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Heat Stress and Urban Resilience: Alternative Cooling Strategies to Combat Extreme Heat in the Urban Environment

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Background

By 2050, approximately 970 cities worldwide are projected to experience average summer high temperatures of 35°C (95°F) (C40 Cities 2018). Heat stress is already a major environmental health hazard placing millions of people around the world at heightened risk, and disproportionately affecting urban populations, due to a combination of rising global temperatures, the urban heat island (UHI) effect, and social vulnerabilities.

Heatwave exposure among urban populations has increased significantly since the 1980s, with cities experiencing longer and more intense periods of extreme heat (Watts et al. 2021). Global heatwave-related mortality between 1990 and 2019 is estimated to be over 5,000 deaths annually (Zhao et al. 2024). Scholars have also warned of major economic losses caused by the combined effects of global warming and the UHI effect (Burke and Tanutama 2019; Kahn et al. 2021).

UHI refers to dense urban zones that are noticeably hotter than their surrounding rural areas. This temperature difference arises because of the form and materials used in dense urban environments, where buildings and roads tend to absorb and retain more solar heat than natural landscapes like forests or water bodies (United States Environmental Protection Agency 2024).

Within cities, specific neighborhoods experience significantly higher temperatures than others, creating local "hot spots." These disparities can lead to disproportionate exposure to extreme heat, particularly affecting marginalized and vulnerable populations, which are more likely to live in historically redlined communities with limited tree canopy, extensive impervious surfaces, and limited access to cooling (Bird 2022; Philadelphia Office of Sustainability 2019; Plumer et al. 2020; Wilson 2020). This inequity stems from long-term disinvestment in neighborhoods, including discriminatory housing and planning practices (Wilson 2020).

In this policy digest, we discuss UHI and its impact on communities both from a global perspective and from a highly local perspective, through a case-study of such "hot-spot" within Philadelphia, Pennsylvania—the Hunting Park neighborhood, where a heat awareness and response survey with over 600 residents was conducted in 2019 by city officials (Philadelphia Office of Sustainability 2019).

To provide insights into innovative cooling infrastructure could supplement existing policies and respond to critical gaps, we present takeaways from an urban cooling pilot launched in the Hunting Park neighborhood in 2024, which may provide lessons for larger scale deployment of community-based resilient solutions.

Health, Social Determinants, and Economic Challenges

The intersection of public health and economic inequality in Philadelphia is exacerbated by environmental stressors including heat. Vulnerable populations such as elderly residents, individuals with chronic illnesses, and those in low-income households face compounded health risks and limited financial capacity to adapt.

Heat stress increases hospitalizations for cardiovascular and respiratory illnesses, disproportionately affecting marginalized communities. The Philadelphia Department of Public Health (2024) reports that heat-related illness rates are highest in areas with the least tree canopy and highest poverty levels. There has been a marked increase in emergency room visits for heat exhaustion during summer months, disproportionately affecting African American and Latino populations (Philadelphia Department of Public Health 2024).

These health challenges are amplified by limited access to health care and preventive services. Economically, heat events reduce productivity, increase utility costs, and can even lead to job loss—particularly in labor-intensive occupations (Matsumoto et al. 2021). Residents struggling to afford cooling often face higher energy bills in poorly insulated rental units, a burden known as energy poverty. According to the Philadelphia Office of Sustainability (2024), many Philadelphia's low-income households experience energy insecurity annually.

Social determinants such as income inequality, housing quality, education access, and health disparities critically shape the city's resilience to climate-related stressors, particularly extreme heat. Philadelphia's poverty rate—one of the highest among major U.S. cities at 22.3%—correlates with reduced adaptive capacity to climate impacts (U.S. Census Bureau 2023).

Communities with limited financial resources often lack access to air conditioning (AC), live in poorly insulated homes, and have minimal access to green space. These neighborhoods are also disproportionately composed of Black and Brown residents, reflecting systemic disinvestment and environmental racism (Grant et al. 2022).

Education and social capital are also pivotal. Areas with higher educational attainment and civic engagement are more likely to participate in resilience planning, access public resources, and implement protective actions.

However, Philadelphia's educational inequities perpetuate knowledge gaps that hinder adaptive behavior and resilience. Investments in workforce training, equitable green infrastructure, and participatory planning processes are essential to building long-term resilience. Addressing them through inclusive policy and community-driven action is imperative for a climate-resilient Philadelphia.

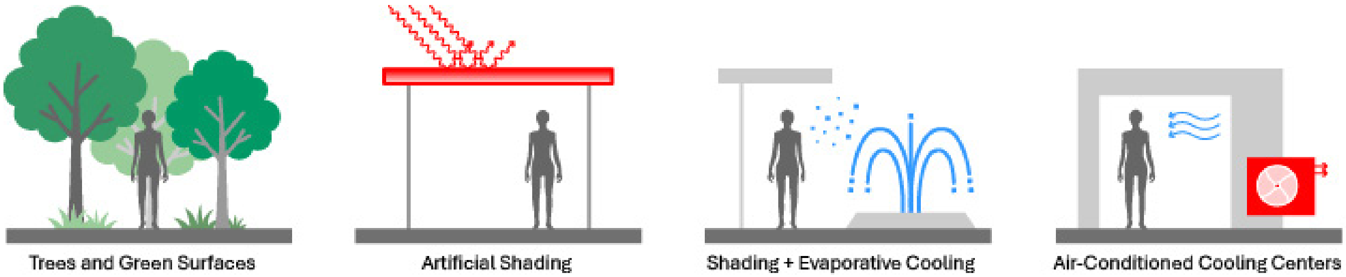
This includes expanding cooling subsidies, retrofitting housing through weatherization assistance, and increasing Medicaid coverage for climate-related illnesses. Job training programs in green infrastructure and energy efficiency can simultaneously reduce unemployment and build adaptive capacity. Philadelphia's public health and economic resilience are intertwined. Without targeted, equitable interventions with community participation, climate change will continue to widen disparities and threaten the city's long-term sustainability.

Existing Urban Cooling Policies

In response to the increased environmental health risks posed by UHI, numerous efforts have been initiated at both national and international levels to help communities mitigate the impacts of the UHI effect. In the United States, the Environmental Protection Agency (2008) continues to collect and share examples of voluntary initiatives and mandatory policies implemented by state and local governments.

These efforts are recorded in the Heat Island Community Actions Database (U.S. Environmental Protection Agency 2014). Globally, the United Nations Environment Programme (UNEP) and its partners

Figure 1. Existing Urban Cooling Strategies



Drawing by Jiaye Li, Thermal Architecture Lab

have developed a comprehensive handbook featuring 80 case studies of effective urban cooling strategies (Campbell et al. 2021). The handbook categorizes community-focused urban cooling interventions into three groups:

1. Public cooling infrastructure including the establishment of cooling centers, the integration of public shaded areas and the incorporation of water features like fountains and misting stations
2. Nature-based solutions and such as planting street trees and developing parks
3. Action plans for heat events which delineate clear roles, responsibilities, and response strategies for various stakeholders

Urban cooling strategies include both passive and active approaches to reduce heat stress in cities. Passive methods—such as shading devices, trees, greenery, pervious surfaces, and reflective roof coatings—aim to lower ground, air, and indoor temperatures by blocking solar radiation, reducing heat absorption, and enhancing water retention Shashua-Bar et al. 2011).

Water features like fountains and misting stations provide evaporative cooling, though their effectiveness depends on climate conditions and water availability (Elangovan 2019; Office of Environmental Risk and Resilience 2022; Theochari et al. 2023). Potable water stations also play a key role in reducing heat-related illnesses, particularly in water-stressed regions (Singh et al. 2019; Zawiah Mansor et al. 2019)

In contrast, active solutions like air-conditioned cooling centers—designated existing public buildings such as libraries and malls—are a widely adopted intervention for mitigating extreme heat, implemented in many cities across the U.S. and worldwide (Bedi et al. 2022; United States Environmental Protection Agency 2024) with their number varying significantly by location (Adams et al. 2023).

Cooling solutions differ in not only in energy use, but also in cost, ease of implementation, and durability. Temporary shading tarps, for instance, offer a quick, low-cost option for short-term heat relief but lack long-term resilience. In contrast, planting trees requires more investment and time to mature but can provide lasting benefits, including sustained cooling and broader social impacts like reduced urban violence over time (Kondo et al. 2020).

Critical Gaps in Existing Solutions

Limitations of Passive Solutions

Implementation of passive interventions for reduction of urban heat is necessary and attainable on a large scale. Shading and vegetation strategies are especially impactful in reducing the heat island effect. Trees and shading canopies can reduce urban heat continuously throughout the hot season.

Trees and vegetated surfaces are especially effective in the hot and dry climates, where the added benefit of evapotranspiration from plant surfaces is added to the major effect of shading in reducing urban heat locally (Shashua-Bar et al. 2011). However, selecting tree species suited to local conditions is essential; when inappropriate trees are planted, they often die, require intensive maintenance, or cause property damage from broken branches—leading to community distrust. Moreover, nature-based cooling measures are particularly challenging to implement in regions facing water scarcity.

Depending on the level of heat stress caused by environmental conditions, passive strategies alone may not be sufficient and some of them may take time to implement at scale and necessitate intermediate solutions that can be deployed in the more immediate future.

Hazardous heat stress can occur in both hot-dry and hot-humid climates (Foster et al. 2024). A prolonged exposure to a hot-dry environment presents the risk of dehydration and heat stroke. While outdoor water features may be used in dry climates to lower the air temperature via evaporative cooling (to the extent that adequate access to water is possible), they are largely ineffective in humid climates.

In hot and humid climates, when both the air temperature (dry bulb temperature) and the wet bulb temperature (indicating the limit of the body's ability to cool itself via evaporation of water from the skin) are high, the body's main mechanism for cooling itself is hindered, placing humans in increased heat stress (Sherwood and Huber 2010).

To combat heat stress in such conditions, active cooling solutions, which can significantly reduce the heat stress of the body, are necessary. However, the reliance on air-conditioned cooling centers as a singular solution for active urban cooling presents major challenges as well.

Drawbacks of Cooling Centers

Although cooling centers are widely promoted as a heat relief strategy, they face growing criticism due to issues of underuse, unsustainable energy demands, and vulnerability during emergencies (Berisha et al. 2017; Hirji 2024; *Los Angeles Times* 2020). Some of these challenges stem largely from a lack of meaningful community engagement in the design and implementation of such facilities.

Many centers are underutilized because of barriers like limited public awareness, accessibility, and inconvenient hours (Allen et al. 2023; Bedi et al. 2022; Widerynski et al. 2017). Their reliance on air conditioning raises environmental concerns, as AC use contributes significantly to global electricity consumption, carbon emissions, and urban heat islands (Aviv et al. 2025; Gabrielse et al. 2024).

Moreover, during emergencies such as power outages—which frequently occur during heat waves (Burillo et al. 2019; Zhang et al. 2021) or public health crises, cooling centers may become inoperable or unsafe, especially when enclosed spaces limit fresh air circulation and increase the risk of airborne disease transmission, as seen during the COVID-19 pandemic (Morawska et al. 2020; Centers for Disease Control and Prevention 2020; Mead et al. 2020). To operate during emergencies, cooling centers require preventative maintenance and backup power, often relying on diesel generators that introduce additional environmental and public health risks.

An Alternative Design Solution: Open-Air Solar-Powered Cooling

Other active cooling solutions exist, that resolve some of the major drawbacks of overreliance on air-conditioned cooling centers. Evaporative cooling technologies are effective in hot and dry climates, although water supply must be managed carefully in these regions (Dhariwal et al. 2019).

In hot humid climates, where outdoor evaporative cooling is not effective, most cooling solutions have concentrated on air-cooling technologies, namely AC, which require an enclosed environment where chilled air can be circulated, with high energy costs. However, heat stress in the outdoor environment can also be reduced using radiant systems, which manipulate the Mean Radiant Temperature (MRT) instead of the air temperature.

A new advancement in radiant cooling, expanding its applicability to open-air humid climates, suggests this technology is a promising scalable alternative to AC: In 2019, an international group of researchers that demonstrated radiant cooling below the dew point without condensation in the hot-humid climate of Singapore (Teitelbaum et al. 2020).

In the demonstration in Singapore, an open-air shading structure that consisted of ten membrane-assisted radiant cooling panels operated under hot and humid conditions without condensation. The thermal comfort study on the pavilion validated that people could be made to feel “cool” with panels operating below the dew point (Teitelbaum et al. 2020). A similar experiment in Los Angeles in 2024 demonstrated the effectiveness of radiant cooling structures using hydronic panels and IR-reflective surfaces in reducing mean radiant temperature and improving outdoor thermal comfort (Abraham et al. 2025).

The advantage of such a system is that it can be installed in outdoor spaces that are occupied by urban residents, such as bus stops and major pedestrian pathways. They can also be installed intentionally to protect vulnerable populations such as children in playgrounds or school courtyards.

For the outdoor laborers, they will take major advantage of designated cooling centers, as they allow urban residents to find shelter from the heat in those locations that they may pass through to arrive to work, rather than forcing people to miss work in order to protect themselves from the heat. To be truly effective in responding to community needs, though, it is necessary to design and implement these systems in collaboration with community members. Otherwise, they may not reflect the true needs of the community and become un/underused or neglected.

Pilot in Philadelphia

During the summer of 2024, we tested for the applicability of open-air solar powered cooling in the Hunting Park neighborhood of Philadelphia. Hunting Park is a neighborhood with noted UHI effect due in part to its history of industry and a lack of trees and green surfaces. Tree canopy coverage in Hunting Park is only 9%, compared to 19% in Philadelphia overall (Philadelphia Office of Sustainability 2019).

In a study with 40 residents of the community conducted by the Philadelphia Office of Sustainability together with partners in other departments in the City of Philadelphia government in 2019, residents indicated that the lack of bus shelters in their neighborhood had a major impact on their outdoor comfort and suggested the construction of such shelters as one of the main interventions they would like to see implemented in the neighborhood (Ibid.).

To address this need, we developed a shelter prototype in collaboration with the community organization North10, Philadelphia which is dedicated to improving life outcomes for community members of Hunting Park-East Tioga in North Philadelphia. North10, using a collective impact approach, is aimed at addressing challenges resulting from a history of disinvestment in the neighborhood, including environmental health risks.

As part of a co-design process aimed at testing the viability of this outdoor cooling solution for the community, we installed a full-scale cooling shelter, which can perform as a bus stop, equipped with a shading canopy, radiant cooling panels, and a conductive cooling bench powered by solar PV panels (Bae et al. 2025, 2026).

This open-air shelter, named, Tenopy (to represent the cooling canopy and its location at North10), was constructed and tested in the front yard of the North10 community center (the Lenfest Center) in August 2024. Twenty local community members participated in a survey to provide feedback of their experience in the cooling shelter.

Impact on Heat Stress

The shelter incorporates a shading canopy, solar-powered radiant cooling panels, and a conductive cooling bench, enabling effective open-air cooling while greatly reducing energy consumption compared to conventional air conditioning. Users can experience

Figure 2. Construction of the Open-Air Cooling Station at the Lenfest Center, Home to the North10 Organization in the Hunting Park Neighborhood

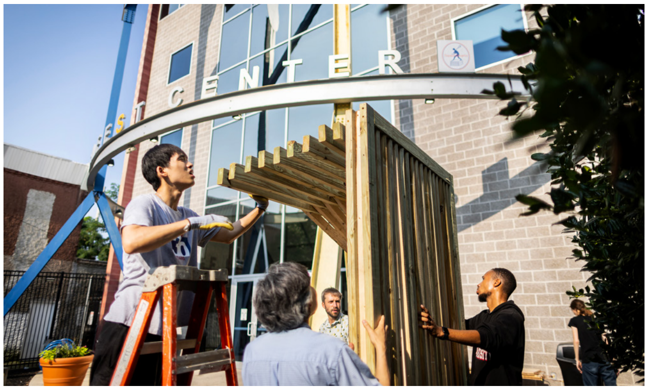


Photo by Eric Sucar, Penn Comms

Figure 3. The Solar-Powered Cooling Shelter Being Tested by Community Members in August 2024

Photo by Eric Sucar, Penn Comms

Figure 4. Rendering Showing the Cooling Station Installed as a Bus-Stop Shelter

Drawing by Ji Yoon Bae, Thermal Architecture Lab

thermal relief either by sitting on the cooling bench, which transfers heat away from the body, or by standing near the radiant panels located beneath the shaded structure.

Our environmental analysis based on surface temperature measurements using infrared thermography showed that the mean radiant temperature (MRT) inside the cooled shelter was over 20°C lower than the surrounding outdoor conditions (Bae et al. 2026). Such MRT reduction leads to a major reduction in heat stress (Thorsson et al. 2014).

In addition to the measured and modelled results, we conducted a thermal comfort survey amongst 20 community members who participated in the shelter testing, and a vast majority of participants reported thermal satisfaction with the shelter: 80 percent of the participants reported they were either neutral (neither hot nor cold) or cooler than neutral, after being exposed to the radiant panels, and 90 percent reported neutral or cooler sensation after sitting on the bench for a prolonged period .

When testing the Tenopy, residents provided open-ended feedback about ideal open-air solar powered cooling technology in their communities. During testing of the shelter, residents suggested adding practical amenities, improving airflow and weatherproofing, and praised its solar panels, spacious interior, and informational design. Most felt the shelter would fill a gap by offering a place to sit, cool off, and learn about heat risks, while another urged sustained funding so similar installations can serve broader climate and neighborhood needs. Overall sentiment was strongly positive, tempered by requests to fine-tune comfort features and choose locations carefully.

Infrastructure Resilience and Scalability

The Tenopy shelter demonstrated successful off-grid operation using rooftop photovoltaic panels, which generated 2.4 kWh of electricity—40% more than the 1.7 kWh required by the cooling system during peak hours—confirming the feasibility of solar-powered cooling. Because peak solar radiation aligns with heatwave conditions, solar energy is available precisely when cooling is most needed.

The system's components, including radiant panels and a conductive bench, are designed for open-air use, eliminating the need for enclosed structures and reducing both energy and construction costs. Comparable in cost to a small refrigerator, the system is scalable, adaptable to various urban contexts, and proven effective in reducing heat stress and energy consumption globally. Furthermore, the system is mobile and simple to operate. It can be operated by community members and does not need continuous maintenance to be operable during the hot months.

The Tenopy pilot was followed this past summer (2025) by a publicly-accessible solar-powered modular cooling shelter built in Governors Island in New York City (Gonchar 2025), further extending the size and flexibility of the system.

Call for Action

To strengthen urban resilience against rising temperatures and ensure equitable adaptation to extreme heat, a combination of multiple policies is required. Urban cooling strategies must combine community engagement, nature-based- and design-and-technology-based interventions. These should be complementary rather than exclusive, as articulated by international efforts such as UNEP's handbook. Below we provide the primary takeaways from our study.

Cities should adopt the following community-centered policy directives:

1. Provide Resilient Urban Cooling Infrastructure

Resilient cooling infrastructure must withstand emergency situations. While entirely passive solutions such as tree planting and shading canopies are important measures to mitigate UHI, they may not be sufficient on their own to combat high levels of heat stress. Providing low-energy solar-powered active cooling solutions guarantees access to cooling even during power shortages. Additionally, open-air active cooling solutions can be deployed in critical locations for community members, such as transit-stops or school yards, providing fresh air while alleviating strong heat stress. Built as modular, lightweight systems, they can also serve as mobile infrastructure for emergency deployment, providing adaptable relief when fixed cooling centers lose power.

2. Require Inclusive Community Engagement in Heat Resilience Planning

Planning and design processes for heat mitigation must include structured, early, and continuous engagement with residents, particularly those in heat-vulnerable neighborhoods. Incorporating lived experience and localized knowledge will optimize resource allocation, enhance usability, and prevent the underutilization of resilience infrastructure.

3. Institutionalize Community Ownership of Infrastructure

City governments should promote local stewardship over climate adaptation assets by embedding community ownership models in cooling infrastructure projects. This includes participatory governance structures, community-based maintenance protocols, and neighborhood-level oversight to ensure sustained functionality and relevance.

4. Embed Public Education and Awareness in Climate Programs

Climate policies must include comprehensive public education strategies that raise awareness of alternative cooling methods and how they deliver relief from heat stress. Public understanding is seen as critical for effective heat resilience policy, as demonstrated by diverse initiatives worldwide. In Phoenix, Arizona school-based initiatives bring together teachers, students, and families on low-cost cooling strategies, such as adjusting uniforms, modifying outdoor activity schedules, and using shaded areas (Office of Heat Response and Mitigation, n.d.-a).

This program is part of a broader HeatReady initiative that aims to embed heat mitigation into urban planning, emergency response, and public communication. In Athens, Greece one of Europe's most heat-vulnerable cities, the Chief Heat Officer has led public awareness campaigns to inform residents about heat risks, promote the use of public cooling spaces, and distribute guidance on hydration, activity timing, and the benefits of passive cooling (Myrivili 2022). These programs reflect a growing recognition that behavior change is essential for adapting to increasing heat.

Locally, Philadelphia's Beat the Heat program engages residents through heat vulnerability mapping, neighborhood ambassadors, and tailored education on accessing cooling centers, water, and shade (Office of Sustainability n.d.). Taken together, these efforts are based on the idea that public education when embedded in policy and community design can assist individuals to access safer, more sustainable heat resilience.

While these programs demonstrate the potential of public education to reduce heat-related harm, their impact is often limited by inconsistent funding, language barriers, lack of sustained engagement, and inadequate incorporation with a full range of heat resilience infrastructure and policy.

5. Mandate Tiered Heat Resilience Action Plans

Cities shall adopt a phased approach to urban heat resilience that combines short-term response with long-term sustainability:

Immediate Response Measures. Deploy temporary interventions, including mobile shade structures, hydration stations, misting units, and emergency cooling shelters, to safeguard public health during acute heat events. Provide preventative maintenance to ensure operation teams and equipment are prepared for emergency events. Invest in innovative, renewable-energy-powered cooling technologies, such as solar-powered shelters, particularly in transit corridors and high-density neighborhoods with local community participation.

Sustainable Long-Term Solutions. Expand and preserve urban green spaces—such as parks, forests, and green corridors—to serve as permanent cooling systems while co-delivering flood resilience, ecosystem and public health benefits.

Conclusions

Urban resilience to extreme heat requires a diverse and adaptable set of cooling strategies. No single solution is sufficient—cities must adopt a comprehensive palette of interventions tailored to their unique environmental conditions, community needs, and planning stages. Deployable and modular cooling structures offer flexible, scalable responses that can serve both immediate and transitional needs, without requiring permanent infrastructure. These mobile systems can complement long-term green infrastructure, ensuring coverage in underserved areas.

However, sustainable cooling solutions must be grounded in local realities. Effective policy design must account for a city's specific climate, built environment, resource availability, and—most critically—the voices of its residents. Community-driven approaches that center lived experience will ensure that heat resilience plans are inclusive, effective, and equitable. Each city should define its own action plan through participatory planning processes, ensuring adaptive and place-based strategies are prioritized in the face of increasing heat risks, to build a collective climate resilience.

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Cover Photo: Ji Yoon Bae, Thermal Architecture Lab.

Appendix

Table 1: Urban Cooling Strategies and Programs (Ongoing)

City	Cooling Strategy Type	Policy Instrument	Initiative / Program Name	Cooling Intervention	Year Start	Source
Phoenix (U.S.A.)	**Comprehensive Plans and Collaborative Initiatives**	Comprehensive Plans; Design Guide or Standard	Shade Phoenix	Urban tree planting (27,000 new trees); Built shade structures (550 new structures); Prioritized investments in vulnerable communities; Enhanced shade maintenance	2024	(City of Phoenix, 2024)
		Comprehensive Plans; Outreach and Education; Project or Program	Set up Phoenix's Office of Heat Response and Mitigation		2021	(Office of Heat Response and Mitigation, n.d.-c)
	Cooling Infrastructure and Pilot Initiatives	Project or Program	Cool Pavement Pilot	Cool pavements reflective pavement coating): A water-based asphalt treatment that is applied on top of the existing asphalt pavement. It's made with asphalt, water, an emulsifying agent (soap), mineral fillers, polymers and recycled materials.	2020	(Street Transportation Department, n.d.)
		Outreach and Education; Project or Program; Plan	Nature's Cooling Systems	Neighborhood-specific heat action plans; Cooler pedestrian routes; Shade structures at bus stops; Trees and green spaces in neighborhood; Heat safety training	2017	(Nature's Cooling Systems Project, 2019)
		Design Guide or Standard; Project or Program; Ordinance or Resolution; Code	Walkable Urban Code	Requirement: 75% sidewalk shading (structural/ landscaping)	2015	(Walkable Urban Code, 2015)
		Design Guide or Standard; Project or Program; Code	Phoenix Cool Roofs Initiative	Reflective cool roof coatings (coating rooftops white reflects the sun's heat)	2013	(Cities of Service, n.d.)

City	Cooling Strategy Type	Policy Instrument	Initiative / Program Name	Cooling Intervention	Year Start	Source
Phoenix (U.S.A.)	**Public-Facing Resources and Services**	Project or Program	Extreme Heat Resources	Emergency alert system; AC cooling centers & buses; Free hydration stations; Interactive map for locating cooling resources	/	(Bock, 2023; Office of Heat Response and Mitigation, n.d.-b)
Miami-Dade County (U.S.A.)	**Comprehensive Plans and Collaborative Initiatives**	Project or Program	Resilience Hub Network Strategy	Resilience hubs and mobile cooling infrastructure: - Retrofitted community centers with backup power, extra AC capacity, and fortified insulation - Mobile resilience pods (rvs, trailers, CONEX containers) equipped with backup power - Provide reliable cooling and water access during heat waves or power outages	2023	(Atlantic Council Climate Resilience Center, n.d.-b; Miami-Dade County & Atlantic Council Climate Resilience Center, 2024)
		Administrative Order	Heat Illness Prevention Policy	Heat illness prevention standard operating procedure; Employee heat safety guidelines; Workplace heat risk mitigation (risk assessment, shade access, rest breaks, hydration stations, heat safety training)	2023	(Miami-Dade County, 2023)
		Comprehensive Plans; Design Guide or Standard	Extreme Heat Action Plan	Public Heat Awareness & Protection: education, heat warnings, worker safety, healthcare preparedness; Home & Facility Cooling: financial assistance, cool roofs, energy resilience at shelters Neighborhood Cooling: tree canopy expansion, cool pavements, expand access to water and shade, cool commutes	2022	(Office of Environmental Risk and Resilience, 2022)

City	Cooling Strategy Type	Policy Instrument	Initiative / Program Name	Cooling Intervention	Year Start	Source
Miami-Dade County (U.S.A.)	Comprehensive Plans and Collaborative Initiatives	Design Guide or Standard	Extreme Heat Toolkit	Enhance urban greenery and water features; Heat-resilient buildings & transit; Community engagement strategies	2022	(Office of Civic and Community Engagement, 2022)
		Comprehensive Plans; Outreach and Education; Project or Program	Appointed the U.S.'s first Chief Heat Officer		2021	(Office of Environmental Risk and Resilience, n.d.)
	Cooling Infrastructure and Pilot Initiatives	Incentive or Rebate	Matching Grant	Incentive to plant trees on public land (e.g. streets, transit sites, bus stops, schools, parks, public housing)	2025	(Parks, Recreation and Open Spaces, 2025)
		Ordinance or Resolution	Sustainable Buildings Program	Green building certification requirements; Sustainable design and construction guidelines	2007	(Creating the Sustainable Buildings Program for County-Owned Projects, 2007)
	Public-Facing Resources and Services	Policies and Procedures	Extreme Heat Activation Response and Recovery	Coordinate extreme heat response for homeless populations (Water & cooling supplies; Informational materials; transportation to cooling centers; Designated air-conditioned shelters; Early season planning & partner coordination)	2024	(Miami-Dade County Homeless Trust, 2024)
		Project or Program	Extreme Heat Resources	Emergency alert system; Air-conditioned cooling centers; Water distribution & hydration stations; Extended access to splash pads, pools & misting stations; Interactive heat risk map for locating resources	/	(Office of Civic and Community Engagement, 2022)

City	Cooling Strategy Type	Policy Instrument	Initiative / Program Name	Cooling Intervention	Year Start	Source
Los Angeles (U.S.A.)	**Comprehensive Plans and Collaborative Initiatives**	Comprehensive Plans; Outreach and Education; Project or Program	Appointed LA's first Chief Heat Officer		2022	(City of Los Angeles, 2022)
		Mapping or Research	Los Angeles Urban Cooling Collaborative	Modeling study of current and projected heat impacts (Identify heat-vulnerable areas; Evaluate tree cover and solar reflectance scenarios; Quantify reductions in heat mortality; Climate warming delay estimates)	/	(TreePeople, n.d.)
	Cooling Infrastructure and Pilot Initiatives	Project or Program	Million Trees LA	Citywide fruit and shade tree planting (Free fruit tree adoptions; Food desert focus; Environmental, health & social benefits)	2006	(LA2050, n.d.)
		Project or Program	Cool Streets LA	Cool pavements (reflective coating); Trees and vegetation	2021	(Bureau of Street Services, n.d.; City News Service, 2021)
		Ordinance or Resolution	Los Angeles Cool Roof Ordinance	Mandatory cool roof standards (solar reflectivity and thermal emittance requirements for residential roofs)	2014	(Cool Roof Ordinance, 2014)
	Public-Facing Resources and Services	Project or Program	Extreme Heat Resources	Emergency alerts via NotifyLA; Free hydration stations; Pet-friendly cooling centers with transportation assistance; Interactive cool spots map app	/	(Emergency Management Department, n.d.)

City	Cooling Strategy Type	Policy Instrument	Initiative / Program Name	Cooling Intervention	Year Start	Source
Athens (Greece)	**Comprehensive Plans and Collaborative Initiatives**	Design Guide or Standard; Project or Program	Heat Risk Reduction Guidelines	Framework for cooling public spaces using urban greenery, water elements, and reflective or heat-resistant building materials; Include technical specs tailored to diverse urban forms based on Athens typologies	2023	(Theochari et al., 2023)
		Comprehensive Plans; Outreach and Education; Project or Program	Appointed the first Chief Heat Officer		2021	(Atlantic Council Climate Resilience Center, 2022)
	Cooling Infrastructure and Pilot Initiatives	Design Guide or Standard; Project or Program	Urban Redesign for a Cooler Future	Climate-responsive urban design: - Reviving ancient solutions: Aqueduct for green space & shade; Whitewashed walls & shutters for passive cooling; - Greening and cooling public spaces: Pocket parks & street trees; Design guidelines for cooler public spaces (parks, streets, and squares) using vegetation, water features, and heat-resistant materials	After 2021	(Wallace, 2023b)
	Public-Facing Resources and Services	Outreach and Education; Project or Program	Heat Risk Communication & Awareness	Heat wave categorization & naming system; Early warnings; Targeted alerts to vulnerable groups; Public education on hydration and shade-seeking	After 2021	(Wallace, 2023b)
		Outreach and Education; Project or Program	Extreme Heat Preparedness & Response	Personalized heat risk assessments via extrema global app; Maps of cooling shelters,air-conditioned public spaces, and shaded routes; Caregiver training; Elderly outreach programs; Expanded cooling centers & water distribution for homeless populations	After 2021	(Wallace, 2023b)

City	Cooling Strategy Type	Policy Instrument	Initiative / Program Name	Cooling Intervention	Year Start	Source
Free-town (Sierra Leone)	**Comprehensive Plans and Collaborative Initiatives; Public-Facing Resources and Services**	Outreach and Education; Project or Program	Heat Season Campaign	Identify urban heat hotspots; Raise public awareness via flyers, SMS, and social media; Promote innovative heat adaptation solutions	2023	(Wallace, 2023a)
	Comprehensive Plans and Collaborative Initiatives	Outreach and Education; Project or Program	Freetown's First Climate Action Strategy	GHG reduction targets; Urban heat risk mapping; Passive cooling architecture; Green corridors; Heat action plan; Building code; Community-based resilience programs; Heat alerts system	2022	(Freetown City Council, 2023)
		Comprehensive Plans; Outreach and Education; Project or Program	Appointed Africa's first Chief Heat Officer		2022	(Atlantic Council Climate Resilience Center, 2021)
	Cooling Infrastructure and Pilot Initiatives	Project or Program	Market Shade Cover Project	Low-cost, scalable shade covers in open-air markets (steel-framed Danpalon covers with solar-powered lighting; waterproof and semi-translucent for year-round use)	2022	(Atlantic Council Climate Resilience Center, n.d.-a)
		Project or Program	Freetown the Treetown Initiative	Urban reforestation for heat resilience: 1 million trees in 2 years; Community-led planting using social media, mobile payments & machine learning; Creates green jobs for women and youth	2020	(Fisseha et al., 2021; Jones et al., 2022)

Note. Policy Instrument column adapted from U.S. Environmental Protection Agency. (2014, June 17). Heat Island Community Actions Database [Data and Tools]. *https://www.epa.gov/heatislands/heat-island-community-actions-database*

Table 2: Singapore's Urban Cooling Strategies and Programs (Ongoing)

Country	Cooling Strategy Type	Policy Instrument	Initiative / Program Name	Cooling Intervention	Year Start	Source
Singapore	**Comprehensive Plans and Collaborative Initiatives**	Comprehensive Plan	Singapore's Green Plan 2030	Urban greening and shade (1000 ha new green space; universal park access by 2030)	2021	(Ministry of Sustainability and the Environment, 2021)
		Mapping or Research	Cooling Singapore	Urban heat research; Digital planning tools: UHI/OTC metrics & mitigation strategies; Climate-responsive urban design guidelines; Digital urban climate twin for simulation-based cooling solutions	2017	(Singapore-ETH Centre, n.d.)
		Incentive or Rebate	Landscaping for Urban Spaces and High-Rises (LUSH) Scheme	Skyrise and vertical greenery incentive (encouraging greenery on rooftops and building facades; 300+ ha added greenery; cooling load reduction, enhanced pedestrian comfort)	2009	(Urban Redevelop-ment Authority, 2022)
	Cooling Infrastructure and Pilot Initiatives	Project or Program	Green Towns Program	Cool coating (facade / pavement); Greenery intensification (urban farms, extensive greenery, or community/ allotment gardens to the top decks of selected multi-storey car parks)	2020	(Housing and Development Board, n.d.)
		Project or Program	OneMillionTrees Movement	Urban tree planting campaign (1 million trees in 10 years)	2020	(National Parks Board, 2025)
		Project or Program	Walk2Ride Program	Sheltered walkway infrastructure (connecting homes & public facilities to transit hubs within 200–400m; improves thermal comfort & walkability)	2018	(Land Transport Authority, 2025)

Country	Cooling Strategy Type	Policy Instrument	Initiative / Program Name	Cooling Intervention	Year Start	Source
Singapore	**Public-Facing Resources and Services**	Policies and Procedures	Guidelines on Managing Heat Stress in the Workplace	Acclimatization protocols, hydration guidelines, rest & shade provisions, emergency response planning	2020	(Ministry of Manpower, 2024)
		Project or Program	Extreme Heat Resources	Heat alerts and safety guidance; Air-conditioned cooling centers in community hubs; Water dispensers at hawker centres, parks, and transport node	/	(Ching, 2025; Meteor-ological Service Singapore, n.d.; Ministry of Health, 2023)

Note. Policy Instrument column adapted from U.S. Environmental Protection Agency. (2014, June 17). Heat Island Community Actions Database [Data and Tools]. https://www.epa.gov/heatislands/heat-island-community-actions-database

Table 3: Philadelphia's Urban Cooling Strategies and Programs (Ongoing)

City	Cooling Strategy Type	Policy Instrument	Initiative / Program Name	Cooling Intervention	Year Start	Source
Phila-delphia (U.S.A.)	**Comprehensive Plans and Collaborative Initiatives**	Comprehensive Plan	Philly Tree Plan	Urban Forestry Expansion for Cooling; Long-term strategy to grow and protect the urban tree canopy; Prioritizes tree planting and maintenance in low-canopy, heat-vulnerable neighborhoods; Builds partnerships with communities to increase shade equity and climate resilience across the city	2023	(City of Philadelphia, 2023)
		Comprehensive Plan	Philadelphia Climate Action Playbook	Expand tree canopy and green infrastructure; Support home weatherization and geothermal cooling; Advance neighborhood heat planning	2021	(Office of Sustain-ability, 2021)

City	Cooling Strategy Type	Policy Instrument	Initiative / Program Name	Cooling Intervention	Year Start	Source
Phila-delphia (U.S.A.)	Comprehensive Plans and Collaborative Initiatives	Outreach and Education; Project or Program; Plan	Beat the Heat Hunting Park: A Community Heat Relief Plan	Engages residents and city agencies to develop local heat-action solutions; Plan to install green stormwater infrastructure; Expand seasonal tree giveaways and training; Launch a neighborhood heat relief network; Build citywide climate planning and multilingual outreach tools	2018	(Office of Sustain-ability, 2019)
		Comprehensive Plan	All-Hazard Mitigation Plan (update 2025)	Open cooling centers during heat waves; Operate Heatline for health guidance; Deploy Code Red emergency shelter outreach; Prioritize tree planting and green space in high-risk neighborhoods; Expand UHI mapping to guide targeted cooling investments	2012	(Office of Emergency Management, 2025)
	Cooling Infrastructure and Pilot Initiatives	Project or Program	Cool Roofs Program	Pilots reflective roof coatings in heat-vulnerable neighborhoods; Develops long-term cool roof policy to improve home energy efficiency and neighborhood heat resilience	2024	(Office of Sustain-ability, 2024)
		Project or Program	Cool Pavement Pilot	Apply a light-colored, reflective sealant (CoolSeal) to pavement in Hunting Park; Monitor temperature reduction and material performance 2024	2024	(Office of Sustain-ability & Department of Streets, 2024)
		Outreach and Education; Project or Program	TreePhilly	Distribute free yard trees and expands street tree planting to grow canopy in heat-vulnerable areas; Engage residents in long-term urban forest care	2011	(Fairmount Park Conservancy, n.d.; Philadelphia Parks & Recreation, n.d.)

City	Cooling Strategy Type	Policy Instrument	Initiative / Program Name	Cooling Intervention	Year Start	Source
Phila-delphia (U.S.A.)	**Cooling Infrastructure and Pilot Initiatives**	Ordinance or Resolution; Design Guide or Standard	Cool Roof Law	Require reflective roofs on new low-slope buildings to reduce heat absorption and improve energy efficiency	2010	(The Philadelphia Building Construction and Occupancy Code, 2010)
	Public-Facing Resources and Services	Project or Program	Extreme Heat Resources	Heat alerts via ReadyPhiladelphia; Air-conditioned cooling centers; Heat emergency outreach; Free water-based play spaces; Heatline for health advice; Extreme heat guide; Beat the teat toolkit; Heat vulnerability index mapping tool for locating resources	/	(Department of Public Health, n.d.-a, n.d.-b; McDevitt, 2023; Office of Sustain-ability, n.d.)

Note. Policy Instrument column adapted from U.S. Environmental Protection Agency. (2014, June 17). Heat Island Community Actions Database [Data and Tools]. *https://www.epa.gov/heatislands/heat-island-community-actions-database*

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