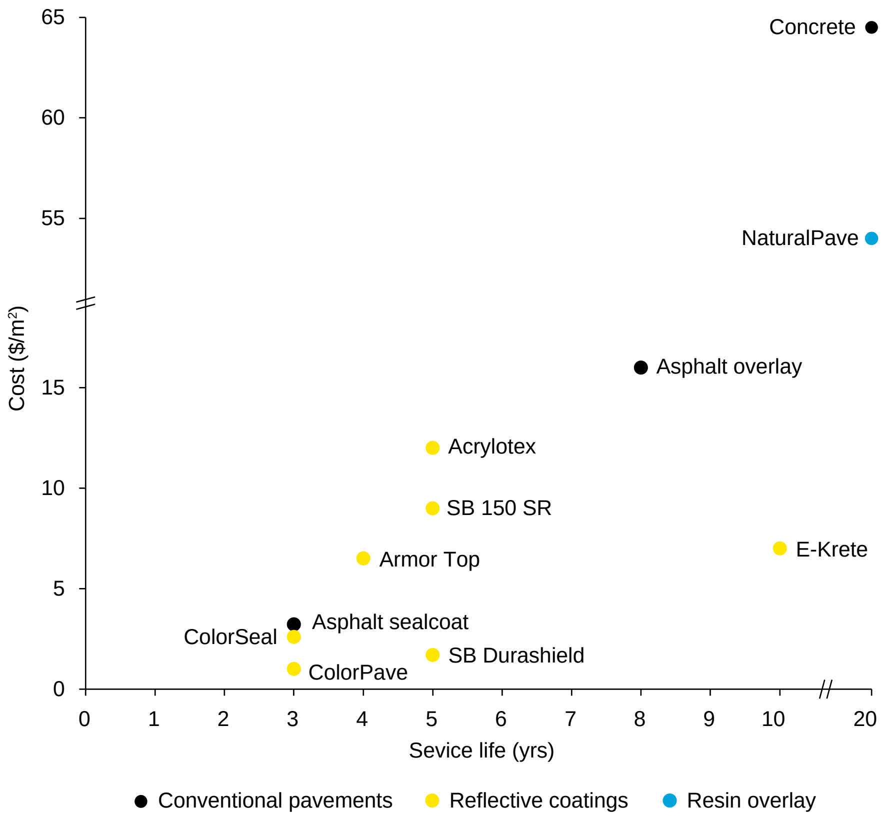
### 3.3.3.2 Solar Reflective Pavement: Other Considerations

The market for solar reflective pavements is relatively new, with few examples of large-scale implementation to date. Los Angeles, California, a city with more than 300 days of sunshine a year and where the mayor pledged to reduce the city's temperature (as part of the city's climate adaptation plan), stands out as one of the first cities to test cool pavements to fight urban heat.[23] Tokyo, Japan, has installed 64 kilometers of cool-coated roadways, primarily along the Olympic Marathon route.[24] Accordingly, the considerations for using solar reflective pavements presented here may not (yet) be fully conclusive, given a lack of long-term performance data and field experience. Consequently, the use of solar reflective pavements should be considered on a location by location basis.

23 Some other cities, including Athens, Greece, and Melbourne, Australia, have also been testing reflective payment coatings or lighter-colored roadways.

24 A case study of Tokyo's initiatives on cool and permeable pavement is included in this primer.

FIGURE 12: COOL PAVEMENT PRODUCT COST VERSUS SERVICE LIFE




*Products not displayed in graph due to lack of available data: E-Pave I, Endurablend, TuffSeal, Tough Coore, SunShield.

*Source:* Bloomberg Associates (2019), "Mitigating Urban Heat Island Effects Cool Pavement Interventions," https://www.bbhub.io/dotorg/sites/32/2019/08/20190516_Cool-Pavement-Research-FINAL.pdf

There are a number of areas where future research would be useful to better understand the potential for cool pavements, as well as to understand potential trade-offs and/or ways to minimize potential unintended consequences (such as any negative impact on thermal comfort of pedestrians). These include:

**Effect on GHG emissions:** There are GHG emissions associated with the manufacturing processes of concrete, asphalt, and pavement coatings. Emissions will vary by manufacturing method, energy mix, feedstock, and other factors. Switching from a dark asphalt pavement to a concrete pavement may increase embodied GHG emissions if the method of producing the concrete is highly inefficient and the electricity mix in the production location includes coal-fired generation. Similarly, formulations for cool coatings vary greatly and, in some cases, these products may embody more energy and carbon than ordinary pavements. It is thus recommended to consider life-cycle emissions associated with cool pavements when evaluating the feasibility of transitioning to different pavement types.

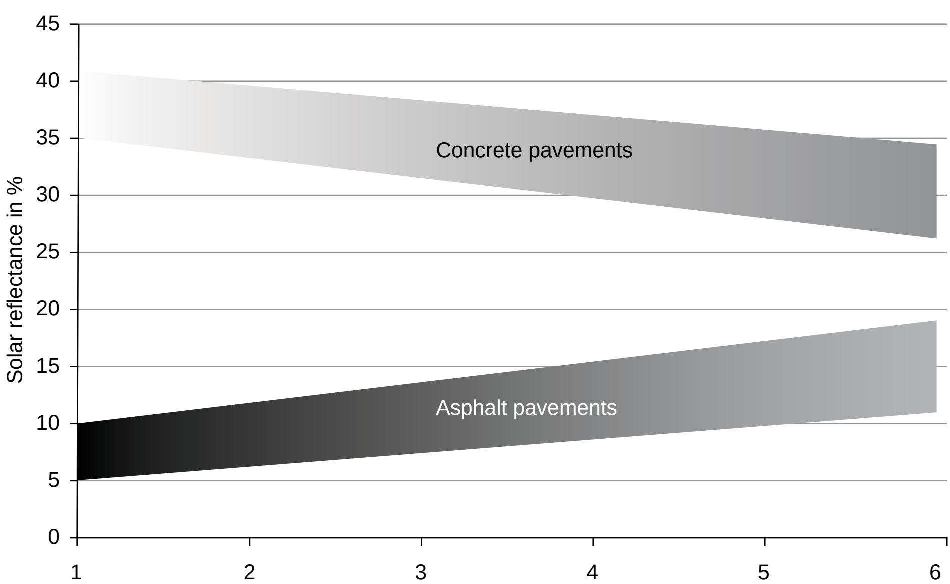
**Energy demand in buildings:** The benefits of solar reflective pavement vary widely and are closely linked to where they are installed. By definition, cool pavements reflect solar radiation. Their effects on energy use in nearby buildings are dependent on how close buildings are to the pavement, building age and wall insulation levels, the building's window-to-wall ratio, and the presence of vegetation between the pavement and the building (Lawrence Berkeley National Laboratory 2017b). For example, reflective pavements may result in a reduction in energy use in buildings because they help lower air temperatures and increase daylighting from reflected sunlight. These energy savings may be offset or reversed if reflected solar energy warms the building interior. These pavement/building interactions will be most apparent in neighborhoods where buildings are close to the pavement and where there are few obstructions (i.e., vegetation or trees) blocking reflected solar energy from being absorbed by the building.

**Effect of shade on heat mitigation potential:** While shading is an important factor for site energy demand and pedestrian thermal comfort, the presence of trees, cars, and shade structures will reduce a pavement's effectiveness as an urban cooling solution. These types of potential trade-offs are location specific and need to be considered.

**Pedestrian thermal comfort:** While reflecting more solar radiation from pavements reduces air temperatures, doing so may cause pedestrians to feel warmer in some cases. This effect will depend on the clothing worn by the pedestrian and the length of time the person stays directly over a sunlit cool pavement.

**Durability:** The service life of solar reflective pavement options ranges from 3–20 years, depending on several factors, including traffic type (pedestrian or vehicular), traffic intensity, base pavement type and condition, thickness of application, and proper installation and maintenance. However, service life may not represent the effective life of the reflectivity of the product. Studies have found that solar reflectivity of cool pavements can decrease by 20 percent in the year after installation due to weathering and soiling (Alchapar, Correa, and Cantón 2013). In general, dark pavements such as asphalt lighten over time. The dark bitumen binder used in asphalt pavement may be worn down by vehicle use or degraded and lightened by sunlight exposure. Initially, lighter-colored pavements such as concrete will darken with use as vehicle tires and fluid deposits mark or wear them down. Figure 13 illustrates the change

**FIGURE 13: CHANGE IN SOLAR REFLECTANCE OF PAVEMENT TYPES, IN YEARS**




*Source:* United States Environmental Protection Agency (2008), "Reducing urban heat islands: Compendium of strategies," https://www.epa.gov/heat-islands/heat-island-compendium (accessed March 2, 2019). Data for graphic provided by LBNL.

in reflectance over time of both concrete and asphalt pavements, while Box 5 describes a relevant pilot in the city of Los Angeles (Photo 5). When deploying cool pavements, cities should therefore base their analysis on what the solar reflectance will be after the pavement ages. This will decrease some benefits, e.g., slightly lower reductions in air temperature, but perhaps mitigate some of the considerations, e.g., reduced negative effect on pedestrian thermal comfort when spending long periods on the cool pavement.

## BOX 5: CASE STUDY: COOL PAVEMENT DEMONSTRATIONS IN LOS ANGELES, CALIFORNIA

**Photo 5: Applying cool pavement coating**

Source: Los Angeles Bureau of Street Services.

Los Angeles has undertaken one of the largest and long-standing cool pavement evaluations in the world. In 2015, the Los Angeles Bureau of Street Services, Parks and Recreation Department, and the city's materials testing laboratory partnered to test a cool pavement coating (in this case, Guard Top Cool Seal) on a portion of a parking lot at a recreation facility. The surface of the paved area in the pilot study remained 5.5°C cooler than the surrounding black asphalt. The pilot study was expanded to 15 city blocks (1 block in each of the city's legislative districts). The city, working with the manufacturers, identified opportunities to improve the durability and application of the coating product. In 2018, the original pilot areas were recoated with a newly formulated coating, which has performed well over the last two years. The city is now in the process of identifying an entire neighborhood of roadways to coat to evaluate the effect on local air temperatures. The city has also developed a testbed for other cool pavement technologies (located at the Los Angeles Cleantech Incubator). Major public transportation hubs in neighborhoods with a high risk of heat stress have also been targeted for demonstrations of an integrated set of urban passive cooling solutions, including cool pavement, water fountains, and enhanced shade.

Notwithstanding the nascent stage of the market, the potential for reflective pavements to reduce urban heat could be substantial. However, because pavements are more visible than roofs and potentially interact more directly with buildings and pedestrians than most roofs, caution is advised in the elaboration and implementation of pavement strategies to ensure that unintended consequences are minimized. Generally, the solutions available today are most appropriate for paved areas with light vehicle or pedestrian traffic with shading present.

## 3.4 PERMEABLE INFRASTRUCTURE AND SHADING

Another solution for urban cooling is permeable infrastructure to facilitate evaporative cooling. This is achieved by increasing vegetated cover or using porous/permeable paved surfaces.[25]

Permeable surfaces allow water infiltration and facilitate cooling by evapotranspiration. Evapotranspiration is the combination of the evaporation of water from soils and surfaces, and transpiration by plants.[26] Evapotranspiration cools the air by increasing the latent heat storage capacity of air—in other words, using heat from the air to evaporate the water present in a tree, vegetated area, or permeable pavement. The effect of vegetation on cooling is complex and will vary by location. For example, highly landscaped cities in desert climates have been shown to have daytime urban cool islands but nighttime heat islands.

Shading refers to the ability of a tree or structure to block sunlight from striking and heating surfaces such as sidewalks or buildings. The amount of sunlight that passes through a tree canopy varies based on plant species. In the summertime, 10–30 percent of the sun's energy reaches the area below a tree. The rest of the sunlight is either absorbed by leaves and used for photosynthesis, or reflected back into the atmosphere. In climates where leaves are lost during winter months, the range of sunlight that passes through a tree canopy in winter is much larger, from 10–80 percent. Tropical climates, where leaves may remain on trees year-round, experience less seasonal shade loss. Tree groves can be 5°C cooler than unshaded open ground around them (U.S. Environmental Protection Agency 2008). Increased tree canopy reduces both daily minimum and maximum air temperatures, but the effect on daily maximum air temperatures is less pronounced (Mohegh et al. 2017).

Cities like Paris, France, and Medellin, Colombia, created "urban cool islands" to provide heat relief to residents. Cool islands are typically created by a combination of trees, shade structures, vegetation, and/or water features. Areas like urban parks, shaded fountains, and highly vegetated suburban developments, may all form urban cool islands. Cities may also try to create cool urban pathways to link the cool islands together. Cities considering increases in tree canopy and vegetated cover could benefit by placing and enhancing vegetation and shade strategically. The "Sponge City" Initiative (Box 6) in Shanghai (Photo 6) also attempts "urban cool island" strategies. Doing so not only reduces overall air temperatures, it also creates cool spaces of respite on extreme heat days.

### 3.4.1 Green Roofs

A green roof is a vegetative layer grown on a rooftop. Green roofs are summarized in Table 8. These are generally categorized into two types—intensive roofs, which may include small trees and shrubs, and extensive roofs, which are covered by a thin layer of vegetation (Akbari and Kolokotsa 2016). Surface temperatures on a green roof depend on the roof's soil and plant composition, moisture content of the growing medium, geographic location, solar exposure, and other site-specific factors. Intensive green roofs may also provide shading from trees and other large plants that contribute to the cooling effect.

25 Though there are technical differences between porous and permeable surfaces, this primer uses the term "permeable infrastructure" throughout to refer to both permeable and porous surfaces for the sake of simplicity.
26 Trees and vegetation absorb water through their roots and emit it through their leaves—this movement of water is called "transpiration."

## BOX 6: CASE STUDY: SHANGHAI'S SPONGE CITY GREENING EFFORTS

Photo 6: Green space in Shanghai, China

Source: DepositPhoto.

In response to heat, flooding, and other environmental challenges associated with rapid growth, Shanghai is one of China's leading cities in adopting green building and green development policies. In 2014, the city set a goal to add 400,000 m$^2$ of green roofs and walls by 2016 and a longer-term goal to reach 2 million m$^2$ by 2020. While the greening initiative is primarily aimed at improving energy efficiency, stormwater retention, and air quality, it is expected to also facilitate urban cooling because it is concentrated in the downtown core of the city where temperatures are elevated and cooling solutions can be deployed in close enough proximity to trigger air temperature reductions. The city is pairing the green roof program with extensive ground-level plantings, permeable pavements, greenspace, and a man-made lake in Lingang (or Nanhui) district that, collectively, is referred to as Shanghai's "Sponge City."

The Sponge City Initiative is part of a national pilot program of 30 cities. By the end of 2020, the national government expects 20 percent of the built area of each pilot district to have Sponge City functions, meaning at least 70 percent of stormwater runoff should be captured, reused, or absorbed by the ground. By 2030, 80 percent of each city will be subject to the stormwater requirements.

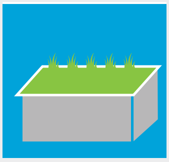
Shanghai combined both incentives and requirements to reach their targets. The city currently offers a subsidy for certain buildings of up to US$29/m$^2$ for green roof and wall installations, with higher subsidies for intensive green roofs and walls. In late 2015, the city also passed an ordinance requiring that new buildings include vegetated coverage on at least 50 percent of their roof area. New construction rates have slowed in recent years, so retrofitting solutions are increasing in importance to help the city meet its goals. Since green roofs typically require strong structural support to bear their weight, a number of innovative lightweight green roofs were tested and deployed.

Authorities estimate that the green roofs can reduce power consumption by 6 million kilowatt hours, prevent 920,000 tons of rainfall from entering the sewer system, and absorb 170 tons of air pollutants annually in Shanghai (Clark 2016).

Using green roofs in cities with limited vegetation can moderate the heat island effect, particularly during the day. Green roof surface temperatures can be 17–22°C lower than those of conventional roofs and can reduce city-wide ambient temperatures by up to 3°C if deployed at scale (Santamouris 2014). A side-by-side demonstration in Chicago found that green roof surface temperatures ranged from 33–48°C, while the dark, conventional roof of the adjacent building was 76°C.[27] The near-surface air temperature above the green roof was about 4°C cooler than over the conventional roof (Dvorak 2016). Vegetation on roofs also offset emissions by capturing GHG emissions. In Mexico City, where the city has approximately 35,000 m$^2$ of green roofs on public buildings, schools, and hospitals, researchers estimate that each m$^2$ of green roof is capturing 1 kg of $CO_2$. Energy efficiency savings would also

27 Measurements taken on August 9, 2001, in early afternoon, conditions were sunny.

## TABLE 8: GREEN ROOF APPLICATIONS, BENEFITS, AND ECONOMICS



**Cooling method:**
Cools via evapotranspiration and shading of roof surface.

| | |
|---|---|
| **Applicable use cases** | Primarily applicable in areas with sufficient precipitation to support vegetation, on structures with sufficient support to bear the weight, and in areas where stormwater mitigation is a priority. |
| **Benefits** | • Net energy savings<br>• Improved indoor thermal comfort<br>• Extended roof life<br>• Air temperature reductions (at scale)<br>• Better stormwater management<br>• Supports biodiversity and habitats<br>• Urban agriculture (for some roofs)<br>• Tends to increase property values<br>• Compatible with solar PV installations |
| **Considerations (significance of effect)** | • Buildings must be sufficiently structurally strong to support green roofs (medium/high)<br>• Water requirements, particularly during establishment period, heat waves, or drought (medium)<br>• Thermal comfort impacts may be mixed—air is cooled by evapotranspiration but the apparent temperature may increase due to increased humidity (minor)<br>• Selection of appropriate plant types is important to roof performance and maintenance requirements (medium) |
| **Economics** | Green roofs tend to have a moderate to substantial cost premium over other roof options. In cases where stormwater management is highly valued, green roofs can have a net benefit. Longer roof life over other options also improves the benefit cost calculation. |
| **General recommendation** | Where appropriate precipitation and building characteristics are present, green roofs are a good option and should be encouraged. Green roofs may also be considered as an exemption to cool roof requirements. |

*Source:* Authors.

be substantial if green roofs were deployed at scale. It is estimated that if 50 percent of all buildings in Southern California converted to a green or cool roof, the region would reduce energy demand by 1.6 million MWh per year, saving residents up to $211 million in electricity costs and reducing GHG emissions by up to 465,000 $tCO_2$.

In addition to promoting urban cooling, green roofs provide other important benefits, including managing and retaining stormwater, extending the roof's service life, providing space for urban agriculture and habitats, increasing biodiversity, enhancing property values, and improving air quality in cities.

### 3.4.1.1 Green Roofs: Economic Considerations

There remains a substantial up-front cost premium to install green roofs compared to other types of roofs. In the United States, the cost of installing a green roof starts at around US$108 per square meter for simpler extensive roofing, and US$269 per square meter for intensive roofs (United States Environmental Protection Agency 2008). In Mexico, installation costs are roughly comparable to the United States at US$64–$215 per $m^2$, depending on the type of vegetation. In Peru, a green roof is reported to cost between US$120 and US$150 per $m^2$ to install.

Annual maintenance costs for both extensive and intensive green roofs in the United States may range from $8 to $16 per $m^2$. Typical maintenance includes fertilization, irrigation, weed control, and replanting when necessary. Intensive green roofs might require maintenance exceeding that required for extensive roofs to maintain their aesthetic and public access uses. Green roofs can be economically favorable over the lifetime of the roof. An economic analysis of green roof applications in Jung-gu sector of Seoul, South Korea, found that applying green roofs to all buildings would generate a benefit/cost ratio of nearly 1.2 (Shin and Kim 2019). Table 9 highlights some of these benefits and their primary recipient.

**TABLE 9: GREEN ROOF BENEFITS AND COSTS**

| BENEFITS/COSTS | ENERGY, HYDROLOGY, AND UHI BENEFITS | OTHER BENEFITS |
|---|---|---|
| Private benefits | • Energy cost savings<br>• Extended service life | • Noise reduction<br>• Aesthetic value<br>• Food production |
| Public benefits | • Urban heat mitigation<br>• Improved stormwater management | • Reduced air pollutants<br>• Reduced greenhouse gases<br>• Human health benefits |
| Private costs | • Installation<br>• Architecture/engineering<br>• Maintenance | N/A |
| Public costs | • Program administration<br>• Fiscal incentives, if provided<br>• Maintenance costs for installation on public buildings | N/A |

*Source:* United States Environmental Protection Agency (EPA) (2008), “Reducing Urban Heat Islands: Compendium of Strategies,” https://www.epa.gov/sites/production/files/2017-05/documents/reducing_urban_heat_islands_ch_3.pdf

The U.S. General Services Administration (GSA), the agency tasked with maintaining property owned and leased by the U.S. federal government, undertook a comprehensive economic analysis of green roof options and evaluated their costs and benefits over a 50-year period. GSA found that installing a green roof generates a net present value of $4.52 per square meter and pays back in 6.2 years at an internal rate of return of 5.2 percent nationally (General Services Administration 2011). Green roof service life can range from 30–50 years, exceeding that of most other roofing options. This longevity reduces replacement and disposal costs compared to shorter-lived roof options and is one of the major benefits accruing from the installation of green roofs. Benefits from stormwater management, energy efficiency, reduced GHG emissions, and other societal benefits also contributed to the net benefit in GSA's analysis. Installation and maintenance, particularly in the first few years as the roof vegetation is established, have the greatest effect on cost. GSA found that maintenance costs are greater than the installation premium over time. On commercial and large residential buildings, green roofs may be included to enhance living, gathering, social, and leisure space that adds additional economic value to the building. A similar cost-benefit analysis of green roofs in China found that the combination of the net present value of private (US$136–$196 per $m^2$) and public (US$479–$752 per $m^2$) benefits of green roofs tend to outweigh costs (US$42–$979 per $m^2$) over the life of the roof.[28]

### 3.4.1.2 Green Roofs: Other Considerations

Green roofs are an important part of an integrated urban cooling strategy that provides benefits beyond heat mitigation. The considerations presented here highlight the importance of deploying green roofs on buildings that can support them and where water is sufficient to establish and maintain the roofs. Where those conditions are met, green roofs are recommended for use.

**Building characteristics:** Green roofs may weigh more than traditional roof systems. Buildings must be able to withstand the added weight of the plants, growth medium, and the retention of water on the roof. Lighter weight extensive green roofs add between 63.5 $kg/m^2$ and 102.3 $kg/m^2$, while an extensive green roof with 25.4 cm of growing medium may add 166 $kg/m^2$ to 258 $kg/m^2$ depending on the amount of moisture saturation in the growing medium (Conservation Technology Inc. n.d.). Some green roof systems are lighter in weight and can be put in place when retrofitting existing roofs. Existing buildings with concrete cement roof systems will require the least amount of structural intervention to be suitable for a green roof system. Roofs with a steel or wood deck may require more structural strengthening. Installing a green roof on a flat or low-sloped roof generally will be easier than installing one on a steep-sloped roof.

**Water usage:** Depending on vegetation selection, climate, and maturity, a green roof may require additional water beyond what is available from rainfall. In those cases, cities in dry or drought-prone areas should carefully evaluate the water requirements of green roofs, particularly in the first years after installation, to determine suitability of green roof options.

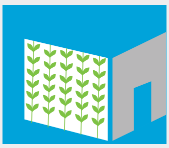
**Competing effects on thermal comfort:** Evapotranspiration from the vegetation on green roofs reduces air temperatures (Wijerathe 2010; Baryla et al. 2019). However, evapotranspiration also increases the humidity of the air during the day time. These effects have opposite effects on human thermal comfort. Higher levels of humidity increase apparent temperature—the air temperature as perceived by a person. Higher apparent temperatures may be problematic for human comfort and health in already humid climates on extremely hot days, even if actual air temperatures are lower. In general, however, the reduction in air temperature more than offsets the increase in apparent temperature (Kalkstein et al. 2013).

28 Analysis assumes a 40-year roof service life and a 3 percent discount rate. Quantified private benefits include energy cost savings, acoustic and aesthetic benefits, value of Leadership in Energy and Environmental Design (LEED) certification, and longevity of the roof structure compared to other options. Quantified public benefits include reduced stormwater runoff, air quality improvements, UHI mitigation, and urban biodiversity. Costs include installation, operation and maintenance, and end-of-life disposal.

### 3.4.2 Green Walls

Green walls, also known as "living walls" and "bio-walls," have existed for quite a long time; the Hanging Gardens of Babylon is one classic example. A green wall is comprised of plants grown in supported vertical systems that are generally attached to an internal or external wall, although in some cases they may be freestanding (City of Melbourne 2013). Applications and benefits of green walls are described in Table 10. Today, green walls typically incorporate multiple plantings in individual containers rather than rely on fewer numbers of plants that climb and spread to provide cover. The containerized approach increases the opportunity for aesthetic variation and allows for easier replacement of damaged plants.

**TABLE 10: GREEN WALLS APPLICATIONS, BENEFITS, AND ECONOMICS**



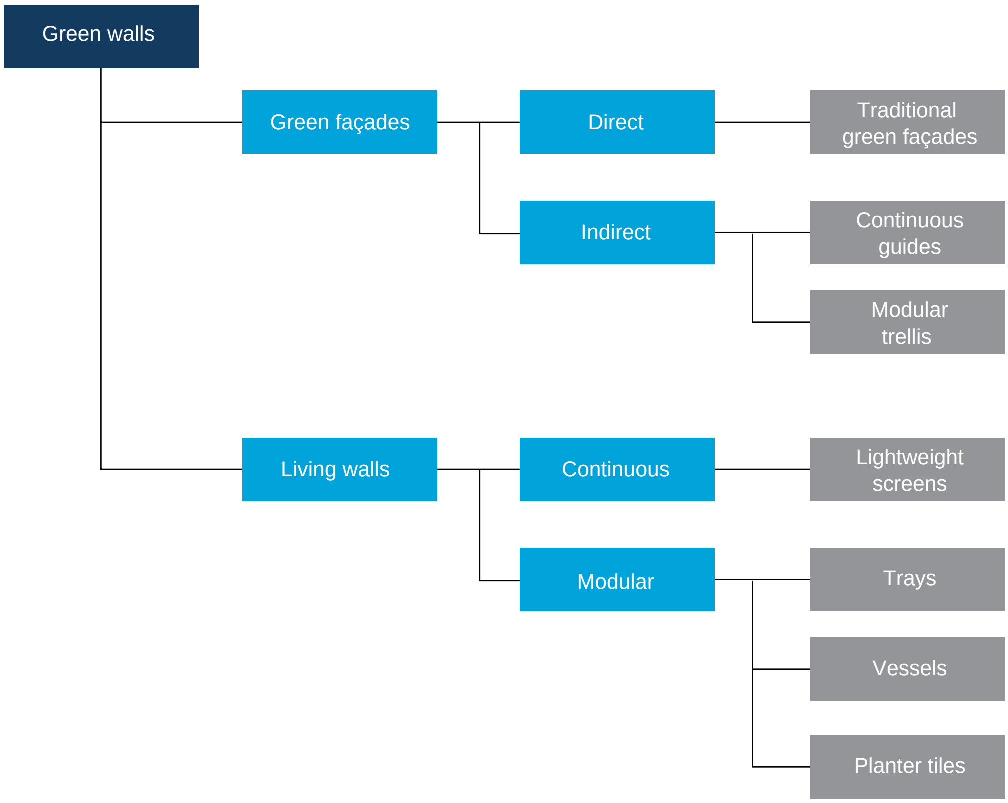
**Cooling method:**
Cools via evapotranspiration and shading of a building's walls.

| | |
|---|---|
| **Applicable use cases** | There are a number of green wall technologies that are technically applicable across a range of building types. The availability of water is critical to the performance of green walls. |
| **Benefits** | • Net energy savings<br>• Improved indoor thermal comfort<br>• Air temperature reductions (at scale)<br>• Aesthetics |
| **Considerations (significance of effect)** | • First cost (medium/high)<br>• Maintenance (medium)<br>• Water requirements particularly during establishment period, heat events, or droughts (medium) |
| **Economics** | Green exterior walls have a substantial cost premium over standard walls on buildings. |
| **General recommendation** | Green walls should be encouraged where water availability is not a constraint. |

*Source:* Authors.

Green walls can be classified into green façades or livings walls, according to their construction and main characteristics (Cuce 2017). Figure 14 illustrates some of the green wall design options. Green façades are classified as either direct or indirect. A direct green façade is a wall where the plants, for example vines, are attached directly to the building surface, while an indirect green façade includes a vertical structure that supports the climbing plants. A living wall utilizes complex planter boxes and pre-vegetated and prefabricated supporting structures to facilitate plant growth. The success of a green wall is determined by several factors, such as plant choice (native versus non-native), irrigation system, orientation of the wall, and design conditions such as shading and window placement (Yenneti et al. 2017). Green walls can be found in a number of cities, including Hong Kong, Shanghai, Singapore and Mexico City. The experiences of Singapore and Mexico City are highlighted in Box 7 and Box 8, respectively.

## FIGURE 14: GREEN WALL DESIGNS




*Source:* Yenneti, K., M. Santamouris, D. Prasad, and L. Ding (2017), "Cooling Cities Strategies and Technologies to Mitigate Urban Heat," Cooperative Research Center for Low Carbon Living. http://lowcarbonlivingcrc.com.au/sites/all/files/event_file_attachments/discussion_paper_cooling_cities_final.pdf

## BOX 7: CASE STUDY: SINGAPORE, THE MODERN GARDEN CITY

Singapore has undertaken a series of ambitious initiatives to enhance heat resiliency. For example, the city-state is investing in its 1967 "garden city" plan with large-scale tree planting, sophisticated tree monitoring, and the development of new park land (Photo 7). The greening efforts have turned to green façades and sky gardens as development in the city has become increasingly vertical in nature, driven by the adoption of the Landscaping for Urban Spaces and High-Rises (LUSH) policy. LUSH is a set of building regulations that requires on-site greenery equivalent to the size of the site being developed. By 2030, the city aims to double its current sky garden coverage to 200 hectares.

**Photo 7: Singapore, a modern garden city**

Source: DepositPhoto.

## BOX 8: CASE STUDY: VIA VERDE, TURNING MEXICO CITY'S GREY ROADS GREEN

**Photo 8: Vertical gardens replace grey pillars in Mexico City**

Credit: Via Verde.

In an effort to reduce air pollution and dust, Mexico City has installed a series of vertical gardens (Photo 8) along a major ring road, the Periférico Highway, under an initiative called Via Verde. The project, launched in 2016 after a public petition amassed 80,000 supportive signatures, now covers 1,000 columns along the roadway. Each column has a remotely activated irrigation system and Internet-connected sensors that monitor water, light, temperature, and nutrient levels in real time. Project organizers estimated that the installation would filter 27,000 tons of vehicle emissions, 10,000 kg of heavy metals, and capture 5,000 kg of dust each year. While the project has been well received by the public, there are some concerns that the plants selected for the gardens (primarily resilient succulents) do not achieve the environmental and pollution reducing benefits initially estimated by the project organizers. The project is not funded with public money. Rather, private investment from 50 companies covered the 300 million peso (US$13.5 million) cost of the project, with the understanding that a portion of the columns would be used for advertising. Currently, project organizers are planning to green an additional 800 columns in the greater Mexico City region, with a goal to cover 10 million $m^2$ of gardens, roofs, walls, columns, and bridges by 2030. The project has received international attention and is planning expansions to other major Mexican cities (including Guadalajara, Monterey, and Puebla) as well as cities in the United States, Central America, Europe, and Asia.

### 3.4.2.1 Green Walls: Economic Considerations

The cost of a green wall varies considerably by type, based on a survey of European markets. The cost of grown climbing plants next to a building is around US$34–$168 per square meter, depending on the type of supporting system, planter, and materials used. A living wall system of pre-vegetated panels can significantly vary in cost as well: from US$450 to $1,350 per square meter depending on the system and material used. Much of the difference between the two systems is due to the maintenance needed for the upkeep of the living wall, the materials involved, and the complexity of the design (Perini and Rosasco 2013).

Green walls generate a number of economic benefits, including enhanced building energy efficiency, improved air quality, increased biodiversity, and other ecosystem services with a large social benefit (Green Roofs for Healthy Cities 2008). Green walls also enhance the aesthetics of buildings, leading to higher property values and improved rental rates (Haggag and Hassa 2015; Perini and Rosasco 2013).

### 3.4.2.2 Green Walls: Other Considerations

Green walls are still a small subset of the market for urban cooling products. The considerations for use presented here reflect the fact that markets have not yet reduced up-front cost premiums and other costs. As the market matures and these costs start to fall, green walls could play an important role in urban cooling strategies, particularly in dense, vertical urban spaces.

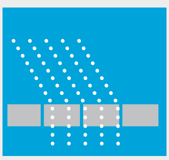
**First cost:** Though there are broad benefits of green walls, many of the systems have high up-front costs. Costs can be mitigated by plant and support material choices, but these systems remain in limited use in urban settings.

**Maintenance:** Maintenance can be time- and cost-intensive, especially for living walls. Watering, nutrient additions, and ensuring soil remains in place requires regular attention.

### 3.4.3 Permeable Pavements

Permeable pavements are very similar to their conventional asphalt and concrete counterparts, but are mixed without fine particles to allow for the passage of stormwater through the surface of the pavement. After the water passes through the permeable surface (see Photo 9), it is temporarily stored in an underlying crushed rock storage reservoir (known as a recharge bed) and slowly released into the underlying soils. A filter fabric is placed on the floors and sides of the recharge bed to prevent soil from migrating into the bed. Applications and benefits of permeable pavements are described in Table 11. While these

**TABLE 11: PERMEABLE PAVEMENTS APPLICATIONS, BENEFITS, AND ECONOMICS**



**Cooling method:**
Cools by evaporating water stored in the pavement.

| | |
|---|---|
| **Applicable use cases** | Most appropriate for lower traffic areas such as parking lots, alleys, curb lanes, or trails. Not appropriate where polluted water would be released directly into a natural body of water. |
| **Benefits** | • Better stormwater management<br>• Cooler surface temperatures<br>• Air temperature reductions (at scale)<br>• Urban heat mitigation<br>• Reduced traffic noise<br>• Reduced ponding/surface water on roadways |
| **Considerations (significance of effect)** | • Urban cooling benefit is reduced when pavement is dry (medium)<br>• Reduced durability if installation is not done properly (medium/high)<br>• Potential to over-tax drainage capacity (minor)<br>• Possible to allow unfiltered pollutants into water bodies (minor) |
| **Economics** | Permeable pavements have a substantial cost premium over standard pavements. Regular maintenance is needed to retain permeability and should be included in operating budgets. Capital budgets may also be affected if municipality buys specialty cleaning equipment. |
| **General recommendation** | Cities should 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. |

*Source:* Authors.

technologies have traditionally been installed to filter, manage, and retain stormwater, they also have a cooling benefit similar to green infrastructure. As pavements heat up, moisture in the structure evaporates and contributes to lower day- and nighttime temperatures. Permeable pavements refer to a number of individual technologies including:

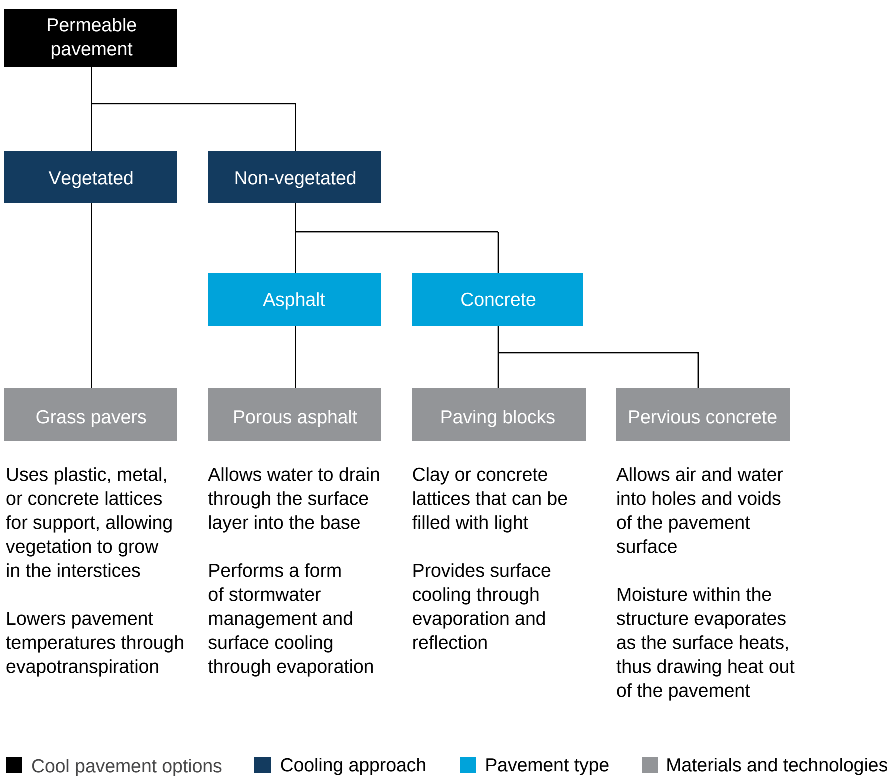
- Porous asphalt
- Pervious concrete
- Pavers (brick, block, or stone)
- Grass or gravel grid pavers

**Photo 9: Porous asphalt allowing water to infiltrate next to an impermeable pavement**

Source: National Asphalt Paving Association.

Permeable asphalt and concrete cool through a roughly similar process of water infiltration through air voids, though permeable concrete may be cooler due to its lighter initial color. Figure 15 summarizes some of the current options for permeable pavements. Key design features of permeable pavement types are shown in the Case Study appendix.

## FIGURE 15: PERMEABLE PAVEMENT DESIGNS




*Source:* Bloomberg Associates (2019), "Mitigating Urban Heat Island Effects, Cool Pavement Interventions," https://www.bbhub.io/dotorg/sites/32/2019/08/20190516_Cool-Pavement-Research-FINAL.pdf

### 3.4.3.1 Permeable Pavement: Economic Considerations

Figure 16 summarizes the estimated service life and installed cost of common permeable pavement technologies and Box 9 describes a case study in Tokyo (Photo 10). There is a substantial up-front cost premium for permeable pavement, based on pricing from U.S. markets (Bloomberg Associates 2019).

**FIGURE 16: SERVICE LIFE AND COST OF PERMEABLE OPTIONS IN U.S. MARKETS**

| | SERVICE LIFE (estimated) | APPROXIMATE COST (U.S.) per $M^2$ | COST PREMIUM OVER HOT MIX ASPHALT |
|---|---|---|---|
| Porous asphalt | 7–10 years | \$21–\$27 | 34%–98% |
| Pervious concrete | 15–20 years | \$54–\$67 | 164%–191% |
| Paver blocks | Over 20 years | \$54–\$108 | 350%–368% |
| Grass/gravel pavers | Over 10 years | \$16–\$62 | N/A |

*Source:* Bloomberg Associates (2019), “Mitigating Urban Heat Island Effects Cool Pavement Interventions,” https://www.bbhub.io/dotorg/sites/32/2019/08/20190516_Cool-Pavement-Research-FINAL.pdf

### 3.4.3.2 Permeable Pavement: Other Considerations

The considerations presented here highlight the importance of the specific placement of permeable pavements. Permeable pavements can be usefully deployed in areas where heat and stormwater present a dual hazard, assuming the following factors are considered.

**Cooling effectiveness when dry:** The ability of dry permeable pavements to influence temperatures is complex and still being investigated by researchers. The air voids in permeable pavement create more surface area that may allow solar radiation to increase daytime surface temperatures and increase the ability of wind to transfer surface heat into the air. However, the air voids also reduce the mass of the pavement, which allows the pavement to cool more quickly and reduce nighttime heat releases into the air compared to traditional pavements.

**Choosing the right use case:** Permeable pavement may be most appropriate for lower traffic areas such as parking lots, alleys, curb lanes, or trails. Permeable pavements are not appropriate for roads that carry heavy-axle loads and where the slope of the road is too steep (over 5 percent grade) (Metropolitan Area Planning Council 2014).

**Proper installation and maintenance:** Like all urban cooling strategies, permeable pavements must be installed and maintained correctly to be effective. Improperly installed permeable pavements may erode rapidly or fail to allow infiltration of water at the volume expected. Dust, dirt, salt, and trash also reduce water infiltration. Regular cleaning may be necessary and may require special vacuum equipment to adequately clean and restore performance to permeable pavements.

**Overtaxing drainage capacity:** Water backups from the recharge bed and flooding may occur if permeable pavements are receiving overflow stormwater from other drainage areas. Installing a backup channel or adding an infiltration area to neighboring drainage areas will help reduce the chances of overloading a single recharge bed.

**Pollution:** There is no way to pretreat stormwater before it infiltrates permeable pavement. Thus, permeable pavements should be avoided in areas where stormwater picks up high pollutant loads from oil, grease, sediments, pesticides, nutrients/fertilizer, animal waste, bacteria, road salt, and heavy metals.

## BOX 9: CASE STUDY: COOL PAVEMENTS IN TOKYO

Photo 10: Shibuya Crossing, Tokyo

Source: DepositPhoto.

Over the last century, average ambient temperatures in Tokyo have risen by 3°C, or about 2.5 times faster than in the rural areas surrounding the city. The Tokyo Municipal Government (TMG) has taken measures to mitigate the impacts of excess urban heat, including covering roofs and walls with greenery and passing the Nature Conservation Ordinance in 2001 (C40 Cities 2015). The Ordinance requires the greening of roofs and walls for all new construction and existing buildings undergoing renovations, as well as increased vegetated cover on building sites. TMG is also promoting cool pavements by including cool coating and permeable/porous pavement installation as a part of road maintenance and construction within identified priority areas in central Tokyo. The city approved reflective and permeable pavement specifications so that they may be used as a part of road maintenance and repair, if applicable and cost effective. TMG also provides a subsidy for cool coatings on pavements to encourage their installation.

TMG undertook an advertising campaign for the conservation ordinance and its compliance requirements and followed it up with strong enforcement practices. Since 2001, more than 5,700 buildings have added about 1.8 million square meters of green roofs in Tokyo.

Promoting the greening of existing buildings has not only helped in beatification of the urban landscape, but has also proven to be an effective measure to counter the heat island effect. Research done in 2004 showed that new, lightweight green roofs applied to existing buildings could lower the roof surface temperature by 25°C and the temperature on the ceiling of rooms below the roof by 1–3°C, even with thermal insulation.

Data collected by the TMG found that reflective and permeable pavements reduce road surface temperatures by a similar amount. The TMG deploys both technologies, typically using permeable pavements in areas where stormwater management is also a priority. TMG has linked the cool pavement programs with the 2020 Summer Olympics (now postponed due to the novel coronavirus pandemic) by installing cool pavements, trees, and shade structures along the marathon routes and on roads around the venues. The program, which costs the city approximately $6.7 million annually, has resulted in 84 kilometers of cool pavements, including 64 kilometers of cool-coated pavements and 20 kilometers of permeable/porous pavements.

### 3.4.4 Tree Canopy and Parks

Increasing urban tree canopy is a common solution to cool cities that provides a myriad of co-benefits. Applications and benefits of tree canopy and parks are summarized in Table 12. Trees and vegetation are most useful as a mitigation strategy when planted in strategic locations around buildings and areas with high pedestrian traffic. Trees provide cooling via evapotranspiration, and they have the added cooling benefit of producing shade on urban surfaces, like pavements and buildings. Comparisons of temperature within more dense urban forests and non-green urban sites have also shown lower temperatures in the forested sites (Bilgili et al. 2013; Huang et al. 2008; Shahidan et al. 2012; Akbari et al.

## TABLE 12: TREE CANOPY AND PARK APPLICATIONS, BENEFITS, AND ECONOMICS

**Cooling method:**
Cools via shade and evapotranspiration.

| | |
|---|---|
| **Applicable use cases** | Trees and parks are appropriate where adequate water is available and when species choice reflects local natives and those that will thrive in expected future local climate conditions. |
| **Benefits** | • Energy savings (when properly positioned)<br>• Improved indoor thermal comfort (when shading buildings)<br>• Air temperature reductions (at scale)<br>• Air quality improvements<br>• Pedestrian thermal comfort<br>• Aesthetics and recreational value<br>• Improved biodiversity and habitats |
| **Considerations (significance of effect)** | • Heat may be slower to dissipate at night (minor)<br>• Avoid introducing non-native, invasive, or other species not suited to future local climate conditions (medium)<br>• Public safety implications (minor) |
| **Economics** | The ecosystem services provided by trees substantially exceeds up-front and maintenance costs. |
| **General recommendation** | Cities should consider planting and maintaining trees wherever appropriate and according to appropriate configuration. |

*Source:* Authors.

1992). A row or a concentration of trees reduces average daytime temperatures by between 0.5–2°C (McDonald et al. 2016). Several cities are developing green corridors to take advantage of these cooling opportunities. One such example from Medellin, Colombia is described in Box 10.

Park space also contributes to urban cooling. A study comparing the temperatures of 61 parks during the summer at noon in Taipei City found that parks over 3 hectares were usually cooler than the surrounding urban area while the temperature difference was much more variable for parks of less than 3 hectares (Chang, Li, and Chang 2007). Studies suggest the cooling effect of large parks extends some distance from the park boundary. A study measuring temperatures at increasing distance from two large parks in Singapore found cooling impacts up to 500 meters from the park boundary. Cooling effects from parks will also depend upon factors such as (Venhari, Tenpierik, and Hakak 2017):

- the size and structure of the park
- type of plants
- irrigation frequency
- level of sky obstruction

- distance between a dense urban area and the park
- the thermal balance of the surrounding areas
- the characteristics of the reference urban area, including density, prevailing climate condition, and climate zone.

### 3.4.4.1 Tree Canopy and Parks: Economic Considerations

Trees generate a substantial economic benefit for communities but often that benefit is not fully captured in the economic decision making of building owners and developers. Table 13 summarizes the ecosystem services that accrue from increased tree cover.

Incorporating the value of these ecosystem services shows substantial net benefits over costs from tree planting and maintenance programs. In Melbourne, studies indicate a cost benefit ratio of 1:6 (Moore 2009). A study from Modesto, California, found that each $1 invested in tree planting yields $2 in benefits for residents. A study of 245 of the world's largest cities found that an ambitious but well-targeted campaign to plant trees would cost approximately US$3.2 billion (about $4 annually per person) and save between 11,000 and 37,000 lives globally from reduced $PM_{2.5}$ exposure and reduced heat wave deaths, with the most polluted cities, Delhi, Dhaka, and Mumbai, among others, reaping the highest benefits (McDonald et al. 2016).

### 3.4.4.2 Tree Canopy and Parks: Other Considerations

In almost every case, adding more tree canopy and park space will be an important urban cooling strategy for cities and provide benefits beyond heat reduction. The considerations presented here should not dissuade cities from pursuing tree canopy or park development, but rather inform how and where that program would produce optimal outcomes.

**Availability of water:** Irrigation may be needed to supplement precipitation to support new tree canopy and parks on a long-term basis. In that case, heatwaves and droughts can quickly dry soils and reduce the cooling benefit of trees and green infrastructure.

**Nighttime urban heat:** While most research suggests that trees and parks reduce daytime heat in cities, several studies found that tree canopy may retain heat longer at night than an open, grassy area as a result of impeded wind flow (Taha, Akbari, and Rosenfeld 1991; Huang et al. 2009). Though tree canopies retain some heat at night, they are more beneficial for nighttime conditions in hot weather relative to a warmed-up, impermeable surface like asphalt. While these impermeable surfaces do cool down quickly, they do so by releasing stored heat as thermal radiation into the air, increasing air temperature.

**Proper plant selection:** Plant and tree species should be carefully evaluated to ensure they are appropriate for the location and climate they will be planted in. Non-native or exotic, imported species may produce unexpected and unwanted side effects, such as an increase in emissions of volatile organic compounds. Native and locally appropriate species should be chosen based on how well they will withstand expected future climate conditions. For example, in India, scientists found that native species like fig, banyan, mango, and ashoka, with their large thick leaves, withstood air pollution better and were more suited to planting in that urban area. In addition, a varied range of tree species should be used to reduce the risk of tree die-offs due to invasive species.

## TABLE 13: ECOSYSTEM BENEFITS OF TREE CANOPIES

| ECOSYSTEM SERVICE | DESCRIPTION |
|---|---|
| Aesthetic benefits | The presence of trees and parks increases people's perception of beauty, and thus their happiness. This benefit has monetary value; for example, homes with street trees in front are worth significantly more money. |
| Recreation | Greenspace is often used for recreation–everything from walking to playing sports to simply relaxing. |
| Physical health | Greenspace is used for recreation, and recreation improves people's health. |
| Mental health | Research shows that interacting with nature decreases stress and increases focus. |
| Spiritual value and sense of place | Greenspace often plays an important role in people's spiritual life and appreciation for their city. (What would New York City be without Central Park?) |
| Biodiversity | The presence of trees and parks helps provide a habitat for biodiversity. |
| Erosion prevention | Trees and other vegetation reduce erosion by stabilizing soil. |
| Stormwater mitigation | Trees and wetlands, whether constructed or natural, can help increase infiltration of stormwater and filter pollutants out of it. |
| Mitigating flood risk | By slowing the movement of stormwater downstream, trees and wetlands can reduce localized flooding risks. Within floodplains, natural habitats provide a place for floodwaters to go, slowing the movement of floodwaters. |
| Coastal protection | Along coastlines, natural habitats such as mangrove forests offer protection from rising seas. |
| Air purification (particulates, ozone) | Trees reduce air pollution concentrations. |
| Shade and heat wave mitigation | Trees reduce ambient air temperatures. |

*Source:* McDonald et al. (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://global.nature.org/content/healthyair

**Safety:** Traditionally, law enforcement officials and policy makers alike have, at times, strategically removed vegetation in open areas with the notion that vegetation created more sense of fear among residents and helped to conceal and facilitate crime. However, an analysis of 98 apartment buildings in Chicago showed that buildings with higher levels of green surroundings saw fewer reported crimes (Kuo and Sullivan 2001).

**BOX 10: CASE STUDY: THE GREEN CORRIDORS OF MEDELLIN, COLOMBIA**

**Photo 11: Medellin, Colombia**

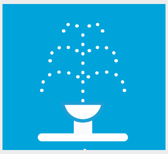
Source: DepositPhoto.

Medellin, Colombia (shown in Photo11), has developed 30 “green corridors” to cool down its nearly 6°C urban heat island. The corridors connect existing green park areas by adding large- and medium- sized trees, as well as smaller vegetation. The city evaluated areas for high traffic and pedestrian usage and prioritized those for early corridor development. In addition to the cooling benefit, the green corridors have improved biodiversity, aesthetics, and access between neighborhoods, particularly those across waterways now connected by bridges or stairs. The municipal government is paying for installation and maintenance, but also for capacity building of volunteer urban gardeners to help maintain plantings, particularly during the dry season.

## 3.5 WATER INFRASTRUCTURE

The surface temperature of water is typically several degrees cooler than the surface temperatures of the surrounding built environment and therefore can contribute to cooling the ambient air through convective processes (Yenneti et al. 2017). Water-based urban landscapes, such as lakes, rivers, and wetlands contribute to “urban cooling islands” and may decrease the city’s ambient temperature by 1–2°C (Manteghi, bin Limit, and Remaz 2015). Water infrastructure may be man-made and include fountains, swimming pools, and misting stations. Active or hybrid water components such as evaporative wind towers and sprinklers have been developed, tested, and implemented in urban public spaces around the world (Yenniti et al. 2017). In addition to their passive cooling benefits, water features such as fountains and pools may be repurposed on extreme heat days to serve as cooling stations for urban residents. Some cities like Tokyo have experimented with misting or irrigating roads and other paved urban surfaces to enhance cooling.

## TABLE 14: WATER INFRASTRUCTURE APPLICATIONS, BENEFITS, AND ECONOMICS



**Cooling method:**
Cools via convection of air over cooler water surface and as a swimming feature.

| | |
|---|---|
| **Applicable use cases** | Employ in combination with shade to reduce evaporation. |
| **Benefits** | • Local cooling center during extreme heat<br>• Cooler surface temperatures<br>• Contributes to cooler air temperatures in combination with other strategies<br>• Aesthetics and recreational value<br>• Urban heat mitigation |
| **Considerations (significance of effect)** | • Water quality must be maintained if used for swimming (major) |
| **Economics** | Little to no cost to repurpose existing water infrastructure to support heat resiliency. New water infrastructure will incur first costs and ongoing maintenance. |
| **General recommendation** | Cities should consider existing water features as strategies for mitigating urban heat during extreme heat events. This may require signage, safety enhancements, and water quality checks. |

*Source:* Authors.

## 3.6 URBAN DESIGN

Urban planning aspects (e.g., population density, land use mix, road density, and percentage of green open space) and landscape features (e.g., spacing, orientation, and positioning of buildings, green space, and pavements) are important factors impacting excess urban heat. These factors influence urban heat intensities by affecting how much sunlight is absorbed by urban surfaces, how effectively wind moves through urban communities, and how efficiently buildings and pavements shed heat. Urban design for heat resiliency should be evaluated at the neighborhood level. The interactions between neighborhood design and heat are complex and shift throughout the day. A structure providing over-hanging shade (e.g., free-standing solar panels, cantilevered building features) will promote a cooler environment during the day, but may capture heat emissions and slow cooling at night. Box 11 describes some of the common urban design concepts that are relevant to urban heat.

## TABLE 15: URBAN DESIGN APPLICATIONS, BENEFITS, AND ECONOMICS

**Cooling method:**
Cools by minimizing heat gain and stored heat in urban structures and optimizing natural wind flow.

| | |
|---|---|
| **Applicable use cases** | All cities, with a particular focus on areas of new development. |
| **Benefits** | • Energy savings (when shading buildings)<br>• Improved indoor thermal comfort (when shading buildings)<br>• Air temperature reductions (at scale)<br>• Air quality improvements<br>• Pedestrian thermal comfort<br>• Aesthetics and recreational value<br>• Equity and social connectedness<br>• Urban heat mitigation |
| **Considerations (significance of effect)** | Urban design for cooling is easier and less costly to implement in the development of new neighborhoods and cities than in existing ones. (medium) |
| **Economics** | No cost premium associated with integrating heat resiliency into existing planning processes. |
| **General recommendation** | All cities should consider incorporating heat sensitive and wind-optimizing design principles into their planning processes. |

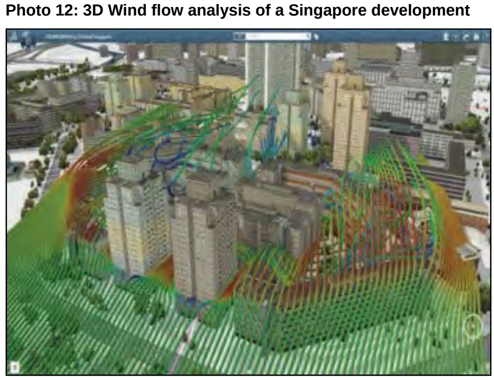
*Source:* Authors.

### 3.6.1 Promoting Wind Flow

Buildings or groups of buildings that impede wind flow contribute to slower wind speeds and reduce the ability of a neighborhood to remove heat and polluted air. Wind corridors are designed to maximize the movement of cool air from natural cooling sources (typically water, large parks, or green infrastructure) toward urban hotspots through advection (Icaza, Dobbelsteen, and Hoeven 2016). Urban wind flow can be improved by (Salat 2019):

- Aligning building corridors with the prevailing wind
- Connecting open spaces
- Prioritizing open spaces near water bodies

**Photo 12: 3D Wind flow analysis of a Singapore development**



Source: 3DEXPERIENCity.

## BOX 11: URBAN DESIGN CONCEPTS RELEVANT FOR UNDERSTANDING URBAN HEAT

Several concepts are relevant for understanding the urban heat implications of urban geometry.

- **Sky view factor:** a measure of the fraction of sky visible from the ground. It is measured on a scale of 0–1, where 0 is totally obscured and 1 is completely open to the sky. A surface with a low sky view factor receives less solar radiation during the day and will be more thermally comfortable than a surface with a high sky view factor. However, an area with a low sky view factor may indicate conditions that trap heat at night, keeping temperatures in those locations higher than areas that can more easily shed stored heat.

- **Aspect ratio:** a measure that describes the height of buildings compared to the distance between them (often abbreviated as H/W). The effect of the aspect ratio on heat conditions is similar to the sky view factor. High aspect ratios indicate a tall but narrow urban canyon that provides lots of shade for thermal comfort during the day but may be difficult to cool down at night due to impeded wind flow.

- **Object height ratio:** a measure that compares the heights of adjacent buildings and trees. In the context of heat, object height ratio is a determinant of how much shade is generated on built surfaces and, in some cases, how well wind flows through the area.

- **Object orientation:** the layout and shape of buildings in an urban environment. Considering heat, building orientations that minimize direct solar exposure and maximize natural wind flows will generate the most urban cooling potential. Certain orientations are generally more heat trapping than others. For example, cities laid out on precise grids experience more intense urban heat islands than cities with a more disordered layout (Poon 2018).

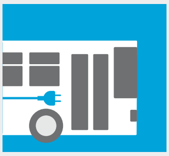
- Arranging buildings to channel wind
- Increasing building setback from property lines
- Reducing monolithic wall space where possible
- Encouraging stepped building height profiles.

Urban designers and planners use an increasing number of analytical tools (one of which is shown in Photo 12) to evaluate the effect of new construction on wind patterns.

## 3.7 REDUCING WASTE HEAT

Waste heat in a city is typically generated by the operation of air-conditioning/chiller units (used for space cooling), portable generators, industrial processes, or by vehicles. Addressing these heat sources is an important part of an integrated cooling strategy for cities, although they are not the primary focus of this primer. This section provides a brief overview of strategies that cities may adopt to manage and reduce waste heat. Additional and more detailed coverage of these concepts may be found in other resources, including in the forthcoming (2020) *ESMAP Primer on Space Cooling* (C40 Cities n.d.).

## TABLE 16: REDUCING WASTE HEAT APPLICATIONS, BENEFITS, AND ECONOMICS



### Measures to mitigate waste heat:

Strategies, within municipal government control, to reduce heat emissions from space cooling, transportation, and industrial processes. These may include:

- Building and energy codes and measures to enhance energy and cooling efficiency
- Government procurement and contracting policies
- Awareness raising, communication to influence behavior change and encourage more efficient use of energy and limit excessive space cooling
- Enhanced public transportation and/or vehicle regulations to reduce heat. Transition to electric mobility
- Encourage shift from private to public transport and implement measures to reduce vehicles in city (offering alternative options)
- District cooling
- Measures to encourage waste heat recovery

| | |
|---|---|
| **Applicable use cases** | Improved space cooling efficiency, waste heat recapture, and enhanced transportation policy to reduce heat are globally applicable strategies. District cooling suitability is site specific (e.g., depends on water availability, costs, proximity of sufficient anchor load). |
| **Benefits** | • Energy cost savings<br>• Improved indoor thermal comfort<br>• Air quality improvements<br>• Reduced traffic congestion (if enhancing public transportation options)<br>• Urban heat mitigation |
| **Considerations (Intensity of negative effect** | • Risk of refrigerants leaking when replacing AC systems (moderate)<br>• Ensure right conditions (including legal, economic and financial) are in place for district cooling (major)<br>• Measures/efforts needed to convince/encourage private automobilists to shift to public transportation (major)<br>• Planning charging infrastructure for electric vehicles (major) |
| **Economics** | • High investment cost of district cooling<br>• High investment cost of many public transportation options, with cost savings for individual users (compared to private individual car)<br>• More efficient space cooling has a higher first cost but typically lower life-cycle costs than less efficient units, due to energy costs savings over time. |
| **General recommendation** | • Integrate heat resiliency into transportation and urban planning processes.<br>• Encourage or require higher efficiency and low global warming potential space cooling options.<br>• Facilitate demonstrations of district cooling and industrial waste heat recapture where appropriate. |

*Source:* Authors.

### 3.7.1 Space Cooling (Air-Conditioning)

Space cooling can be defined as the means through which people are provided thermal comfort by maintaining the optimum temperature, humidity, and ventilation within built environments. In a warming world and in cities facing urban heat island effects, access to space cooling is key for the health, productivity, and well-being of citizens. The strategies to provide space cooling and achieve thermal comfort can be grouped into two categories: passive and active cooling. Passive cooling, which refers to building design and measures (such as building orientation, insulation, natural ventilation, and shading) that avoid or eliminate the need for mechanical cooling, does not generate waste heat. Cities can encourage such measures through building codes and other measures to enhance the energy efficiency of buildings. Active cooling involves the use of mechanical means, with the main ones for many urban dwellings consisting of essentially electric fans and air-conditioning systems, including chillers. Air conditioners reduce indoor air temperatures as well as humidity levels and are the dominant technology for space cooling, poised to increase significantly in many developing countries.[29] However, while air conditioners are effective at helping people cope with increasing temperatures in cities, they exhaust heat generated by their mechanical and electrical components into the air and contribute to outdoor temperature increases. Space cooling is typically managed at the building or room scale, leading to a large number of cooling units adding heat to warming cities. Space cooling will be an important part of most cities' strategies to cool down and become more resilient to rising heat. Efforts to enhance passive cooling, improve the energy efficiency of air-conditioning units, and to promote more resource-efficient district cooling, where feasible, will help to offset the effect of increases in cooling demand on urban heat.

**Improved energy efficiency:** While all of the cooling strategies presented in this primer will help offset the warming effect caused by waste heat, measures to improve the energy efficiency of space cooling are important to reduce air conditioners' heat effect in the first place. Even in markets where high-efficiency air-conditioning units are available, the average unit sold tends to be the least expensive and least efficient model. In addition to air conditioner energy efficiency, other waste heat reduction strategies include, improving ventilation for space cooling units and raising indoor cooling temperature set points. Cities may influence consumers to purchase more efficient air-conditioning units by enacting and enforcing more stringent building energy codes, through their own procurement and contracting practices, and by providing incentives to upgrade to more efficient units. Cities may also establish programs to raise awareness among the general public about the trade-offs between indoor cooling and outdoor comfort and encourage the purchase of more efficient units.

**District cooling:**[30] District cooling delivers chilled water to buildings from a central plant or a set of distributed sources. Such systems offer cities a more efficient and climate-friendly cooling option to substitute the individual room air-conditioning units and chillers and therefore could contribute to the efforts to mitigate excess urban heat. District cooling systems allow easier integration of renewable energy and thermal energy storage, and produce less air and heat pollution than mechanical cooling. That said, district cooling may not be a feasible option in all cases. District cooling uses more water than other cooling strategies and may be less appropriate for places with limited access to water or where fresh water is expensive to obtain. Also, the high up-front costs pose a significant barrier for many cities. Furthermore, district cooling investments typically need to be made in commercial and high-density residential buildings with significant cooling loads to be financially sustainable. By aggregating the cooling need of a cluster of buildings, district cooling creates an economy of scale that reduces peak electricity demand for cooling by shifting production to periods of the day or night when there is less pressure on the electrical network. Box 12 highlights a district cooling project implemented in Medellin, Colombia.

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29 The IEA (2018) estimates that the global average rate of household ownership of air conditioners jumps from just over 30 percent in 2016 to almost 65 percent in 2050, with India and China accounting for about half of the increase, and with significant growth projected in Africa and in the Middle East.

30 For more information on district cooling, please see International District Energy Association (n.d.) and U.N. Environment District Energy in Cities Initiative (n.d.).

**BOX 12: CASE STUDY: MEDELLIN, COLOMBIA—LA ALPUJARRA DISTRICT COOLING PROJECT**

Medellin's municipal utility, EPM, built a district cooling system for Medellin's high-profile administrative campus. At a cost of nearly US$18.5 million, the system serves seven public buildings with chilled water from a central plant consisting of a small gas turbine (1 MW), an electrical substation, an absorption chiller, cooling towers, and a heat exchanger. The project is estimated to lead to energy savings of 15–20 percent (compared to previous consumption), the elimination of ozone depleting substances, a 30 percent reduction in $CO_2$ emissions, and a reduction in the city's urban heat island effect. Project planning and development was funded by EPM, the Swiss State Secretariat of Economic Affairs (SECO), the Technical Ozone Unit of the Colombian Ministry of Environment and Sustainable Development, and Colombia's International Presidential Cooperation Agency. Going forward, the utility will recover costs via customer service charges (both a fixed charge and variable usage fee). The municipality played a key role in coordinating the various market stakeholders and, crucially, providing a guaranteed buyer for enough of the district cooling services to justify the up-front investment.

### 3.7.2 Transportation[31]

Cars and trucks in concentrated urban areas are another source of anthropogenic waste heat, particularly when idling. Excess urban heat caused by vehicles can be mitigated by reducing the number of vehicles in the city, improving fuel economy, switching from hot combustion engines to cooler electric engines, putting in place mechanisms such as dynamic pricing to reduce time vehicles spend circling for parking, implementing information communication technologies (ICT) and sensors to smooth traffic, increasing delivery windows to maximize vehicle loads and reduce trips, and so forth. Cities have experimented with various ways to provide mobility options to their citizens, while reducing congestion and lowering GHG emissions and waste heat, including:

- more available, safe, clean and convenient public transportation, with integrated transport passes, real-time information on arrival/departures, and considerations for intramodality
- financial and convenience incentives to switch from personal to public transit
- vehicle bans, no-car days, even/odd license plate restrictions, congestion charging, and limited parking, etc., in downtown districts
- encouraging electric vehicles by developing charging infrastructure and converting municipal government vehicle fleets
- bicycle sharing and personal mobility programs
- expanded pedestrian and bicycle rights-of-way.

### 3.7.3 Industrial Processes

Heat is a byproduct of a number of industrial, data center, and manufacturing operations, many of which are located in cities or urbanized areas. A substantial amount of energy used by industry is wasted as

31 For more resources on transportation and heat, please see Sustainable Mobility for All (n.d.).

heat in the form of exhaust gases, air streams, and liquids leaving industrial facilities. Recovering and reusing that waste heat can reduce excess urban heat, as well as provide additional industrial efficiencies and value streams. Reusing industrial waste heat within industrial processes, district energy systems, and combined heat and power facilities can offer opportunities for cities to reduce the energy used for space cooling and heating in residential, commercial and municipal buildings (Woolley, Luo, and Simeone 2018). The use of waste heat in district energy systems can be found in London, England; Reykjavik, Iceland; Tokyo, Japan; and Seoul, South Korea. Assuming district energy is deemed to be a viable local option, cities can play an important role in supporting district energy systems by incorporating their use into urban planning processes, offering incentives (e.g., accelerated depreciation, purchase agreements to improve market security, low-interest financing) to develop infrastructure, and coordinating the local district energy market stakeholders. Cities may also encourage industries to recover and reuse the waste heat they generate.[32]

## 3.8 LINKAGES BETWEEN URBAN HEAT MITIGATION STRATEGIES, ENERGY EFFICIENCY, AND RENEWABLE ENERGY

There is no "one-size-fits-all" solution for reducing urban heat. Deployments of multiple solutions will help facilitate cooling and contribute to other important societal and environmental goals. The urban cooling mitigation potential from the combined use of a variety of approaches is often greater than the sum of the contributions of each individual solution (Yenniti et al. 2017). Since air temperature reductions at the community and city level occur when strategies are deployed at scale, a combination of strategies is often needed to change enough of the urban landscape to produce the deployment scale needed for meaningful urban cooling. Some recent examples of the enhanced benefits of a combined deployment strategy include:

- Increased solar energy output from solar panels placed above a green roof versus panels over a black roof (Hellman 2018). Cooler roof surface temperatures reduce electrical resistance as electricity from the panels is transmitted to inverters and to the electrical grid.
- Solar reflective roofs and walls reduce evaporation by 9 percent and allow for more ground and near-surface moisture to be used to sustain trees, parks, and green space (Lawrence Berkeley National Laboratory 2017b).
- Shaded solar reflective pavements maximize pedestrian thermal comfort compared to shade and reflective pavements deployed separately (Taleghani, Sailor, and Ban-Weiss 2016).
- Solar reflective roofs paired with appropriate levels of insulation help optimize heat flow into and out of buildings in both winter and summer (Ramamurthy 2015).
- The combination of measures to incentivize passive cooling (energy-efficient buildings) and active cooling (energy-efficient air conditioners) will lower the overall energy requirements for space cooling, without compromising comfort. Air-conditioned buildings that undertake energy efficiency improvements reduce GHG emissions and the heat generated by the cooling equipment.
- Urban design and planning that prioritize heat mitigation will help optimize building and community-scale cooling strategies, such as increased green space and solar reflective surfaces.

32 For more resources on waste heat recapture, please see The World Bank (2014) and the U.S Office of Energy Efficiency and Renewable Energy (EERE) (2017).

Credit: Allison Kwesell/World Bank.

# 4. BARRIERS TO IMPLEMENTING URBAN COOLING STRATEGIES

Though the potential benefits of urban cooling strategies are great, a number of substantial barriers have slowed progress toward cooler cities worldwide. Many of the barriers associated with implementing energy efficiency in buildings are also factors for slow progress in implementing urban cooling. For example, both urban cooling and building energy efficiency face challenges due to differences between who pays for and who benefits from the measures (also referred to as the "principal-agent problem" or "split incentives"). However, urban cooling implementation also faces some unique barriers to progress including:

**No one owns the problem of urban heat:** There is no central authority in cities responsible for policy making, funding, and implementing solutions to address the challenges of heat on urban systems. Instead, the response to heat (or cooling) is often siloed in different agencies and organizations and pursued in an uncoordinated way. This is a challenge for cities in both the developed and developing world.

**Lack of awareness and availability of cooling solutions:** Particularly in developing countries, there remains a lack of information on available urban cooling solutions, how they perform in a local context, and the potential benefits of adopting them. Efforts to better quantify the effects of urban cooling measures and to evaluate and attribute qualitative/societal effects to urban heat mitigation will help strengthen the case—and build support—for taking action. Moreover, some urban heat mitigation/cooling solutions, such as products to increase solar reflectivity, may be limited or unavailable in a number of developing country markets. Limited availability of products increases the likelihood that prices will be higher than prices in developed markets. Additionally, there may be substantial certifications, requirements, tariffs, and duties that restrict, substantially delay, or raise the cost of imported products.

**Lack of comprehensive policy guidance or regulatory frameworks:** While there are numerous examples of good practices and policies to promote urban cooling, there are very few, if any, examples of cities taking a fully integrated approach to the challenge of urban heat. Cities have been largely opportunistic to address urban heat, and have generally not taken a systematic, multi-stakeholder approach to the challenge. There is a particular need to incorporate urban cooling more systematically into broader urban design, planning, zoning, regulatory, procurement, and building code processes.

**Limited applicability of some cooling strategies due to differences in roof usage and inadequacy of building construction and maintenance:** Buildings, particularly in cities in developing countries, may be old and poorly maintained, illegally constructed, or structurally deficient. Further, roof space may be used as living space and thus limit the types of cooling interventions that can be considered.

**Limited financing/incentives for cities and building owners:** To date, there have been insufficient financial resources dedicated to supporting and sustaining municipal cooling efforts from within city budgets, national budgets, development banks, or the private sector. Limited funding is a problem for cities in both developing and developed countries. Many cities face high levels of indebtedness and/or debt limits restricting their borrowing capacity; cities may also have difficulties accessing financing and attracting private investment due to a lack of creditworthiness. Further, the difficulty associated with monetizing the benefits of many of the urban cooling solutions, e.g., increased park land or tree canopy, along with the challenge of aggregating small and fragmented urban cooling solutions, e.g., cool roofs or green surfaces, makes it hard to attract private capital or to fund via municipal bonds or other mechanisms.

Incentives to invest in urban cooling solutions may take different forms, including regulatory, e.g., faster permitting, or financial, e.g., tax credits. When considering incentives, and how to justify them, it is important to understand the barriers, as well as the benefits. In addition to building energy savings, many passive cooling solutions also generate substantial non-energy benefits (including health, comfort, resilience, and employment, etc.). For example, a study on three diverse American cities estimates that energy efficiency benefits of passive cooling solutions like reflective roofs represent approximately 25–30 percent of the total estimated economic benefit generated by their use. Quantitative analyses that assess costs and benefits more comprehensively are helping demonstrate that a wide adoption of cost-effective urban cooling solutions can deliver large financial and economic benefits to cities and their residents, as well as keep the cities livable in a warming world (Kats and Glassbrook 2018). Section 7 covers financing options for urban cooling strategies in more detail.

# 5. ESTABLISHING AND IMPLEMENTING COOL CITY POLICIES

Excess urban heat is a uniquely complicated challenge that touches a wide array of city agencies, departments, private sector actors, the public, research institutions, and other stakeholders. Policy makers and practitioners should consider several questions when planning and taking action on urban heat.

- How can cities help individuals and households adapt to higher temperatures and provide a livable and resilient urban environment?
- How do they manage the negative side effects of individual cooling actions, such as temperature increases from waste heat generated by mechanical cooling and vehicles?
- How do cities catalyze and organize collective action?

To help cities answer these questions and develop an appropriate urban cooling strategy, this section proposes a framework, which has been effective in a number of cities that have used it. This framework seeks to inform efforts through a better understanding and characterization of the local challenges of urban heat, identification of existing activities and policies that support or hinder progress toward urban cooling, identification of data that may be needed to make informed decisions, engagement of relevant stakeholders, and evaluation of policy options (Table 17). The framework outlined here does not prescribe particular policies but rather a process to help identify which suite of measures and policies will be most effective and could be broadly supported. Examples of cities that have adopted urban cooling policies are presented in Section 6. While implementing this framework requires a great deal more coordination to be successful than an opportunistic, department-by-department approach, cities that have undertaken it have built broad, strong, and persistent support for the cooling strategies adopted. The framework also encourages coordinated planning for multiple hazards. Integrated hazard planning can uncover opportunities for heat mitigation strategies to serve multiple benefits, such as siting green infrastructure in areas where it may also help address stormwater challenges.

There are a number of steps cities can take to foster a locally appropriate, multi-solution strategy for urban heat mitigation. These steps can be taken in any order, but each is an important part of developing effective, measurable, and successful urban cooling programs. Each of these steps involves a set of questions to ask and actions to take (Table 17).

**TABLE 17: A FRAMEWORK FOR DEVELOPING URBAN COOLING STRATEGY**

| | |
|---|---|
| **Taking stock** | • What is the evidence of urban heat islands in the city? What kind of problem(s) do urban heat islands cause in the city?<br>• How can urban cooling contribute to existing priorities, strategies, and plans?<br>• What existing policies, programs, partnerships, developments, projects, or research would advance cooling efforts? |
| **Gather and analyze data** | • Where do urban heat islands exist in my city?<br>• Where do most vulnerable people live and work?<br>• Are there data on health impacts of urban heat islands?<br>• What data already exist that characterize climate, resource availability, and other unique aspects of my city? What data exist that support action on urban cooling?<br>• Are there already urban cooling measures in place? How are they performing? Is there information on costs and benefits?<br>• Are there other cities with similar characteristics/situations taking action to address urban heat islands? What is their experience? |
| **Stakeholder engagement** | • Which organizations/constituencies should be a part of the policy design process? Which can support the effort directly?<br>• Which groups would serve as effective champions for cooling? What capacity and support do they need to be successful? |
| **Policy development** | • What mix of cooling strategies delivers the most immediate, high-impact results while minimizing negative consequences? What organization, agencies, or other stakeholders are needed to implement these cooling strategies? |

*Source:* Authors.

## 5.1 TAKING STOCK

It is quite possible that cities already have programs in place that affect heat mitigation without expressly recognizing that link. Thus, practitioners should start by:

**Identifying key issues and questions that need to be considered to address the urban heat challenge. The city should outline the information it needs and questions it seeks to answer in order to lay the groundwork for the development of its urban cooling strategy. A list of such potential questions, along with actions that may be needed to find a response, is outlined in Table 18.**

1. **This exercise** helps to articulate the problem of urban heat in a local context and prepare stakeholders, within the municipal government, private sector, and wider public, for the planning and implementation activities to come.

2. **Identifying** existing local priorities and characterizing how heat mitigation efforts could aid in achieving them. This exercise helps reframe the issue of heat in the context of existing issues that already have potentially strong political support and awareness within municipal government and the public at large. The effort to identify local priorities also helps build communication and collaboration between government agencies. Often the departments that deal most directly with excess

## TABLE 18: LAYING THE GROUNDWORK FOR URBAN COOLING

| ACTIVITY | QUESTIONS TO ASK | ACTIONS |
|---|---|---|
| **Understand UHI effects** | • What is the evidence of urban heat islands in the city?<br>• What are complaints/concerns voiced by citizens or stakeholders? Who are most affected?<br>• What can be the effects of urban heat islands? What are heat-related illness situations among city inhabitants? | • Identify temperature trends (and any gaps in data collection). Establish heat mapping in the city. Begin collecting information on heat-related illnesses and hospital visits. |
| **Identify existing priorities** | • Are urban cooling strategies a part of existing plans, codes, laws, regulations, or incentives?<br>• To what extent have cool city materials been widely deployed in your region?<br>• Are there any high-profile local examples?<br>• Where are the greatest sources/locations of urban heat, and who is at greatest risk from urban heat? | • Identify existing climate, sustainability, or resiliency plans for your city/state/region.<br>• Research existing building and energy codes, stormwater programs, and incentives.<br>• Review existing aerial and satellite imagery to determine areas of excess surface heat, heat vulnerable populations, and penetration of cool city solutions. |
| **Evaluate existing activities and potential** | • Is there existing local research on heat mitigation and what institution produced it?<br>• What types of buildings and pavements are common in your city?<br>• What types of green spaces or parks exist?<br>• What are the climate and weather characteristics?<br>• What is the market availability of cool city solutions today?<br>• What is the cost of measures and activities in place that also support mitigating the urban heat? What are the benefits they generate, and who are the beneficiaries?<br>• What are the options to integrate urban heat considerations in urban design and urban planning? | • Identify weather and air quality data files as well as building construction and pavement characteristics.<br>• Obtain from utility/grid operators energy consumption and pricing data, including on peak demand.<br>• Engage local contractors, distributors, and manufacturers to determine availability of heat mitigation measures.<br>• Develop the economic case for cooling strategies. |
| **Build local support and capacity** | • Who are/could be city champions for urban cooling/ heat mitigation? Who are the key stakeholders? What process could be put in place to engage them? How can you ensure the process captures perspectives from different segments of the city's population?<br>• What are the relevant funding and financing options?<br>• What existing resources and networks are available for technical support, training, and good practices?<br>• What policies are within municipal control, and which require other levels of government to pursue?<br>• What kind of information would be needed to raise awareness, build support, and encourage action to tackle urban heat? What would be the most effective means to communicate this information? How to ensure that it reaches different segments of the city's population? | • Conduct stakeholder mapping.<br>• Find supporters and attract funding and financing options.<br>• Identify technical resources locally and globally.<br>• Join or leverage existing memberships in city/regional organizations.<br>• Develop local training as well as communications campaigns and education programs. |

*Source:* Authors.

heat, such as sustainability offices, have few resources and wield advisory power only. Though these departments take time to develop, establishing a cohort of representatives from various agencies that understand how heat affects their operations and who are willing to incorporate cooling strategies into their planning, targets, and budgets, can drive substantial progress.

3. **Evaluating** existing city policies, programs, partnerships, or research that could support or advance urban heat mitigation implementation and a better understanding of the local potential of urban cooling strategies. This might include existing academic partnerships, major upcoming land developments, and building codes.

## 5.2 GATHERING AND ANALYZING DATA

Measuring and validating implementation progress and effects of cooling strategies are essential to funding, building, and maintaining progress. Practitioners should:

1. **Gather and map** available relevant information and data sources that will inform cool-city policy deployment (Table 19). Relevant data may already exist within city departments, regional or national government agencies, industry, or academic/research institutions. Robust efforts to engage stakeholders (described in Section 5.3) will aid in identifying these existing sources of quantitative and qualitative information. The checklist outlined in Table 19 is indicative and not exhaustive—not all cities may have or need all data; it is also possible that other information may be needed, depending on local context.

Many cities map the data gathered to establish where hot spots currently exist within the city. As a first step, cities may use aerial/satellite imagery to identify elevated surface temperatures. Though useful, relying solely on imagery has several limitations. The imagery may be only periodically available and may not include data from the hottest parts of the day. Moreover, it likely will not include nighttime temperature data; yet, nighttime minimum temperatures are important for assessing health outcomes from excess heat. Finally, the connection between surface and air temperatures is not direct, so a focus on surface heat islands may miss heat pockets or the movement of hot air. To supplement surface temperature maps, temperatures collected via sensor networks and vehicular transects can support and deepen a city's understanding of community-scale heat vulnerabilities. Mapping multiple hazards (e.g., heat and flood risk) will highlight areas where urban cooling strategies can provide several benefits. For example, when detailed vegetation maps for a city are overlaid with other spatial data, including population density, policy makers can identify where in the city tree planting will yield the highest returns on investment in terms of ambient air temperature reductions.

Vulnerability mapping is an additional overlay to heat mapping that visualizes the human health risk of heat and the opportunities of mitigating it. 'Vulnerability' encompasses a wide variety of factors. Demographic data such as population age, race/ethnicity, income, and housing stock can be highly correlated with heat vulnerability. In addition, it is important to keep in mind the vulnerability of populations with health conditions that are aggravated by heat. In fact, cities should also seek to collect data on heat-related illnesses and hospital visits to get a better picture of the impact, and potential benefit, of mitigating excess heat in the city. Two relevant case studies are provided from New York (Box 13) and Vienna (Box 14)

## TABLE 19: DATA NEEDS CHECKLIST FOR URBAN COOLING PLANNING

| | DATA TO COLLECT |
|---|---|
| **Roof tops and walls** | • Estimates of the percentage of surface area covered by roofs and walls ($m^2$)<br>• Total roof and wall area by building type (e.g., commercial, residential, institutional, and municipal buildings) and roof type (e.g., flat and steep-sloped)<br>• Characteristics of common building types including building height and window to wall ratios<br>• Existing building and energy codes for roofs, walls, and insulation requirements<br>• Estimated roof and wall life of locally available products<br>• Market share of local roof and wall types and materials<br>• Number and type of buildings owned or managed by the municipal government including size, no. of floors, age, energy consumption, and existing cooling equipment<br>• Type of plants most suitable for green roofs and walls<br>• List of prices of cool and green roof/walls alternatives, along with list of suppliers<br>• Data on the weight bearing capacity of roofs of key buildings<br>• Roof and wall surface already cool, vegetated, or covered by solar PV<br>• Roof (and/or wall) surface covered by vegetation ($m^2$)<br>• Roof surface covered by solar rooftop PV ($m^2$); number of buildings with solar rooftop PV (#); installed capacity of installed rooftop PV (kW) |
| **Pavements** | • Estimates of the percentage of surface area covered by roads, sidewalks, parking lots, and other paved spaces<br>• Total amount of paved area by type<br>• Breakdown of paved area ownership/responsibility (e.g., municipal, regional/national, private, other)<br>• Schedules for repair and replacement<br>• Materials used by pavement type<br>• List of prices of pavement alternatives and suppliers |
| **Green space/ tree canopy** | • Estimates of percentage of surface area covered by green space and impermeable surfaces<br>• Aerial imagery of tree canopy and vegetated areas<br>• Mapping of population density or the spatial distribution of populations and, if possible, overlaid with socioeconomic information<br>• Inventory of native tree/plant species and tree/plant species resilient to forecasted future local climate conditions, pests, and disease vectors<br>• Ownership of tree/green infrastructure assets (e.g., municipal, private, etc.)<br>• Mapping of utility and other infrastructure locations that might limit tree planting<br>• Cost of maintenance of green space<br>• Available plant species |
| **Building energy consumption** | • Average energy consumption by building type and estimated share due to cooling<br>• Estimate of type, average efficiency, and quantity of air conditioners<br>• Number of buildings by type (residential—single family and multi family, commercial, public) and projected increase in number of buildings to be constructed. |
| **Weather** | • Average solar insolation (amount of solar radiation a surface receives, in watts/$m^2$)<br>• Wind speeds and direction<br>• Seasonal, annual, and peak rainfall<br>• Maximum and minimum daily temperatures (daytime and nighttime), cooling degree days, heating degree days, or average temperature by day for several years<br>• Air quality (air quality index)<br>• Frequency and intensity of extreme heat or extreme rain events<br>• Average seasonal humidity levels |
| **Other** | • Maps of surface or air temperatures to identify hot spots<br>• Maps of heat vulnerable populations (e.g., income level, age, disease prevalence, etc.)<br>• Number of patients per year visiting/admitted to hospital for heat-related illnesses |

*Source:* Authors.

## BOX 13: CASE STUDY: URBAN HEAT ISLAND WORKING GROUP AND COOL NEIGHBORHOODS NYC

As part of the OneNYC initiative, New York City (NYC) convened an Urban Heat Island (UHI) Working Group in 2015 to meet two goals:

- to identify and pursue strategies that mitigate the UHI effect in neighborhoods that are particularly vulnerable to heat impacts
- to increase access to cool spaces for vulnerable populations.

In support of these goals, NYC, through its UHI Working Group, was tasked with evaluating the best available science on UHI in order to (a) invest in better data collection and monitoring of neighborhood-level temperatures in NYC, (b) understand the impact of current and needed interventions using real-world metrics, and (c) identify effective capital investments and operational strategies to benefit the city's most vulnerable communities.

The Working Group was also tasked with evaluating the feasibility of achieving heat mitigation goal targets for NYC and present prospective scenarios that can help achieve those targets. Finally, the Working Group sought to understand cost-benefit calculations to make specific recommendations for future investments in heat mitigation strategies in NYC, including green and natural infrastructure and other cooling strategies. The Working Group, which included representatives from across the municipal government, community organizations, researchers, and other heat experts met regularly for several years under the leadership of the Mayor's Office of Recovery and Resiliency and culminated in the Cool Neighborhoods NYC initiative. Launched in 2017, Cool Neighborhoods NYC is a US$106 million set of programs to minimize the effects of extreme heat by increasing the number of cool roofs, tree plantings, and other urban passive cooling measures. It also provided training for home health aides on how to anticipate, recognize, and address heat stress in their largely vulnerable and elderly clientele. The program leveraged the Working Group's assessment of neighborhood-level heat vulnerability and prioritized the most at-risk areas. In addition to deploying urban passive cooling measures, the program undertook a series of measures to enhance the city's response to extreme heat events, including encouraging changes to the state's Low-Income Home Energy Assistance Program to simplify the application process, increasing accessibility to cooling centers, and calling on the general public to check on at-risk neighbors, through the Be a Buddy NYC initiative. Cool Neighborhoods NYC is led by the Mayor's Office of Recovery and Resiliency, in partnership with many of the municipal departments that participated in the Working Group, including NYC Parks, the Health Department, Small Business Services, Emergency Management, and the private sector.

### BOX 14: CASE STUDY: URBAN HEAT ISLAND MITIGATION PLANNING IN VIENNA

In 2018, Vienna, Austria, released an urban heat island mitigation strategy[33] in response to an anticipated 11 percent increase in population (up to a total of 2 million urban residents) by 2030 and a 58 percent increase in dangerously hot days each year. The plan is primarily targeted at municipal government stakeholders to help them evaluate what actions can be taken and what level of control the municipality has over those actions, and to establish the legal, regulatory, and data gathering frameworks needed for heat-resilient urban planning. The plan also includes practical actions, such as increasing street greening, green roofs and walls, passive building cooling measures, shade, water infrastructure, and cooling in and around public transportation routes, to reduce urban heat applicable to municipal and private sector stakeholders. Analysis and evaluation of heat and heat mitigation has also been underway at the national level. The Austrian Central Institute for Meteorology and Geodynamics (ZAMG) gathered and analyzed a wide range of data for five cities in Austria (Vienna, Linz, Salzburg, Klagenfurt, and Graz), including surface geometry, soil and surface properties, and atmospheric conditions to support a set of policy recommendations for heat resilient urban planning and development. This data-driven approach spurred the inclusion of heat mitigation strategies as part of Vienna's urban planning processes.

## 5.3 ENGAGING STAKEHOLDERS

Cultivating a group of stakeholders to support the development and champion the implementation of cooling strategies will improve their effectiveness and chances for long-term success. Practitioners should:

1. **Build** local support among relevant stakeholders inside and outside of municipal government. Given the interdisciplinary nature of the cooling/heat resiliency challenge, practitioners will need a strong network of stakeholders to provide technical, political, financial, and public support for urban cooling strategy implementation. Champions for action on urban cooling are essential to launching and sustaining urban cooling strategies and can come from a wide variety of backgrounds and organizations, including public health, public works, utilities, and capital and budget planning entities. Engaging the local ecosystem of non-government actors such as community organizations, developers, contractors, hospitals, and foundations will bring important insight into policy development and program implementation. Early engagement also improves acceptance of new programs and makes it easier to raise public awareness. Promoting academic or scientific partnerships for cooler cities is of particular value. Technical partners significantly bolster the ability of municipal governments to gather and analyze data to understand where there are hot spots, where vulnerable populations live, and what combination of mitigation strategies perform best in a local context. Beyond helping to prioritize action on heat, this information is important for tracking progress and effects over time. Building local support and growing the stakeholder base for urban cooling can be formalized through public-private partnerships. These structures are particularly useful for major infrastructure investments such as district cooling. There is also a need to engage and coordinate with other levels of government. In some cities, new urban areas are outside municipal control but nevertheless have an effect on heat in areas that are under their control. Additionally, decisions on

33 The full plan is accessible at City of Vienna (2018), "Urban Heat Island Strategy," https://www.wien.gv.at/umweltschutz/raum/pdf/uhi-strategieplan-englisch.pdf

some policy options that support urban cooling, such as building codes, may be outside of municipal control and require collaborative effort to change.[34]

Cities may need to work closely with key stakeholders to gather information and help respond to questions needed to inform decisions on specific cooling measures. These more detailed questions and recommendations for how to answer them are included as a checklist in Table 18.

## 5.4 DEVELOPING POLICIES

Cities can consider which mix of policies and actions will be most effective, based on local conditions, resources, data, and the mix of participating stakeholders. Practitioners should:

1. **Create** an integrated suite of urban cooling strategies. There is no “one-size-fits-all” approach to cooling cities. Cities must evaluate the individual and combined benefits of particular strategies and potential negative consequences. For example, as mentioned earlier, promoting broad usage of space cooling, which includes air-conditioning, improves indoor thermal comfort but will lead to increased waste heat evacuated outside, which increases outside air temperatures, thus exacerbating the heat challenge for those working outside or without access to space cooling. Section 6 describes the many urban cooling policies cities have adopted worldwide and can serve as a starting point for practitioners to develop the suite of strategies unique to their cities’ goals, challenges, and resources.

2. **Measure** the many aspects of urban cooling initiatives to track progress. First, identify existing metrics or develop new ones that highlight the physical changes brought by successful urban cooling strategies (e.g., neighborhood air temperature reductions, vegetated cover changes over time, surface solar reflectance changes over time) as well as more “people-oriented” metrics that highlight the human effect of cooler cities (e.g., reduced emergency room visits, reduced mortality, and improved air quality). Box 15 describes a relevant case study from Singapore (Photo 13). To the extent possible, establish a baseline of data and performance for each metric. Evaluate how existing policies that indirectly affect heat mitigation are measured and determine whether those metrics are relevant for tracking urban cooling. Cities should also identify resources and equipment needed to monitor changes in each metric over time (e.g., a network of weather monitors or reporting requirements for hospitals).

34 While setting or updating buildings, codes may be the responsibility of the national or regional/state/provincial government, their implementation and enforcement is typically the responsibility of local authorities.

## BOX 15: CASE STUDY: COOLING SINGAPORE INITIATIVE

**Photo 13: Singapore skyline at sunset**

Source: DepositPhoto.

Singapore has experienced a 1.1°C increase in temperature since 1972 (National Climate Change Secretariat n.d.). This warming is amplified by the urban heat island effect that can increase temperatures in urban zones by as much as 7°C as compared to nearby nonurban zones.

Singapore has invested considerable resources into a research-based approach to integrated urban cooling. To that end, the National Research Foundation funded a consortium of research institutions called Cooling Singapore to develop a road map to reduce the country's temperature and improve thermal comfort. Cooling Singapore also hosts regular convenings and outreach campaigns to raise awareness of urban heat issues.

The project's researchers have developed several deliverables:

1. A highly detailed simulation of the determinants of urban heat in Singapore, with a focus on modeled thermal energy gains and losses across multiple sectors.
2. A comprehensive review of 86 measures to reduce urban heat and improve thermal comfort covering urban geometry, green space promotion, building material changes, reduced human-generated heat, and other strategies.
3. A guide to existing tools and models that could be used by Singapore's government to assess the effect of strategies to reduce urban heat and enhance thermal comfort.
4. A report laying out the existing local and regional stakeholders relevant to urban heat analysis and mitigation.

Cooling Singapore provides technical support to track the effect the city-state's integrated cooling efforts have on excess heat and thermal comfort. To evaluate urban-heat characteristics, the initiative produced a map correlating urban form[35] with air temperature and used data collected from 14 weather stations operated by the Meteorological Service of Singapore to validate its findings. The map can be used to prioritize regions for urban cooling strategy implementation. To evaluate thermal comfort, Cooling Singapore monitors humidity, temperature, and wind speed in a chosen location. At the same location, researchers conduct surveys of nearby pedestrians to assess their perceived thermal comfort, including how hot or cold they feel, what activities they have been taking to remain comfortable, and how long they have spent outdoors.[36]

35 Urban form refers to the horizontal and vertical layout of buildings and streets.
36 More on Cooling Singapore is available at https://www.coolingsingapore.sg/

Credit: World Bank/Sambrian Mbaabu.

# 6. POLICIES, PRACTICES, AND PROGRAMS FOR COOLER CITIES

Cities around the world have adopted and are implementing policies, including incentives, requirements, information gathering, awareness raising, and municipal operations to spur the deployment of heat mitigation measures. Some cities choose to implement a single activity, while others combine a number of approaches to address excess heat. In this section, we break out policy activities into four categories:

- **Awareness raising** activities engage and inform the public and other stakeholders about urban heat mitigation.
- **Leading by example** activities address program and policies affecting buildings, pavements, and urban areas directly controlled by city government.
- **Incentives** are forms of rewards to encourage heat mitigation implementation in buildings and other spaces.
- **Mandatory activities** are requirements (e.g., regulations) enforced by government to compel implementation of heat mitigation strategies.

Table 20 outlines examples of urban cooling policy options within each of the four broad categories, as well as cities where they have been implemented, including Guadalajara (Box16).

There is no single "best" combination of policies. Each city should evaluate what suite of policies best suits its unique situation. Not all options will be equally feasible in all cities. For example, poorer cities with already inadequate budgets to satisfy basic services may not be able to find the resources to pursue some of the options. There may also be legal/jurisdictional constraints for some cities. Moreover, depending on the particular situation of individual cities, including climate and energy cost, for example, the economic case for particular options may vary. That said, these policies can be compared based on the:

1. **Effort** required to design and implement the policy.
2. **Effect** on urban cooling of successful implementation of the policy, including the time it takes for the effect to be felt at scale.
3. **Speed** at which the implemented policy delivers the desired effect.

Figure 17 makes a general comparison of the policies based on these three factors.

## BOX 16: CASE STUDY: GUADALAJARA—CIUDAD FRESCA

The city of Guadalajara (shown in Photo 14) experiences temperatures in its urban core that are 1–9°C warmer than in surrounding rural areas. In an effort to reduce this difference and contribute to the goals of the Paris Agreement, Guadalajara has undertaken plans to:

**Photo 14: Guadalajara, Mexico**

Source: DepositPhoto.

- Map and monitor areas of excess heat in the city. The city has created detailed maps of surface temperatures that identify hot areas of the city. These maps are used to prioritize cooling strategies.
- Launch awareness campaigns to highlight the local benefits of cool roofs. The city has developed public outreach materials built around "Can you imagine having a cool house in summer?" that highlight the benefits of cool roofs to residents and how products can be applied.
- Plant 15,000 new trees around 15 main roads, 39 parks, 19 sports facilities, and in areas of excess heat. The city estimates that the annual environmental value in terms of pollution reductions, reduced runoff, carbon emissions avoided, and improved building values totals approximately US$21 million per year, plus a one-time benefit of nearly US$8 million from carbon storage.
- Encourage nurseries to foster the redevelopment of 74 tree species native to the region that are now scarce, with a goal of fostering over 30,000 new native trees.

## TABLE 20: MEASURES AND ACTIONS TO REDUCE EXCESS HEAT IN CITIES

| CATEGORY | POLICIES & PROGRAMS | EXAMPLE CITIES/COUNTRIES |
|---|---|---|
| **Awareness raising** | Guidelines, toolkits, design guides, and handbooks | Bogota, New York, Melbourne |
| | Heat health alerts | Seoul, Paris, Athens |
| | Demonstrations in heat vulnerable areas | Nairobi, Pretoria, Hyderabad |
| | Media campaigns | Guadalajara |
| **Leading by example** | Strategic planning | Washington D.C., Singapore |
| | Heat action planning | Ahmedebad |
| | Tree planting and maintenance | Singapore |
| | Park development | Seoul |
| | Heat-sensitive urban planning | Tokyo, Singapore |
| | Municipal government procurement specifications | Los Angeles, Toronto |
| | Enhanced public transportation access policy | Medellin |
| | Vehicle fleet electrification | Shenzhen |

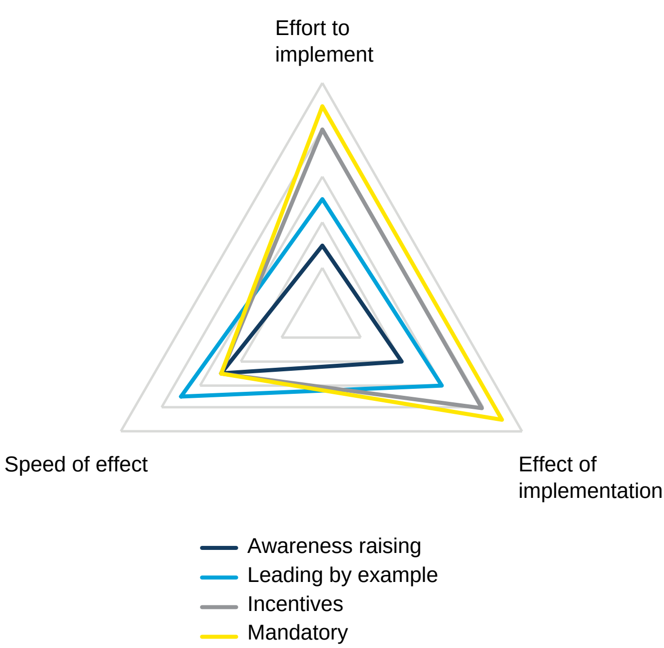
## TABLE 20: CONTINUED

| CATEGORY | POLICIES & PROGRAMS | EXAMPLE CITIES/COUNTRIES |
|---|---|---|
| **Incentives** | Cool roof rebates | Austin, Athens, Toronto |
| | Property tax reductions* | France, Mexico City, Portugal |
| | Tree giveaways | Durban |
| | Increased floor area ratios for green space provision | Seattle |
| | Fast tracking for permit approvals | Chicago, New York |
| | Planning fee waiver | Austin |
| | Stormwater fee discounts | Philadelphia |
| **Mandatory** | Stormwater credits | Washington D.C. |
| | Urban cooling/passive design regulations | Los Angeles, Paris, Tokyo, New Delhi, Chicago |
| | Tree ordinances | Melbourne |
| | Vehicle access restrictions | London |

*Indicates an activity that may involve/require regional or national authority.

*Source:* Authors.

## FIGURE 17: CONSIDERATIONS FOR SELECTING COOLING PROGRAMS AND POLICY OPTIONS




*Source:* Authors.

## 6.1 AWARENESS RAISING ACTIVITIES

Awareness raising activities engage and inform the public and other stakeholders about urban heat mitigation and how to take action. Cities could undertake campaigns to raise awareness via media, advertising, community meetings, or a mayoral proclamation. These activities could also target key stakeholders (such as developers) with design guides, toolkits, or handbooks. Cities could also use social media channels or leverage the communication channels used by existing heatwave warning systems to share practical steps residents could take in the short term and long term to increase their resiliency to heat. Finally, undertaking demonstration projects not only raises awareness of cooling measures but also provides a platform for gathering locally relevant performance data, and can be used to develop local capacity as well as to build confidence and support.

### 6.1.1 Guidelines, Toolkits, and Handbooks

These materials are typically technical in nature and targeted to specific audiences that implement urban cooling solutions. Design guidelines provide a connection between general planning policies and implementing regulations, such as zoning codes and subdivision regulations. Green guides, such as the *Growing Green Guide* (Box 17) in Melbourne (Photo 15), inform landscape architects and developers on appropriate plantings so the city may achieve its canopy and green infrastructure targeting. Cities may publish design guides for heat-mitigating roofing options, their installation, their appropriate use cases, and the effects of installing them on the building and the surrounding community that are written for an audience of architects, developers, and construction industry representatives.

#### BOX 17: MELBOURNE'S *GROWING GREEN GUIDE*

**Photo 15: Melbourne, Australia**

Source: DepositPhoto.

Melbourne, Australia, is facing a doubling of population over the next 30 years and an increased urban heat island effect, and is therefore highly vulnerable to heat-related illnesses and deaths in the future. To address this proactively, Melbourne released the *Growing Green Guide* in February 2014. The guide promotes vegetated surfaces and provides technical advice on how to design, build, and manage green roofs, walls, and façades so they can provide multiple long-term benefits for building owners and the wider community. Prior to releasing the guide, city officials conducted an extensive public review through public meetings and shared the *Growing Green Guide* with citizens in order to gain input from multiple stakeholders.

The guide has been useful in spurring local, regional, and international implementation activity. There are currently around 50 green walls, 100 green roofs, and many green façades across Melbourne—and the numbers are growing. This effort is complemented by the State of Victoria's (of which Melbourne is the capital) awareness and communications material to encourage energy efficiency in buildings (both passive and active measures).

### 6.1.2 Heat Health Alerts

Heat alerts are communications to the public warning of dangerous heat conditions. Cities use a variety of metrics and thresholds to trigger emergency communications. Some examples include days with daytime maximum temperatures above a certain degree, days with maximum apparent temperatures above a certain level (an approximation of people's perception of heat derived from the combined effect of temperature and humidity), or number of days above a certain daytime maximum temperature. Approximately 40 cities worldwide have a more sophisticated system that uses locally specific algorithms based on increases in mortality when particular air masses are present over a city. Air masses include a number of meteorological factors, including, but not limited to, heat and humidity. Some European cities like Athens and Paris are also launching smart phone applications that communicate directly with application users when they enter areas of excess heat to provide directions to cooling zones and proactively message personal contacts set by the user. Municipal communications are useful, but may not effectively reach or be trusted by the most at-risk audiences. As mentioned in Box 13, in an attempt to address these limitations, New York City launched a training program in 2018 for home health care aides to help them recognize the early stages of heat stress in their clients and to further share information with them on how to reduce their risk during extreme heat conditions. Cities may also make similar indirect public outreach efforts to local community groups and religious institutions.

### 6.1.3 Demonstrations

Demonstrations of urban cooling strategies help gather important performance data for policy making and serve as a tangible example to raise public awareness. Demonstration projects have taken place in public parks, schools, and other public facilities, as well as in privately held communities and informal settlements. Cities may also play a supportive role in demonstrations by private entities. Demonstrations may be for a single measure or include multiple measures to evaluate their combined ability to cool buildings and air temperatures, such as the integrated pilots of cool pavements, shade, and water features at transit hubs in hot Los Angeles neighborhoods. Based on existing field studies, a community-scale pilot may be sufficient to generate a meaningful cooling response to inform broader-scale action.

Demonstrations are an opportunity to measure the local effect of heat mitigation solutions. For a building, this may include measurements of roof surface temperature, heat transfer into and out of the structure, and indoor air temperature changes. For community-scale pilots, there may be opportunities to measure temperature changes before and after installation or against nearby buildings that have not been modified. Demonstrations may also provide the first opportunity for local anecdotal experiences to be gathered from occupants of the pilot buildings, which are valuable in generating public support for urban cooling solutions. Demonstrations are most successful when they occur in high-profile locations, integrate local community leaders, gather performance data, and share lessons from implementation to support replication. Box 18 describes a case study from Hyderabad (Photo 16).

## BOX 18: CASE STUDY: IMPROVING THERMAL COMFORT FOR THE VULNERABLE IN HYDERABAD, INDIA

The city of Hyderabad in Telangana, a hot and arid region of south-central India, is home to over 7 million residents with 1.9 million living in one of the city's official 1,468 low-income and heat-vulnerable communities (Natural Resources Defense Council 2016).

**Photo 16: Hyderabad, India**

Source: DepositPhoto.

In 2017, government and technical partners implemented a cool roofs pilot in a low-income neighborhood of Hyderabad to showcase and document the benefits and impacts of cool roofs. The cool roof pilot, which covered 1,000 square meters and affected 100 residents, sought to identify cost-effective cool roof solutions for low-income housing, thereby contributing to increased thermal comfort. The pilot monitored physical conditions in coated and control structures and also administered surveys to 40 households to gauge reactions.

The pilot found indoor air temperatures fell by an average of 2°C in the homes with cool roofs as compared to similar homes without cool roofs. The surface temperature of the cool roofs in the pilot were 15°C lower than surface temperatures of asbestos roofs and 10°C lower than surface temperatures of cement roofs.

Of the residents in the survey group, 76 percent expressed satisfaction with the cool roofs, while residents in the control group and other parts of the neighborhood began to apply makeshift cool roof membranes on their own roofs in response to the positive feedback by the trial.

More details about this program are available in the annex, *Cool City Case Studies: Reducing Urban Heat*.

*Case study source:* National Resources Defense Council NRDC (2018), "Cool Roofs: Protecting Local Communities and Saving Energy Issue Brief May 2018," https://nrdc.org/sites/default/files/ib_-_cool_roofs_-_hyd_workshop.pdf

## 6.2 LEADING BY EXAMPLE

Leading by example includes efforts that the municipal government could undertake to support heat mitigation and adoption of more efficient space cooling options on structures and assets they control. These include planning processes that establish heat mitigation as a priority for the city and create frameworks within which heat mitigation can be implemented (e.g., heat action/emergency plans). They also include implementation opportunities in municipally controlled buildings, assets, and spaces. Cities may modify procurement requirements to promote heat mitigating strategies and energy-efficient buildings and cooling equipment, as well as to encourage municipal contractors to consider what effect their activities have on excess heat. Municipal governments could also undertake a demonstration projects and other activities to reduce excess heat. Examples from Washington DC (Box 19, Photo 17) and Paris (Box 20, Photo 18) are described as case studies.

## BOX 19: CASE STUDY: WASHINGTON D.C. LEADING BY EXAMPLE—MUNICIPAL SMART ROOF PROGRAM

**Photo 17: Washington, D.C.**

Source: DepositPhoto.

In 2011, the Washington D.C. Department of General Services (DGS) launched the Smart Roof Program to assess the potential of each roof in its portfolio of 435 buildings (covering 1 million square meters of roof area) to meet its goals for reduced heat islands, improved stormwater retention, and increased solar energy production. Roof consultants assessed the physical condition of each roof and evaluated (i) the economics of each sustainable technology option, (ii) the structural load capacity of the roof (necessary for vegetated roofs), (iii) the viability for high efficiency solar energy installations, (iv) watershed effects, and (v) existing roof insulation levels. Economic evaluations factored in any available credits for solar energy and stormwater mitigation, as well as the effect of power purchase agreements. The evaluation included a schedule for roof interventions based on estimated remaining roof life and upgrade costs to allow Washington D.C. to better plan capital expenditures.

At current deployment rates, the Smart Roof Program will save Washington D.C. US$33 million, not counting societal benefits, over 20 years. The use of coatings to restore and extend the life of functioning roofs will reduce capital requirements by 75 percent and has generated 224 new local jobs with the potential to create an additional 300 more.

More details are available in an extended case study in the annex, *Cool City Case Studies: Reducing Urban Heat*.

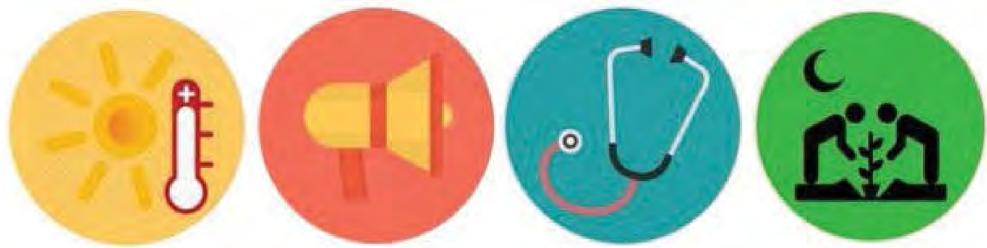
### 6.2.1 Strategic Planning

Strategic urban planning generally involves a multi-stakeholder process to establish goals and the pathways for achieving them. Strategic plans may be adopted by a mayor, city manager, or local legislative body and set forth policies, goals, and objectives within the planning jurisdiction. Strategic plans generally have a broad scope and long-term vision. In the context of such strategic urban plans, some cities have adopted temperature reduction targets as the guiding goal for urban cooling activities. For example, Los Angeles has adopted a 0.9°C reduction in the difference between urban and nearby rural temperatures by 2025, while Melbourne has an aspirational goal to reduce urban temperatures by 4°C (a figure in line with the city's average temperature difference with rural areas).

### 6.2.2 Heat Action Planning

Heat action planning, a similar exercise to strategic planning, is focused on preparing for and responding to extreme heat hazards. Ideally, planning is coordinated between multiple departments to ensure smooth and effective responses to dangerous heat. Plans also typically include a public outreach component to improve residents' ability to respond to an extreme heat event. Heat action planning may also include the establishment of early warning systems for heat events and an opportunity to build awareness of heat illnesses among health care professionals. Cities like Ahmedabad, India (Figure 18), have developed plans incorporating all of these elements and go through an annual process to ensure that information and contacts are properly updated and included.

## FIGURE 18: KEY COMPONENTS OF AHMEDABAD'S HEAT ACTION PLAN



**Early Warning System & Interagency Emergency Response Plan**

Alert residents of predicted high and extreme temperatures & formal communication channels to alert governmental agencies

**Public Awareness & Community Outreach**

Communicate the risk of heat waves and implement practices to prevent heat-related deaths and illnesses

**Capacity Building of Medical Professionals**

Training focus on primary medical officers and other paramedical staff, and community health staff

**Reducing Heat Exposure and Promoting Adaptive Measures**

Access to potable drinking water and cooling spaces during extreme heat days & promote adaptive measures

*Source:* Ahmedabad Municipal Corporation (2017), "Ahmedabad Heat Action Plan 2017," https://nrdc.org/sites/default/files/ahmedabadheat-action-plan-2017.pdf (accessed on 02 May 2017).

## BOX 20: CASE STUDY: FOUR INITIATIVES TO INCREASE HEAT RESILIENCY IN PARIS

Like many cities, Paris adopted an urban cooling strategy in response to a particularly intense heat emergency. The European heat wave of 2003 saw temperatures rise above 40°C and stay at least 35°C for nine straight days in Paris. Nearly 1,100 people died within the city during the heat wave, 88 percent of whom lived alone. The city expects to face more frequent and intense heat events due to the effects of climate change. In response, the city has undertaken four related programs to create pockets of heat resiliency throughout the city.

**Photo 18: Paris, France**

Source: DepositPhoto.

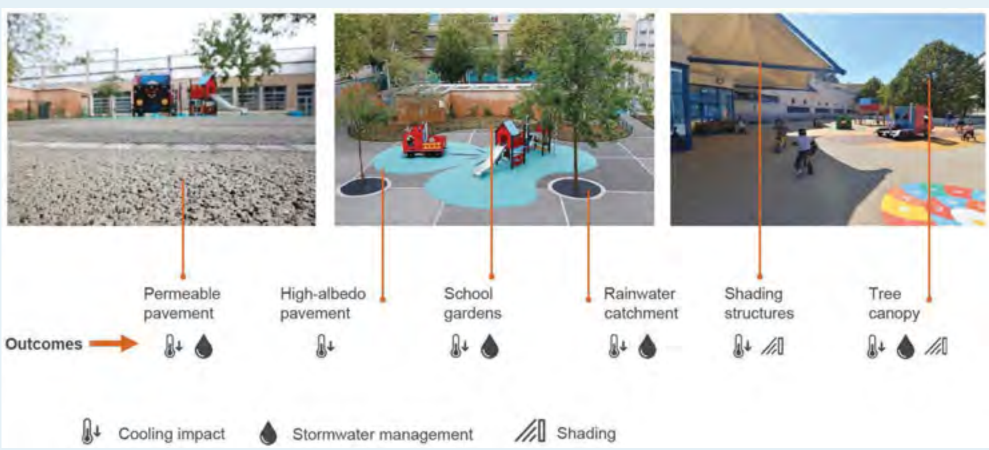
## BOX 20: CONTINUED

**Cool islands:** This initiative aims for every Parisian to be within a seven-minute walk of a 'cool island' by the end of 2020. A cool island is defined as a naturally or actively cooled area of respite from the heat. This can be anything from a swimming area, water/misting feature, and municipal building to places of worship and parks. In addition to serving as emergency cooling locations during extreme heat events, cool islands reduce urban heat islands overall, raise awareness about heat and heat resiliency, and improve access to parks and open spaces within the city.

**Cool pathways:** Paris plans to link the network of cool islands to create cool pathways to allow Parisians to minimize thermal discomfort as they move about on hot days. Cool pathways would be formed by a combination of measures including enhanced and continuous shading of pedestrian walkways with tree canopies or structures; added green, permeable, and solar reflective pavements; and preferences for paths that are close to waterways.

**Urban oasis:** This program retrofits schoolyards in the most heat vulnerable neighborhoods with shading, greenery, permeable surfaces, and cool payments. These spaces are used by students and also the community when school is out of session. Figure 19 illustrates some of the schoolyards upgraded by the program.

### FIGURE 19: COOL OASIS STRATEGIES IN PARISIAN SCHOOLYARDS




*Source:* Bloomberg Associates (2019), "Mitigating Urban Heat Island Effects Cool Pavement Interventions," https://www.bbhub.io/dotorg/sites/32/2019/08/20190516_Cool-Pavement-Research-FINAL.pdf

**Extrema heat safety application:** In 2018, Paris partnered with the National Observatory of Athens to launch Extrema, a mobile application to help Parisians stay cool during extreme heat events. The application alerts users when they have entered an area of dangerously high temperatures, maps a route to the nearest cool island, and can prompt family and friends to check on the user's well-being during heat emergencies.

More information on Paris' cooling efforts is included in the annex, *Cool City Case Studies: Reducing Urban Heat*.

*Case study source:* Adapted from Bloomberg Associates (2019), "Mitigating Urban Heat Island Effects Cool Pavement Interventions," https://www.bbhub.io/dotorg/sites/32/2019/08/20190516_Cool-Pavement-Research-FINAL.pdf

### 6.2.3 Tree Planting and Maintenance

Municipal tree programs expand the number of street trees, increase canopy in existing parks, and help ensure that the appropriate trees are planted and that tree canopy remains healthy. Thoughtful targeting of the planting location and type of tree is critical. Within cities, there is substantial variation in the ability of trees to remove particulate matter, mitigate ambient air temperatures, and thus deliver on the return on investment in terms of ecosystem services. Maintenance is also very important for retaining existing cover. Maintenance may include periodic scheduled evaluations of individual trees and responses to comments from the public, or be based on sophisticated tree monitoring sensor networks. Cities should consider the availability of water, expected future climate, and native species when planning tree programs.

### 6.2.4 Park Development

Parks are another way to increase permeable green space in cities and to create cool islands. Park development includes both improvements to the health and robustness of existing park space and the creation of new park areas. Cities may also focus on creating lots of small park areas rather than finding space for new medium or large parks. Pocket parks are small-area green spaces that may be created when roads are closed, parking lanes are reorganized, or formerly paved areas like parking lots are reclaimed. While not as useful for community-scale urban cooling as large parks, pocket parks provide localized cooling via shading. Seoul, South Korea, recently added 1,000 new parks and forests within city limits, primarily by developing pocket parks. Cities may opt instead for water features that provide cooling services for residents during extreme heat events and aesthetic improvements at other times. However, water infrastructure may not be appropriate in places facing water scarcity.

### 6.2.5 Heat Resilient Urban Design

Cities should consider the effect of new developments on excess urban heat when making site developments or zoning decisions. These regulations generally dictate function, building height and bulk, population density, and parking requirements for an area. Zoning codes can accelerate the deployment of urban cooling strategies by requiring them in new developments or redevelopments. For example, cities may establish regulations for heat mitigation solutions to be deployed in particularly heat-sensitive areas. They may also require developers to help fund heat mitigation solutions put in place by the municipal government. Cities (or national governments) may use incentives to encourage desired development patterns in particular areas. Box 21 highlights an example of using zoning and incentives to guide urban renewal that could be used to promote a more heat resilient urban environment.

### 6.2.6 Municipal Procurement Specifications

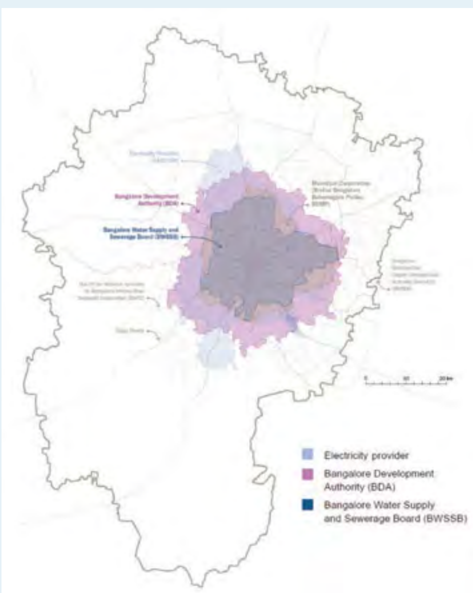
Procurement specifications for urban cooling solutions integrate heat considerations into regular maintenance, replacement schedules, and capital budgets for municipally controlled buildings. It is also a way for cities to lead by example and potentially create pilot projects to demonstrate the local efficacy of heat mitigation strategies. Because they affect building stock that is within municipal control, heat-sensitive procurement strategies are often more straightforward to enact and enforce than regulations on the private sector. However, changing procurement policy can be a long and bureaucratic process. In the short term, cities can, either on their own or with partner cities, issue requests for information (RFIs), a process to collect written information about the capabilities of different suppliers. RFIs typically do not require formal approval and can be used to signal market demand for cooling solutions.

## BOX 21: ZONING AND INCENTIVES TO SPUR HEAT-RESILIENT DEVELOPMENT

In 2003, South Africa passed a law offering tax incentives to developers to build, extend, or improve buildings in specific urban development zones (UDZs). The model focused on economic uplift and improved building stock; however, the framework could be adapted to promote urban heat mitigation. The incentive allowed for accelerated asset depreciation on investments to refurbish housing, other decaying buildings, and infrastructure. Acceptable costs that could apply to urban cooling solutions include demolition and construction, utility connections, added vegetation, improved drainage, and pedestrian access infrastructure. Land purchase or transfer costs are not covered under the program. The incentives can be claimed by property owners, but also lessees on government-owned property, land controlled by public-private partnerships, or other tax-exempt entities. The national government established UDZs in major cities across South Africa. The largest UDZ, at roughly 18 km$^2$, is located in Johannesburg. The program has generally been seen as a useful catalyst for urban redevelopment. In 2018, the tax incentives were reapproved through 2020.

In many cases, new urban developments that affect the heat conditions in inner municipal areas are actually occurring outside the jurisdiction of the affected municipality or where multiple authorities have functional control. Figure 20 illustrates this issue. The map shows the areas of control over various services provided in Bangalore, India. Only the central city enjoys overlapping coverage of all services (Mahendra and Seto 2019). Collaboration and coordination on a regional basis is critical to ensuring that cooling measures are optimized in these cases.

### FIGURE 20: JURISDICTIONS OF CITY SERVICE PROVIDERS IN BANGALORE




*Source:* Mahendra, A., and K. Seto (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

### 6.2.7 Heat-Sensitive Contracting

The municipal contracting process is another opportunity for cities to incorporate urban cooling strategies into a wide variety of contractor and service provider activities. Cities may add a requirement that bidders elaborate the effect their activities will have on urban heat into municipal tenders and requests for proposals. The requirement compels successful bidders to consider how their actions contribute to or mitigate urban heat and signals a municipality's overall commitment to cooling and thermal comfort.

## 6.3 INCENTIVES

Incentives seek to encourage adoption of urban cooling measures, passive design, and building energy efficiency in both the public and private sector. Incentives may take many forms and are not all financial in nature. For example, cities may consider nonfinancial incentives such as preferential permitting or expanding the allowed building area on a site. Financial incentives include product rebates, low-interest loans, tax credits, fee waivers, or giveaway programs for trees or other urban cooling measures. There are a number of legal, financial, and economic factors that cities should take into account when considering potential incentives, including clarity of their justification, which involves, for example, assessing the market barriers limiting their implementation, their cost, and the marginal cost of the passive cooling solution, along with the financial and economic benefits they may generate.

In the case of incentives to encourage energy efficiency and other cooling measures in buildings, cities may develop their own criteria to trigger an incentive. Many opt for using existing green building certification programs. These certification programs (such as LEED, BREEAM, EDGE, GreenMark, Green Globes) have the advantage of being regularly updated by experts, thus facilitating steady improvement in performance goals over time without having to regularly re-evaluate city programs.

### 6.3.1 Rebates

Rebates help defray the cost premium that still exists for some urban cooling strategies such as green roofs, certain cool-roof options, and energy-efficient cooling appliances. Rebate programs for cooler building materials are similar to rebates for energy-efficient technologies, so experience with one would be helpful when implementing the other. Rebates may be funded by municipalities (e.g., as in Louisville, Kentucky, and Toronto, Canada as described in Box 22) or by utilities (e.g., Los Angeles Department of Water and Power, Pacific Gas and Electric, Sacramento Municipal Utility District, Progress Energy Florida, Public Service Enterprise Group Long Island). A large number of U.S. municipal and state governments have put in place programs that subsidize cool roofs as part of broader residential and commercial energy performance programs in the United States (The Cool Roof Rating Council n.d.).

### 6.3.2 Low-Interest Loans

Low-interest loans may be used to reduce the up-front costs of deploying urban heat mitigation solutions and have been used extensively to fund other energy efficiency measures (e.g., the Toronto Home Energy Loan Program and the Vermont Home Energy Loan). Governments that are creditworthy may

## BOX 22: SPURRING PRIVATE ACTION TO BUILD GREEN ROOFS IN TORONTO

The Toronto City Council adopted a Green Roof Strategy that encouraged the construction of green roofs on municipal and privately owned buildings—through incentives, public education, and streamlined development approval processes. The strategy led to the adoption of the City's Green Roof Bylaw and the Eco-Roof Incentive Program for cool and green roofs in 2009.

**Photo 19: Toronto, Canada**

Source: DepositPhoto.

The Green Roof Bylaw—the first of its kind in North America—sets out a green roof requirement for new developments that are greater than 2,000 $m^2$ in gross floor area. The requirement ranges from 20 to 60 percent of the available roof space of a building.

To complement the bylaw, Toronto (Photo 19) also adopted a rebate program called the Eco-Roof Incentive Program. The Eco-Roof Incentive Program encourages the installation of green roofs and solar reflective roofs on existing (and some new) buildings through financial incentives. The program offers up to Can$100 per $m^2$ for green roof projects and Can$2–5 per $m^2$ for cool roof projects. In addition, applicants who want to construct a green roof on an existing building may be eligible to receive a Structural Assessment Grant, which provides up to Can$1,000 to help offset the costs associated with determining whether the building is suitable for green roof construction. The program is self-sustaining, drawing funding from cash-in-lieu payments through the Green Roof Bylaw.

Between 2010 and 2017, approximately 420 green roof permits were issued in Toronto, totaling 450,000 $m^2$ of green roof space. The Eco-Roof Incentive Program has received over 500 applications and successfully supported 336 eco-roof projects since 2009. Annual impacts of projects funded by Eco-Roof include: 11 million liters of stormwater diverted from sewers, energy savings of 1,000 megawatt hours, and GHG emission reductions of 220 metric tons (C40 Cities 2018).

use their own borrowing power, administer funding from other sources (e.g., utilities, and regional or national governments) or provide a guarantee to help improve borrowing terms and improve access to financing.[37]

### 6.3.3 Tax Credits

Tax credits have also been used extensively in energy efficiency financing and are often applicable to building-based urban heat mitigation measures. In 2015, Mexico City approved a 10 percent tax incentive to encourage green roofs on buildings in the city, applicable against the property tax. In the United States, a federal tax credit was enacted in 2009 for 30 percent of material costs up to a total credit of US$1,500 for new roofs that meet Energy Star requirements for solar reflectance.

37 In the context of many cities in developing countries, a lack of creditworthiness may limit access to affordable financing.

### 6.3.4 Tree Giveaways

Municipal governments may provide the seeds, saplings, or young trees directly to residents or offer a rebate to reduce up-front costs of purchasing trees. Giveaway programs are self-selecting, meaning that often the trees end up being planted by individuals who are more likely to maintain and care for them, such as the Reforest London program, the Yard Tree Giveaway Program in Vancouver, and the free tree giveaway program in Sydney. Community participation is important because most urban trees are not under public jurisdiction. Giveaways should be paired with training on how to properly plant and nurture the tree in the first several weeks after planting to improve survivability. In order for trees to be most effective at improving thermal comfort, the appropriate tree species must be selected, and it must be planted in the appropriate location to create useful shade. To help overcome these challenges, public shade tree programs may require participating households to receive a home visit from a trained arborist or forester who helps them choose the appropriate location for the tree. Alternatively, public maintenance and care guides can be developed and distributed to participating households. Tree giveaway programs have also been used in some cities such as Durban, South Africa, to advance social and economic uplift goals. The municipal government provides residents with seedlings or young trees and pays residents to plant and 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 result has been both a cost savings to the municipal operating budget, improved tree health and survivability, and new economic opportunities for under-resourced communities.

### 6.3.5 Developer Incentives

These incentives typically aim to improve the construction permitting process for developers willing to install heat mitigation solutions in their project. The incentives fast-track permits approvals to reduce project downtime and waive certain permitting or planning fees. Such programs currently exist in a number of U.S. cities.[38] Developer incentives may also allow certain permitting regulations to be loosened, such as increasing floor area ratios to allow more buildable space on a particular site in exchange for installing energy-efficient or green infrastructure. Hong Kong offers up to a 10 percent increase in allowable gross floor to developers that pursue certification under BEAM Plus (Hong Kong's local green building rating and certification scheme). Singapore and Tokyo have similar programs allowing extra floor area in return for installing efficiency measures.

### 6.3.6 Stormwater Credits and Fee Discounts

These incentives are intended to encourage the installation of green infrastructure but have the added benefit of improving a city's response to excess heat. Cities may provide discounts on stormwater fees when building owners commit to install and maintain green infrastructure or green roofs.

38 Some cities with developer incentives include Asheville, North Carolina; Chicago, Illinois; Dallas, Texas; Gainesville, Florida; Kirkland, Washington; Los Angeles, California; and Washington D.C.

## 6.4 MANDATORY ACTIVITIES

Mandatory activities are requirements (e.g., codes and regulations) enforced by government to compel implementation of urban cooling strategies. As with incentives, cities may choose to use green certification programs, minimum energy performance standards (MEPS), or building codes to establish minimum performance requirements for their policies. Requirements can be imposed via a stand-alone ordinance or via modifications to existing building and energy codes, zoning statutes, stormwater requirements, or similar mechanisms. Cities should consider how mandates will be monitored and enforced once adopted. The effectiveness of mandatory activities depends on the capacity and ability of authorities to enforce them.

### 6.4.1 Cool/Green Roof Regulations

Cool and green roof requirements have been included in building codes since 1999. Cities such as Chicago, New York, Denver, Los Angeles, Toronto, Paris, and New Delhi have some form of cool- or green-roof requirement. Model codes such as ASHRAE 90.1 and 90.2[39] may be adopted by cities to require that new or substantially repaired roofs be highly solar reflective or vegetated. Regulations vary, but are typically aimed at low-slope (i.e., flat) roofs and buildings of a particular size. Cities like Los Angeles, however, also require new roofs on steep slope and residential buildings to be highly solar reflective.

Cool- or green-wall regulations are becoming more common and may be included in codes as a credit or to offset another requirement. Several recent Chinese building energy efficiency standards at the national, provincial, and local levels assign reflective roofs and walls a thermal resistance value that can reduce the requirement for physical roof and wall insulation. Some offer this trade-off only for highly solar reflective walls, while others provide a thermal resistance benefit that scales with wall solar reflectance (Ge and Levinson 2015). The reflectance tradeoffs may also offset exterior shading requirements.[40]

Green building and building energy codes may reduce the energy consumption for space cooling via air-conditioning and thus also reduce the associated warming impact of waste heat generated. Box 23 highlights code language to require cool roofs on certain buildings in India's Energy Conservation Building Code.

**BOX 23: COOL ROOFS IN BUILDING CODES: INDIA'S ENERGY CONSERVATION BUILDING CODE**

The Indian Energy Conservation Building Code 2016 (Indian Bureau of Energy Efficiency 2016) includes cool roofs as a prescriptive requirement and allows exemptions for roof area covered by solar photovoltaic panels, solar hot water, and vegetation.

Cool Roofs Code 4.3.1.1 states:

"Roofs with slopes less than 20 degrees shall have an initial solar reflectance of no less than 0.70 and an initial emittance no less than 0.75. Solar reflectance shall be determined in accordance with ASTM E903-96 and emittance shall be determined in accordance with ASTM E408-71 (RA 1996)."

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39 ASHRAE has members in over 120 countries that develop, maintain, and regularly update model building and energy codes that may be adopted in part or in whole. ASHRAE 90.1 refers to the model building code for commercial buildings. 90.2 is the model code for low-rise residential buildings.

40 ASHRAE 90.1-2016: Energy Standard for Buildings Except Low-Rise Residential Buildings permits east and west walls to be unshaded in ASHRAE climate zone 0 (hot and tropical conditions) if they have a solar reflectance index (SRI) not less than 29, which would typically correspond to an albedo of at least 0.28.

### 6.4.2 Tree Ordinances

Tree ordinances are a common tool used by local governments to ensure public safety, protect trees or views, and provide shade (United Nations FAO 2016). Ordinances may require direct developer/ building owner action or allow for developers to pay a fee to exempt themselves from certain requirements. Three types of ordinances are most useful from an urban cooling perspective: tree protection, street trees, and parking lot shade.

Tree protection ordinances prohibit the removal or pruning of trees without a permit. Often these ordinances apply only to native trees or trees with historical significance. The effectiveness of this type of provision depends on enforcement and how strict the requirements are for granting tree removal permits. Some ordinances protect not only trees but also the ground under the crown area of a tree to prevent root damage. In addition to requiring a permit, Melbourne, Australia, values the total ecosystem services provided by individual trees and requires that amount as payment if a developer wishes to remove the tree. The process funds other municipal tree promotion and maintenance programs.

Street tree ordinances generally govern how to plant and remove trees along public rights-of-ways and land that is privately owned but accessible to the public. At a minimum, these ordinances designate the numbers or types of trees that should be planted. More effective street tree policies include guidelines on tree selection, installation, and maintenance to lengthen a street tree's life and minimize problems with pavement, electrical wires, and buildings. Seattle, Washington, requires a street use permit before landscaping in a planting strip in a public right-of-way. For street trees, the strip must be at least 1.5 meters wide, unless specific approval from the city's arborist is received. A guide is available to help property owners select and plant trees in accordance with the city's requirements.

Some communities require parking lots be shaded to cool the pavement and cars, which improves comfort, reduces the heat island effect, and lowers evaporative emissions from parked cars. For example, since 1983, an ordinance in Sacramento, California's zoning code has required that enough trees be planted to shade 50 percent of new, or significantly altered, parking lots after 15 years of tree growth (United States EPA 2008).

# 7. FINANCING URBAN COOLING STRATEGIES

There are different types of municipal financing mechanisms that can be used for urban cooling efforts. The availability and cost of these mechanisms will depend on the municipality's fiscal situation, its ability to borrow, its creditworthiness, local legal and regulatory frameworks, and the type of urban cooling measure considered. For example, municipalities may use public finances such as taxes and intergovernmental transfers, as well as permits or licenses to fund urban cooling measures. A city that has not reached its borrowing limit and has a good credit rating may be able to access commercial financing (e.g., through the issuance of municipal and/or green bonds). Investments in urban cooling measures that lead to energy cost savings to the municipality (e.g., measures that lead to reduced cooling loads in municipally operated facilities) will free up municipal financial resources otherwise used to pay the electricity bill and can be used to repay borrowed money for the investments, and continue to generate budgetary savings over a longer period. One innovative way of attracting private capital being promoted by the World Bank is an "impact bond," an innovative performance-based contract between an investor, an outcome funder, and a provider of social or environmental services like 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.[41] Some municipalities may leverage private investments in urban cooling through credit lines or risk guarantees. 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 these to finance certain urban cooling investments.[42]

Many cities have a limited opportunity to raise revenues, have reached (or nearly reached) their borrowing limit, and/or have limited ability to access commercial financing due to a lack of creditworthiness. All cities face competing priorities for limited municipal budgets. To make the best case possible, it is helpful to take a broader societal view of the economic effects of municipal urban cooling measures. Cities looking to manage and finance the cost of municipal cooling, passive design, or efficiency programs should consider, for example:

- Identifying, quantifying, and recognizing the full economic benefits of urban cooling (including both energy-related as well as non-energy benefits, such as improved human health, greater work productivity, and more resilient energy infrastructure) to inform policy and budget decision-making processes.
- Where available, participating in national programs or financing schemes (e.g., energy efficiency revolving funds).[43]

41 Some 28 impact bonds are in the implementation and design stages in developing countries (Global Partnership for Results-Based Approaches, 2020). The most popular sectors are health, employment, agriculture, education, and social welfare. For a more detailed explanation and examples, see Global Partnership for Results-Based Approaches (n.d.),

42 See ESMAP (2018) for a description of categories of municipal financing mechanisms applied to municipal energy efficiency projects. The Basel Agency for Sustainable Energy (2019) discusses financing mechanisms in the public and residential, as well as commercial sectors. Sustainable Energy for All (SEforAll) (2020) reviews the current status and challenges to the many cooling needs that are not being met through commercial products, including heat extremes in urban slums.

43 Such programs are described in ESMAP (2018), and Aditya (2018).

- Highlighting how urban cooling strategies may have a beneficial effect on city credit ratings of urban cooling or, conversely, the credit risk of unchecked urban warming. Credit rating agencies[44] are now beginning to include municipal climate adaptation and mitigation programs and climate risk in their credit analysis methodology, citing the potential for reduced revenues, increased costs, impaired assets, and other economic challenges resulting from climate change and rising heat.
- Taking advantage of urban cooling's uniquely cross-cutting effects and seeking opportunities from existing funds promoting energy efficiency, green bonds, health infrastructure resiliency, and climate preparedness, etc.
- Prioritizing policies with low municipal operating costs. For example, requiring urban cooling measures through regulation will typically burden municipal budgets less than incentive programs targeted at residential or commercial sectors.
- Actively seeking philanthropic funding. Cities (or city networks) can be valuable partners to foundations seeking to support the implementation of projects that deliver tangible benefits to sustainable development (e.g., urban resiliency, public health, or climate change response). Cities may also benefit from partnerships with national governments to access climate finance sources, such as the Global Environmental Facility or the Green Climate Fund.
- Exploring possibilities to engage with development banks, including multilateral development banks such as the World Bank. These organizations can support infrastructure investments in urban cooling, and also advise on ways to organize urban cooling activities into a bankable package for the finance community.

44 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."

# 8. SUMMARY OF RECOMMENDATIONS FOR CITIES

This primer presented cooling strategies for cities facing a warming world exacerbated by the urban heat island effect. Cities need to mitigate urban heat while facilitating cooling and thermal comfort and safety of their inhabitants. Taking action limits the incidence and costs of illnesses and deaths caused by more intense and frequent heatwaves. There are a number of technical urban cooling solutions available to cities (detailed in Section 3) that city leaders may consider and tailor as appropriate. Table 21 provides an overview of those solutions and their recommended use cases.

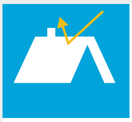
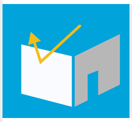
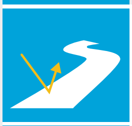
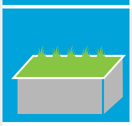
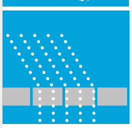
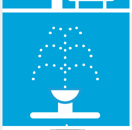
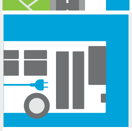
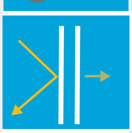
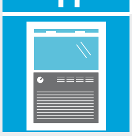
City practitioners must balance the immediate needs of their citizens to stay cool with the long-term urban heat island effects of technologies such as air-conditioning. This primer presented an approach for how to identify urban cooling needs, technical solutions, and policies, all while building the base of stakeholders and data needed to support successful implementation (Section 5). The primer also presented a list of policies that cities have adopted, along with a framework for evaluating those policies based on the size of the policy's effect, how fast those effects would be felt in a city, and the relative challenge of adopting and implementing the policy (Section 6). While there is no "one-size-fits-all" approach to urban cooling, a global review of municipal activities reveals several common characteristics. These include:

**Develop a cooling action plan:** Urban cooling actions will be implemented across a variety of public and private organizations. Having an overarching cooling action plan (or urban heat mitigation plan) to articulate the local imperative for urban cooling, set targets and goals, and establish a means to measure progress is essential to organizing strategies and actions toward cooler cities. Cooling plans should be developed with a broad set of stakeholders and periodically updated to smooth integration with other city strategies for climate response, planning and development, resiliency, and sustainability.

**Identify heat vulnerable areas and populations:** Knowing where cities are hot and where residents are at greatest risk of heat stress can form the basis for a variety of targeted interventions, including outreach and communication efforts, incentives, programs providing enhanced access to cooling, and access to shelters from extreme heat. Poor and marginalized populations bear a disproportionate burden from rising temperatures because they tend to live in neighborhoods lacking vegetation, in substandard buildings and, in the case of rapidly growing cities, potentially without access to a social safety net of friends and family. Cities seeking to gain the maximum benefit for urban cooling efforts should map local hot spots (both surface and air temperatures during the day and night) and where populations most vulnerable to heat stress are living and working. This information can form the basis for a variety of targeted interventions including incentive programs, programs providing enhanced access to cooling, or concentrations of shelters from extreme heat.

**Demonstrate urban cooling strategies with pilot projects:** Pilot projects serve to test solutions for a broader urban cooling approach while raising awareness of urban cooling, building confidence, and providing a tangible experience for policy makers, the public, and other stakeholders. Measuring and monitoring pilots will produce invaluable local data to inform decision making, build capacity and engagement among stakeholders, and potentially signal market demand.

## TABLE 21: USE CASES FOR URBAN COOLING STRATEGIES

| | STRATEGY | APPLICABLE CLIMATES FOR COOLING BENEFITS | APPROPRIATE USE CASES |
|---|---|---|---|
|  | **Solar reflective roofs** | All but polar climates | All buildings |
|  | **Solar reflective walls** | All but polar climates | All buildings |
|  | **Solar reflective pavements** | All but polar climates | Site specific. Optimal benefit on pavements with little building interactions and sufficient shade over pedestrian areas |
|  | **Green roofs** | All climates with sufficient rainfall or access to low-cost water | Low-slope roofs with sufficient structure support for the roof system |
|  | **Green walls** | All climates with sufficient rainfall or access to low-cost water | All buildings |
|  | **Permeable pavements** | Climates with summer rainfall | Pavements with sufficient drainage or catchment areas that are not receiving polluted stormwater runoff |
|  | **Tree canopy and parks** | All climates | All locations where sufficient space for root structures and tree canopy is available |
|  | **Water infrastructure** | All climates | All locations |
|  | **Urban planning** | All climates | All locations, but especially in newly developing areas |
|  | **Reducing waste heat** | All climates | All locations |
|  | **Thermal insulation** | All climates | All buildings |
|  | **Appliance and other active energy efficiency** | All climates | All buildings |

**Engage the public:** Ultimately, the purpose of urban cooling strategies is to improve the lives of the people living and working in cities. Creating an environment where the public plays a meaningful role in the policy development process is essential, especially for poor or marginalized communities where the need for urban cooling is greatest but where trust in government may be low. Cities could create media campaigns, websites, and local opportunities to share feedback on urban cooling ideas and potential measures. In addition to political buy-in, engaged communities can serve as citizen scientists and volunteers to help gather relevant and actionable data on local conditions.

**Lead by example:** Cities have the most control over municipally owned assets and the services they provide. Municipal procurement that takes into account urban cooling, efficiency, and broader resiliency improvements will help create local markets for these solutions, provide test cases for the public, and build implementation and evaluation capacity. Incorporating mandatory responses into government funding tenders establishes a new lens through which contractors review their own internal processes.

**Make urban cooling measures the standard:** Establish passive design principles (e.g., solar reflective surfaces, vegetated surfaces, natural ventilation, and shade) and energy efficiency in buildings within building and energy codes. Codes should establish the minimum design requirements to promote urban cooling (likely solar reflective surfaces) with compliance pathways for more expensive or high-impact measures such as green roofs or solar PV panels. Pair new standards with incentives to spur compliance and/or to exceed the requirements. In addition to prescriptive requirements, cities could consider policies like building labelling programs that render energy efficiency and urban cooling more visible, providing important data for public and private decision makers.

**Consider incentives:** Properly designed incentives encourage adoption of urban cooling measures, passive design, and energy efficiency in both the public and private sector. Incentives may stand alone, be used to help comply with requirements, or encourage people to exceed requirements. Targeting incentives to particularly heat vulnerable areas or populations can substantially increase the positive results of such programs within limited budgets.

**Expand urban forestry efforts:** Revitalizing urban tree canopy and park space with native species that are appropriate to expected future local climate conditions can provide substantial cooling and other benefits to most locations, although suitability depends on water availability (e.g., they may not be appropriate in desert and highly water constrained climates). Establish green corridors linking existing park and urban canopy concentrations, with a priority on routes with heavy pedestrian activity, neighborhoods with a relative lack of existing canopy, areas with a large number of highly heat vulnerable people, and areas with high concentrations of particulate matter and other pollutants.

**Work with other cities and city networks:** As the primer documents in detail, some approaches have been tested and evaluated in multiple locations and over many years, while others are still relatively new and yet to be fully tested and documented. In addition, differences in local circumstances, such as the range and frequency of high temperatures experienced, may impact the cost and efficacy of different measures. Cities will therefore benefit from sharing experiences and lessons learned—from those just starting to consider an urban cooling strategy, to those that have spent years developing and implementing one. Experience sharing can help others learn from challenges and identify innovative approaches to replicate. City leaders can learn from research or market experiences in other cities with similar characteristics (e.g., climate, building type, and urban layout) to make decisions before local data are readily available. In some cases, cities can partner to increase their buying power and negotiate lower product prices, particularly if they are in the same marketplace. Global networks of cities, such as the C40 Cool Cities Network, are already focused on urban cooling issues.

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# APPENDIX—COOL CITY CASE STUDIES: REDUCING URBAN HEAT

## INTRODUCTION

The need to protect populations from extreme heat is one of the key resiliency and sustainability challenges of the twenty-first century. The combined trends of urbanization in developing countries, global climate change, and rapid growth in urban temperatures mean that billions of people need cooling solutions to live and thrive. The negative effects of excess heat on urban systems are significant and impact nearly every aspect of urban life. Successfully implementing measures to cool urban air temperatures will lead to many benefits, including for health, well-being, productivity, air quality, and energy systems.

This appendix provides case studies of cities that have implemented urban cooling solutions to the benefit of their residents.

The following case studies are presented in this report:

**Paris:** Creating cool islands and pathways to protect against extreme heat

**Ahmedabad:** Building roofs to cool homes

**Toronto:** Spurring private action to build green roofs

**Washington, D.C.:** Leading by example—Smart Roof Program

**Hyderabad:** Improving thermal comfort for vulnerable communities.

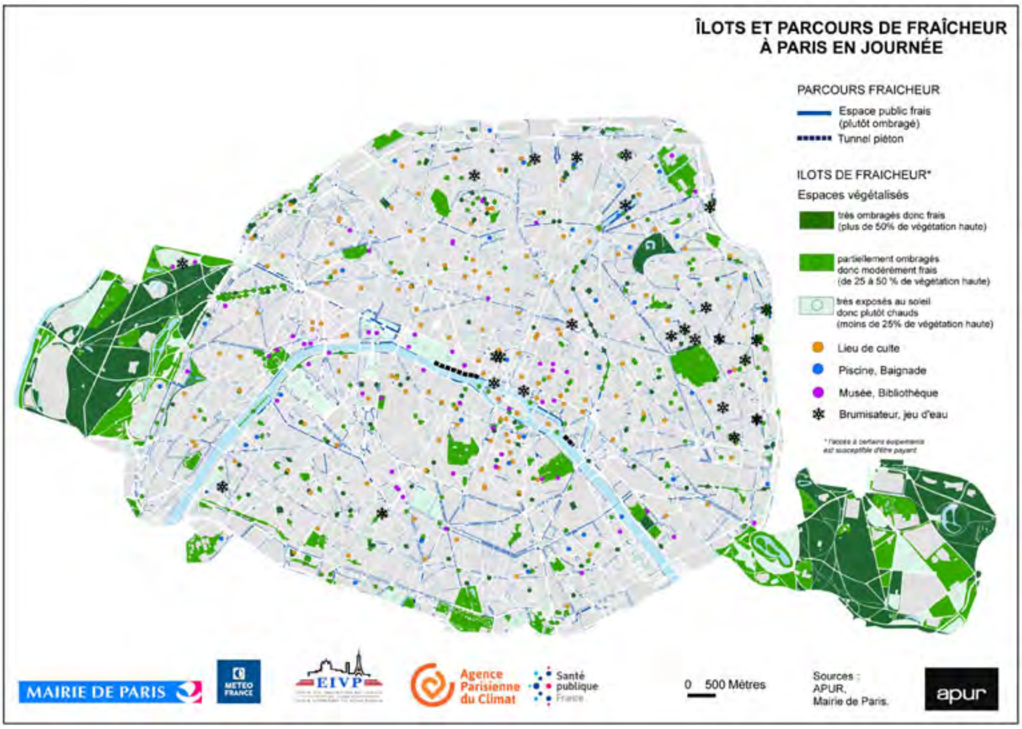
## PARIS: CREATING COOL ISLANDS AND PATHWAYS TO PROTECT AGAINST EXTREME HEAT

### Summary

Like many cities, Paris adopted an urban cooling strategy in response to a particularly intense heat emergency. The European heat wave of 2003 saw temperatures rise above 40°C and stay at least 35°C for nine straight days in Paris. Nearly 1,100 people died within the city during the heat wave, 88 percent of whom lived alone. The city expects to face more frequent and intense heat events due to the effects of climate change. In response, the city has undertaken four related initiatives to create areas of heat resiliency throughout the city.

**Cool islands:** This initiative aims for every Parisian to be within a seven-minute walk of a 'cool island' by 2020. A cool island is defined as a naturally or actively cooled area of respite from the heat. This can be anything from a swimming area, water/misting feature, and air-conditioned municipal building to places of worship and parks. In addition to serving as emergency cooling locations during extreme heat events, cool islands reduce urban heat islands overall, raise awareness about heat and heat resiliency, and improve access to parks and open spaces within the city.

## FIGURE CS-1: PARIS MAP OF DAYTIME COOL ISLANDS




*Source:* Atelier parisien d'urbanisme (2018), "Parcours et ilots de fraicheur à Paris," https://www.apur.org/fr/nos-travaux/parcours-ilots-fraicheur-paris

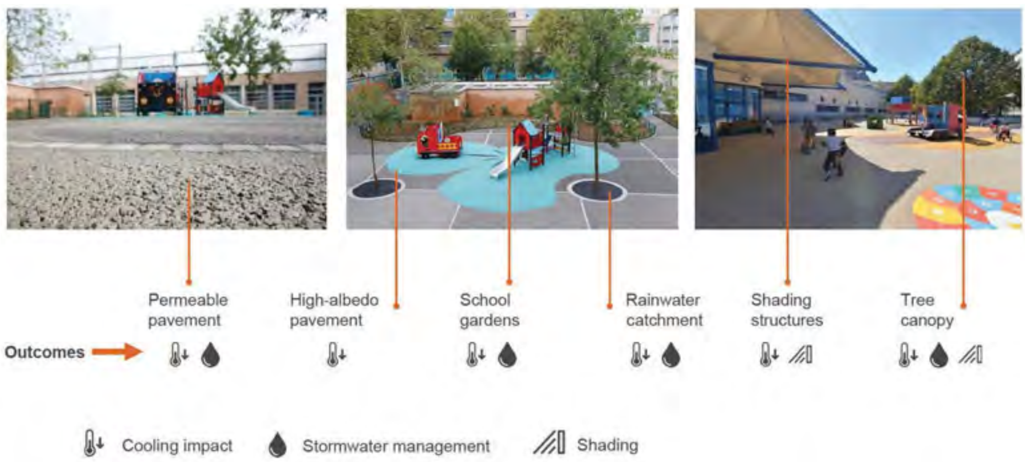
In 2018, Paris identified 822 locations (Figure CS-1) that could serve as daytime cool islands including:

- 565 green spaces
- 142 religious buildings
- 49 museums
- 5 libraries
- 34 swimming pools
- 2 open water swimming areas
- 25 water features.

The city also evaluated sites appropriate for nighttime cooling, primarily in open green spaces. Locations are given a color code to indicate the level of cooling available to residents. The city plans for an additional 300 cool islands to be in place by 2030, including 20,000 new trees planted and 90 new water areas fit for cooling respite.

**Urban oasis:** Schools have been another area of focus because they are municipally controlled, dispersed geographically, and numerous. The Urban Oasis Initiative uses shading, greenery, permeable surfaces, and cool pavements to cool schoolyards that will serve as neighborhood refuges throughout the city. The city received a US$5 million award to convert 30 cool schoolyards by 2019 (each schoolyard cooling project will cost an estimated $330,000). As of May 2020, the Urban Oasis Initiative had converted 31 schoolyards. The initial schools were chosen based on their proximity to high heat areas and heat vulnerable populations identified using a mapping analysis (Bloomberg Associates 2019). Paris aims to complete the remaining 770 Parisian schoolyards by 2040.

## FIGURE CS-2: COOL OASIS STRATEGIES FOR PARIS SCHOOLYARDS




*Source:* Bloomberg Associates (2019), "Mitigating Urban Heat Island Effects Cool Pavement Interventions," https://www.bbhub.io/dotorg/sites/32/2019/08/20190516_Cool-Pavement-Research-FINAL.pdf

**Cool pathways:** Paris plans to link the network of cool islands to create cool pathways allowing Parisians to minimize thermal discomfort as they move about on hot days. Cool pathways would be formed by a combination of measures, including enhanced and continuous shading of pedestrian walkways with tree canopies or structures; added green, permeable and solar reflective pavements; and preferences for paths that are close to waterways. The short-term target is to have one pathway operational by the end of 2020.

**Extrema heat safety application:** In 2018, Paris partnered with the National Observatory of Athens to launch Extrema, a mobile application to help Parisians stay cool during extreme heat events. The application alerts users when they have entered an area of high temperature, maps a route to the nearest cool island, and can prompt family and friends to check on the user's well-being during heat emergencies. Extrema builds on an existing extreme heat registry program in the city known as CHALEX that regularly contacts registrants (currently over 9,000 subscribers) during heat emergencies. The application dynamically updates conditions using surface temperatures measured by satellite every few minutes that are then converted into estimated air temperatures.

**Climespace district cooling:** Paris is home to Europe's largest and first district cooling network. Operating under a concession model from the city of Paris since 1991, the Climespace network is over 75 km long, replacing air conditioners and chillers for many offices, shops, and hotels, as well as for famous landmarks in the center of Paris. The network is completely underground, with 60 percent running through the sewage system, which enabled reaching scale and lower development costs. Three of the network's cold-water production sites make use of the city's free cooling, taking water from the Seine River to pre-cool water before it enters electric chillers, a process that increases energy efficiency and lowers costs and GHG emissions (C40 and UNEP n.d.). As France has experienced a series of heatwaves in recent summers and demand for cooling is growing, the city of Paris plans to increase the cooling network to enable the connection of residential buildings and small businesses.

The Climespace network delivers more than 486 GWh per year of cooling to close to 700 buildings. Compared to autonomous room air conditioners and chillers, the district cooling network is estimated to lead to 50 percent improvements in energy efficiency, 35 percent reduction in electricity consumption, and 50 percent fewer CO2 emissions.

*Case study source*: Adapted from Bloomberg Associates (2019), "Mitigating Urban Heat Island Effects Cool Pavement Interventions," https://www.bbhub.io/dotorg/sites/32/2019/08/20190516_Cool-Pavement-Research-FINAL.pdf

## AHMEDABAD: BUILDING ROOFS TO COOL HOMES

### Background: Ahmedabad's Heat Action Plan

One of India's fastest growing cities, Ahmedabad, is the economic center of the state of Gujarat. Ahmedabad, including the surrounding suburban and rural areas, is home to 7.2 million people. Located in the arid western region of India, Ahmedabad's warm, dry climate is conducive to heat waves. Experts estimated that the devastating heat wave that hit the city in 2010 contributed to more than 1,000 deaths (Gulrez et al. 2014). In response, municipal leadership worked on a plan to protect local communities from future rising temperatures and the deadly threat of extreme heat. In 2013, the city of Ahmedabad and partners launched the ground-breaking Ahmedabad Heat Action Plan. A 2019 evaluation found that the plan, which is updated annually, saves nearly 1,100 lives per year (Hess et al. 2018).

### Cool Roofs

In 2017, the Ahmedabad Municipal Corporation (AMC) unveiled an initiative to coat 3,000 low-income dwellings as a part of the updated Ahmedabad Heat Action Plan (Ahmedabad Municipal Corporation 2017). The pilot was carried out in collaboration with private sector corporate social responsibility activities, and included a student volunteer program.

The initiative sought to:

- **Engage citizens:** The AMC designed dedicated information, education, and communication materials on cool roofs to increase community awareness on what cool roofs are, how they can help reduce indoor temperatures, and what materials can be used to create a cool roof. A group of 50 volunteer students from local colleges joined the drive to support the AMC in coating many rooftops.
- **Showcase municipal leadership:** The AMC included municipal and other publicly owned buildings in the pilot and developed cool roof requirements in their procurement criteria.
- **Engage with local businesses for implementation:** The AMC partnered with a manufacturer to acquire highly reflective cool coatings[45] free of cost for the first pilots. The partnership allowed the AMC to test higher performing building cooling solutions as part of the broader initiative.

45 The product used in the pilot had a solar reflectance index (SRI) of 122. SRI includes the cooling effect of a material's emissivity, as well as its solar reflectance.

The donated paint was sufficient for 10–15 pilot households. The remaining households were painted with three layers of lime by contractors hired by the AMC. The city completed its pilot program and applied coatings of lime wash on 3,000 low-income homes in the city, with 500 in each city zone, covering almost 2 percent of the city's low-income households by May 2017. The total cost of the project was US$10,924, at an average cost of US$3.51 per household.[46]

With a low unit cost of approximately $0.75 per m$^2$, lime wash is a cost-competitive material on a first-cost basis compared with other cool coating options, but it requires regular reapplication. Another pilot program in Indore experimented with a composite roofing material consisting of locally available Mangalore tiles, cement mortar bedding, and lime concrete. The roof system was found to reduce indoor temperatures by 2–3°C and cost US$20 per m$^2$. While significantly higher in cost than lime wash alone, this material could be a long-term alternative for low-income homes in India that often do not have proper roof structures (TARU Leading Edge 2015).

### Results

In 2018, the initiative expanded to include solar reflective paint coatings, and over 20 local real estate developers agreed to apply the coatings on roofs of private buildings in Ahmedabad on a voluntary basis. The city's next steps include adding cool roofs to more municipal buildings, adopting incentive mechanisms for cool roofs on private buildings, incorporating cool roof initiatives into city building codes, and establishing a stable budget and financing mechanisms.

*Case study source:* Adapted from the National Resource Defense Council (2018), "Cool Roofs: Protecting Local Communities and Saving Energy Issue, Brief May 2018," https://nrdc.org/sites/default/files/ib_-_cool_roofs_-_hyd_workshop.pdf

## TORONTO: SPURRING PRIVATE ACTION TO BUILD GREEN ROOFS

### Summary

The Toronto City Council adopted a Green Roof Strategy that encouraged the construction of green roofs on municipal and privately owned buildings through incentives, public education, and streamlined development approval processes. The strategy led to the adoption of the City's Green Roof Bylaw and the Eco-Roof Incentive Program for cool and green roofs in 2009.

The Green Roof Bylaw—the first of its kind in North America—sets out a green roof requirement for new developments that are greater than 2,000 m$^2$ in gross floor area. The requirement ranges from 20 to 60 percent of the available roof space of a building. The bylaw allows developers to seek approval to pay US$200/m$^2$ instead of constructing the required green roof. All funds collected are directed to the Eco-Roof Incentive Program. The bylaw also spurred the development of the Green Roof Construction Standard to govern the design and construction of green roofs by setting out minimum requirements that meet the city's objective.

To complement the bylaw, Toronto also adopted a rebate program called the Eco-Roof Incentive Program. The Eco-Roof Incentive Program encourages the installation of green roofs and solar reflective roofs on existing (and some new) buildings through financial incentives. The program offers

46 Based on a house size of 42m$^2$.

Can$100/m$^2$ for green roof projects and Can$2–5/m$^2$ for cool roof projects. In addition, applicants who want to construct a green roof on an existing building may also be eligible to receive a Structural Assessment Grant, which provides up to Can$1,000 to help offset the costs associated with determining whether the building is suitable for green roof construction. The program is self-sustaining, drawing funding from cash-in-lieu payments through the Green Roof Bylaw.

The Green Roof Bylaw and the Eco-Roof Incentive Program are key components for implementing Toronto's Official Plan Vision, intended to ensure the city evolves, improves, and realizes its full potential in areas such as transit, land use development, and the environment. These two programs are also designed to (i) manage the quantity and improve the quality of stormwater, (ii) reduce GHG emissions, (iii) promote green infrastructure, and (iv) encourage green roofs as an innovative approach to reducing the urban heat island effect. The programs support multiple city-wide environmental policy objectives including TransformTO (Toronto's new and ambitious climate action strategy), and the Wet Weather Flow Management Master Plan (Toronto's plan to protect water quality in Toronto's watercourses and Lake Ontario).

## Results

Between 2010 and 2017, approximately 420 green roof permits were issued in Toronto, totaling 450,000 m$^2$ of green roof space. The Eco-Roof Incentive Program has received over 500 applications and successfully supported 336 eco-roof projects since 2009. Achievements of projects funded through the Eco-Roof Incentive Program are summarized in Table CS-1.

### TABLE CS-1: ECO-ROOF INCENTIVE PROGRAM ACHIEVEMENTS

| | |
|---|---|
| Urban cooling | Widespread implementation of green roofs can reduce local ambient air temperature 1.5 to 2°C. |
| Stormwater management | Approximately 11 million liters of stormwater diverted from sewers annually, resulting in a cost savings of at least $100,000. |
| Energy efficiency | Average of 1,000 megawatt hours per year in energy savings primarily from reduced need for air-conditioning. |
| GHG emission reductions/air quality | Average of 220 metric tons of greenhouse gases avoided annually. |
| Green space enhancement | Green roofs will help increase green space in the urban environment with the potential to enhance biodiversity. |
| Economic development | Minimum of 12 person-years of new employment generated. |

*Source:* Adapted from C40 (2018), "Case Study City of Toronto's Eco-Roof Incentive Program and Green Roof Bylaw," https://www.c40.org/case_studies/city-of-toronto-s-eco-roof-incentive-program-and-green-roof-bylaw

## WASHINGTON, DC: LEADING BY EXAMPLE—SMART ROOF PROGRAM

### Summary

In 2011, the Washington D.C. Department of General Services (DGS) launched the Smart Roof Program to assess the potential of each roof in the DGS portfolio to meet the goals of reduced heat islands, improved stormwater retention, and increased solar energy production. Roof consultants assessed the physical condition of each roof and evaluated the economics of each sustainable technology option, the structural load capacity of the roof (necessary for vegetated roofs), the viability for high-efficiency solar energy installations, watershed effects, and existing roof insulation levels. Economic evaluations factored in any available incentives for solar energy and stormwater mitigation, as well as the effect of power purchase agreements. The evaluation included a schedule for roof interventions based on estimated remaining roof life and upgrade costs to allow Washington D.C. to better plan capital expenditures.

It was calculated that DGS owns or controls 435 buildings with over 1 million $m^2$ of roof space. Approximately 836,000 $m^2$ of the portfolio is made up of low-sloped roofs that are best suited for sustainability interventions. This means that there is large potential for municipal-led rooftop projects.

For roofs in good condition, Washington D.C. considered a silicone-based solar reflective coating to extend the functional life of the roof. Existing roofs with the new silicone coatings received a 20-year warranty. Washington D.C. installed single-ply white membranes on some new buildings and roof replacements on buildings that could not support a vegetated roof. Where feasible, DGS installed both a cool roof and solar PV together.

Washington's *Sustainable DC* plan outlines a set of goals that include maximizing the potential for rooftops to mitigate urban heat islands, manage stormwater, and generate renewable energy. In support of these goals, Washington D.C. adopted cool roof requirements for some commercial buildings and leads the United States in green roof installations (Green Roofs for Healthy Cities 2019).

### Results

At current deployment rates, the Smart Roof Program will save Washington D.C. US$33 million (not counting societal benefits) over 20 years. The use of coatings to restore and extend the life of functioning roofs reduced capital requirements by 75 percent and generated 224 new local jobs with the potential to create 300 more (Bluefin n.d.).

## HYDERABAD: IMPROVING THERMAL COMFORT FOR VULNERABLE COMMUNITIES

### Summary

The city of Hyderabad in the state of Telangana is located in the hot and arid Deccan Plateau in south-central India. The city is home to over 7 million residents and forms one of the largest urban municipal areas in India. Municipal and state leadership have begun to develop a cool roofs policy, with a focus on low-income communities in the city (Natural Resources Defense Council 2016).

Hyderabad's 1,468 low-income communities house a population of over 1.9 million people. A majority of the homes within the city's low-income neighborhoods are constructed with concrete slab or asbestos roofs. As the city works to enhance living and housing conditions in these neighborhoods, the installation of cool roofs provides a great opportunity to improve human health and comfort in Hyderabad.

Telangana's proposed cool roofs policy development process included:

- **Identification of key stakeholders:** The Telangana cool roofs program identifies key government stakeholders for successful policy adoption and implementation, including the state government departments and local bodies such as the Chief Commissioner for the Revenue Department within the state Municipal Administration and Urban Development Department.
- **Engagement of technical partners:** With strong leadership and buy-in from the Greater Hyderabad Municipal Corporation (GHMC), the Natural Resources Defense Council (NRDC) and the Administrative Staff College of India (ASCI), the International Institute of Information Technology–Hyderabad (IIIT–H) has been engaged to implement a trial pilot, assist with the policy development process, and provide implementation support.
- **Implementation of a cool roofs initiative:** Working alongside technical partners, the city will implement cool roof solutions and monitor performance, comfort, and impact on health outcomes, beginning with a trial pilot program and then expanding out to a larger city-wide program.
- **Development of financing solutions for the cool roofs initiative:** To enable an effective and sustainable cool roofs program, the city government, along with partners, sought to develop financing solutions, including exploring city budget allocations and other sources of income, such as corporate social responsibility funds.

In 2017, ASCI and NRDC, with technical support from IIIT–H, implemented a cool roofs pilot program in a low-income neighborhood of Hyderabad to showcase and document the benefits and impact cool roofs can have.

The cool roof pilot program sought to identify cost-effective cool roof solutions for low-income housing and a scalable financial mechanism to support the cool roofs program in the city. The pilot program was undertaken in May and June 2017, toward the end of the hot season in Hyderabad and prior to the monsoon. This period is characterized by a combination of high heat and humidity, often making indoor conditions extremely uncomfortable. The cool roof pilot project covered 25 low-income households in Hyderabad. Dupont India supplied a high-density polyethylene (HDPE) cool roof coating membrane, Tyvek, for the pilot implementation free of cost as a part of their corporate social responsibility efforts. The membrane retails in Hyderabad for US$21.50 per $m^2$.

The main steps in the pilot process were:

1. **Trial site identification:** Organizers chose an informal settlement called Devarakonda basti in west Hyderabad for the pilot project. The neighborhood is surrounded by midrise residential apartments and is characterized by single-floor, densely packed residential homes. The homes are predominantly constructed of reinforced cement concrete and brick, with roofs made of corrugated asbestos sheets or concrete slabs. Almost 50 percent of households have asbestos sheet roofs, making this community representative of the 1,468 low-income communities in Hyderabad (Greater Hyderabad Municipal Corporation 2014).

2. **Pilot project design:** ASCI and IIIT–H designed the pilot program to cover 25 households, with an additional 15 households serving as a control group to compare results.

3. **Stakeholder consultation:** Prior to beginning installation and monitoring, ASCI and IIIT–H conducted a stakeholder consultation with residents and building owners.

4. **Membrane installation process:** The ASCI and IIIT–H teams installed the membranes and testing equipment on the pilot households. The cool roof membrane was secured to the roofs of the 25 houses through the use of ropes or bricks to weigh the membranes down. As no permanent installation took place, the process had many added advantages: first, the membrane could be removed and stored at the end of each heat season, considerably increasing the life of the membrane; second, the membrane provided a waterproofing layer to the buildings that were often improperly constructed and had leaks or cracks in the roof structure; and third, the process allowed for quick and easy installation that did not require specialized labor and served as an example to residents about measures they could take themselves to replicate the process.

5. **Resident surveys:** All 25 households, along with an additional 15 households that served as the control group, were surveyed both before and after the pilot program to capture responses of the residents. The pilot program covered a total roof area of 930 $m^2$ for over 100 residents.

6. **Monitoring:** The team closely monitored performance in four houses, two with cool roof membranes and two from the control group without the membrane. The tests monitored outdoor and indoor ambient air temperature, relative humidity, air speeds, and carbon dioxide levels using indoor air quality measurement meters, anemometers, and testo globes.

### Results

Researchers observed reductions in average indoor air temperatures of 2°C in the homes with cool roofs as compared to similar homes without cool roofs. The surface temperature of the cool roofs in the pilot were 15°C lower than surface temperatures of asbestos roofs and 10°C lower than surface temperatures of cement roofs.

A majority of the residents in the survey group, 76 percent, expressed satisfaction with the cool roofs, while residents in the control group and other parts of the neighborhood began to apply makeshift cool roof membranes on their own roofs in response to the positive feedback by the trial.

*Case study source:* National Resources Defense Council NRDC (2018), "Cool Roofs: Protecting Local Communities and Saving Energy Issue Brief May 2018," https://nrdc.org/sites/default/files/ib_-_cool_roofs_-_hyd_workshop.pdf

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## ESMAP MISSION

**The Energy Sector Management Assistance Program (ESMAP) is a global knowledge and technical assistance program administered by The World Bank.** It assists low- and middle-income countries to increase their know-how and institutional capacity to achieve environmentally sustainable energy solutions for poverty reduction and economic growth. ESMAP is funded by Australia, Austria, Canada, ClimateWorks Foundation, Denmark, the European Commission, Finland, France, Germany, Iceland, Italy, Japan, Lithuania, Luxembourg, the Netherlands, Norway, the Rockefeller Foundation, Sweden, Switzerland, the United Kingdom, and the World Bank.

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