ISSUE 01

THERMAL TOOLKIT

TECHNOLOGIES AND TECHNIQUES FOR VISUALIZING HEAT

A PROJECT OF THE LANDSCAPE ARCHITECTURE FOUNDATION DEB MITCHELL RESEARCH GRANT

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CONTENTS

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INTRODUCTION: HEATING UP

The "Thermal Toolkit" begins with an examination of the pressing issue of urban heat and its multifaceted impacts. This section delves into the adverse effects of increased temperatures on public health, infrastructure, and overall quality of life, particularly within urban settings. It underscores the importance of planning for urban heat resilience as a crucial strategy to mitigate these impacts. By exploring the broader context of climate change, the phenomenon of the Urban Heat Island Effect, and the concept of thermal disparity, we aim to provide a brief overview and primer of the challenges and opportunities associated with managing urban heat.


SURFACE TEMP °F: 89.9
HUMIDITY (%): 43.3%
HEAT INDEX °F: 86.5
WET BULB GLOBE TEMP °F: 80.6
METAL [SUN]: 103.1° F
LAWN [SUN]: 82.1° F
GRAVEL [SUN]: 105° F

USING THE TOOLKIT

We designed the Thermal Toolkit as a primer to equip landscape architecture, planning, and design professionals, as well as academics, with a starting point to address the pressing challenges posed by extreme heat in urban environments. This document is not a comprehensive survey or a systematic literature of extreme heat, but a subjective compilation of extreme heat research that we found to be useful throughout our tenure as the LAF Deb Mitchell Award recipients. This research is really rooted in notions about health and resilience and in the ways that landscapes can provide respite from the increasing frequency of heatwaves. But how do we begin to catalyze change and enable action? The first step is through recognition and in making apparent disparities visible by way of finding paths to better incorporate heat visualization methods into the design process, thereby making our cities cooler and more comfortable places to live.

Our research operated through two parallel streams; 1) The Thermal Toolkit, which would act as a receptacle of our general research into extreme heat, planning and designing for heat resilience, adaptation and mitigation tactics, and heat visualization methodologies, and 2) A Thermographic Case Study, where we employed commercially available (and accessible) tools for visualizing and representing the impacts of urban heat. Organizing the Thermal Toolkit provided us with the theoretical and academic framing required to situate our case study, which focused on Omaha, NE (Chapter 03, Section B and C). It is nearly impossible to capture the breadth of the tremendous amount of heat research available. As such, we imagine this report as one that can evolve and respond to include emerging research and we welcome any feedback in formulating a stronger and more comprehensive toolkit.

There are five sections in the toolkit: **00 Introduction, 01 Designing a Heat Action Plan, 02 Heat Adaptation and Mitigation Tactics, 03 Methods for Visualizing Heat, and 04 Glossary.**

The Thermal Toolkit is structured to guide users through the multifaceted and complex nature of extreme heat, offering resources, practical strategies, and tools for visualizing, planning, and mitigating its impacts.

Here's what you'll find in each section:

Introduction: Heating Up

Climate Change: This section lays the groundwork by exploring how climate change is driving the increasing frequency and intensity of extreme heat events. It provides a broad overview of global warming's effects on weather patterns and delves into the implications for urban areas.

Urban Heat Island Effect: Here, we explore the phenomenon of urban heat islands, where cities experience higher temperatures than their rural surroundings due to human activities and urban infrastructure. This section examines the causes, impacts, hinting at potential solutions to mitigate the UHI effect.

Thermal Comfort/Disparity: Understanding thermal comfort and the disparities in heat exposure is critical for addressing extreme heat. This section delves into the factors that influence thermal comfort in urban environments and highlights the uneven distribution of heat stress across different communities.

Designing a Heat Action Plan

Action planning for heat isn't a new idea. Heat Action Plans have been gaining traction as a process for identifying strategies for countering heat intensity, especially as a form of addressing environmental injustices. These plans are generally produced through transdisciplinary collaborations, meaning through the leadership of experts, like landscape architects and policy makers, but through conversations with communities and engaging them as part of the decision-making process. We provide places to look for existing heat action plans as well as different frameworks for working with communities as part of the design process.

Planning for Urban Heat Resilience: This section offers guidance on how to incorporate heat resilience into urban planning and design. It covers strategies for assessing vulnerability, identifying at-risk populations, and integrating heat adaptation measures into long-term urban development plans.

Resilience Center: The Resilience Center provides users with case studies, best practices, and a repository of data and tools to help build urban resilience to extreme heat. It serves as a hub for connecting users with the latest research and innovative approaches to heat mitigation.

Heat Adaptation and Mitigation Tactics

Many of us want an answer to what will solve extreme heat, but the reality is that adequately designing heat resilient cities requires a complex tapestry of a variety of different approaches at a multitude of scales. There is no, "one-size-fits-all," and requires us as designers, planners, and researchers to understand the unique urban conditions that constitute a specific place. There are many different approaches to "solving" extreme heat and they generally fall into two categories, adaptation and mitigation:

Adaptation is the *adjustment* to environmental conditions by changing behavior to deal with the increased intensity of extreme heat. These can include strategies such as incentiving public transportation, providing free public drinking water, and educational programs, like a heat awareness campaign. We explore adaptation through four distinct lenses: community, emergency, infrastructure, and assessment.

Mitigation involves *reducing* the heat of the urban environment through a variety of nature-based and architectural interventions, including increasing shade through tree planting, using high albedo surfaces, meaning light in color, or reducing waste heat from buildings. We explore mitigation through four distinct lenses: material, architecture, green infrastructure, and energy.

Methods for Visualizing Heat

Understanding and visualizing the spatial distribution of heat is crucial for informed decision-making. This section offers methods that demonstrate how various tools and technologies can be used to map and analyze heat in urban environments:

Landsat Imagery: Landsat is a series of Earth-observing satellites that are are equipped with various sensors which capture data across multiple spectral bands, from visible light to thermal infrared. This diverse range of data allows for detailed analysis of land cover, vegetation health, and, crucially, surface temperature, making Landsat an invaluable tool for studying urban heat islands and other climate-related phenomena.

UAV Infrared Imaging: UAV Thermography refers to the use of Unmanned Aerial Vehicles (UAVs), commonly known as drones, equipped with thermal imaging cameras to capture and analyze heat patterns from an aerial perspective. These specialized cameras detect infrared radiation emitted by objects and surfaces, converting this data into visual images that represent temperature variations.

Handheld Thermal Imaging: Handheld Thermography involves using portable thermal imaging cameras to capture infrared radiation emitted by surfaces, converting this data into visual heat maps. Unlike UAV thermography, which provides broader aerial views, handheld thermography allows for a more detailed and granular examination of specific surfaces and materials at close range. This close-up capability enables landscape architects to assess thermal variations on surfaces like pavements, building facades, or vegetation, which are often missed in broader UAV scans.

Mobile Biometeorological Instrument Platform: The Mobile Biometeorological Instrument Platform, known as MaRTy, is a mobile research station developed by Arizona State University (ASU). It is designed to measure and analyze various aspects of thermal comfort and heat exposure in urban environments, making it a valuable tool in the study of urban microclimates. MaRTy has the capacity to assess mean radiant temperature (MRT), which is crucial for understanding how humans experience heat in real-world conditions.

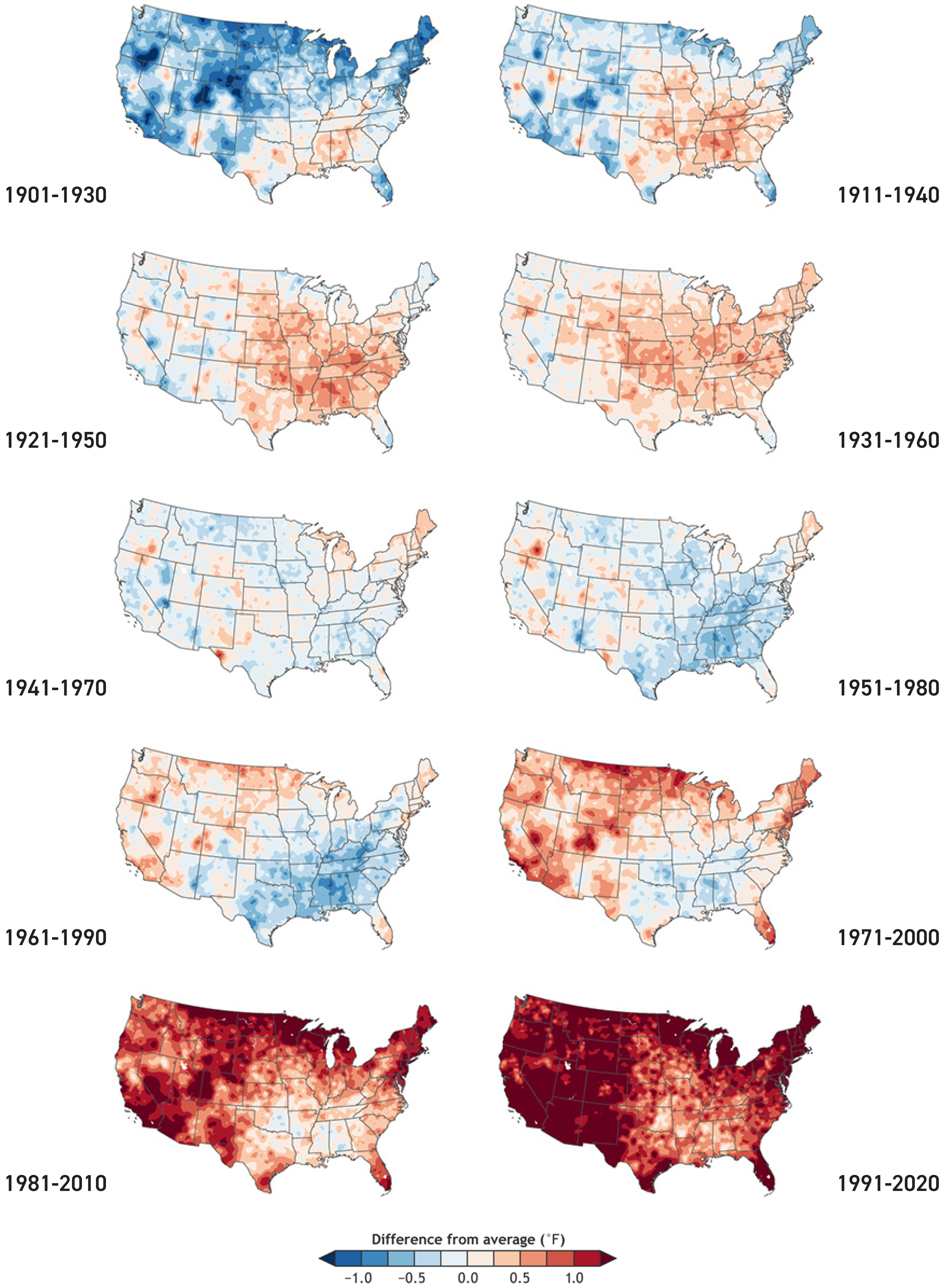
Vehicle-Traverse Collection: Vehicle-traverse collection is a dynamic method used to assess the urban heat island (UHI) effect by equipping vehicles with thermal imaging technology to capture surface temperature data across different urban areas. This approach involves driving a vehicle fitted with thermal sensors, such as infrared cameras or temperature probes, which continuously record temperatures as the vehicle traverses various streets and neighborhoods.

Environmental Simulation: Environmental simulation is a critical process in understanding and predicting the behavior of environmental factors within built and natural environments. This practice involves using advanced computational tools to model various conditions such as temperature, humidity, wind flow, solar radiation, and their effects on buildings, landscapes, and urban spaces.

Community-led Assessment: Community-led heat assessments are a participatory approach to evaluating the impacts of extreme heat within urban environments. Unlike traditional heat measurement tools, such as Landsat imagery, UAV thermography, and handheld thermal sensors, these assessments involve local residents in the data collection and analysis process. This grassroots methodology offers unique insights into heat exposure that may be missed by more conventional methods.

Glossary

The toolkit concludes with a glossary that defines key terms and concepts related to extreme heat, as well as a list of resources. This section serves as a quick reference guide for users, ensuring that they can better understand the nomenclature and access the available resources for their own application.



U.S. 30-year Normal Annual Temperature compared to 20th century average (1901-2000). NOAA Climate.gov using data from NCEI.

CLIMATE CHANGE

Our planet is heating up, and extreme heat events are becoming more frequent and intense due to human-induced climate change. The Intergovernmental Panel on Climate Change (IPCC) reports that global temperatures have been steadily rising, with each of the last four decades being successively warmer than any preceding decade since 1850.[1] Defined by significant shifts in temperature, precipitation patterns, and weather events over extended periods, climate change is primarily driven by human activities, especially the burning of fossil fuels, deforestation, and industrial processes. These activities release large amounts of greenhouse gases (GHGs), such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which trap heat in the Earth's atmosphere, leading to a warming effect known as the greenhouse effect.

Since the Industrial Revolution, the concentration of CO_2 in the atmosphere has risen from about 280 parts per million (ppm) to over 420 ppm in 2024, contributing to a global temperature increase of approximately 1.2°C above pre-industrial levels.[2] This seemingly small temperature rise has far-reaching consequences, including rising sea levels, melting polar ice, and increased frequency and intensity of extreme weather events, including heatwaves. Climate change is one of the most pressing challenges of the 21st century, with profound implications for natural systems, human health, and socio-economic stability.

The scientific consensus is clear: without significant reductions in GHG emissions, global temperatures are expected to rise further, with severe impacts on ecosystems, human health, and the economy. Climate models project that if current emission trends continue, the world could see an average temperature increase of 2°C to 4°C by the end of the century. This would exacerbate existing environmental stresses and lead to more frequent and severe heatwaves.

The impacts of extreme heat are far-reaching and pose significant challenges to human health, infrastructure, ecosystems, and economies. Extreme heat events can lead to a range of adverse health outcomes, including heat exhaustion, heatstroke, and exacerbation of pre-existing health conditions such as cardiovascular and respiratory diseases.[3] Vulnerable populations, including the elderly, children, outdoor workers, and those with limited access to air conditioning or adequate shelter, are particularly at risk. Moreover, extreme heat can strain critical infrastructure systems, such as energy grids, transportation networks, and water supplies, leading to power outages, disruptions in public services, and reduced agricultural productivity.[4] Heat stress can also impact ecosystems, causing shifts in species distributions, changes in phenology (the timing of biological events) and biodiversity loss, and altering ecosystem functioning and services.[5]

Landscapes play a pivotal role in mediating urban microclimates, influencing temperature variations, and mitigating the impacts of extreme heat events. By understanding the dynamics of heat distribution within urban environments, landscape architects can design and implement strategies to optimize thermal comfort, promote public health, and enhance overall livability. Furthermore, as cities grapple with the escalating effects of climate change, landscape architecture serves as a critical tool for climate adaptation and resilience. Design interventions such as green infrastructure, urban forests, and cool roofs can help mitigate the urban heat island effect, reduce energy consumption, and bolster the resilience of communities to extreme heat events.

1. Heatwaves Defined

A heatwave is typically defined as a period of abnormally high temperatures, often accompanied by high humidity, which can have serious health and environmental consequences. The exact definition can vary depending on the region, as what constitutes a heatwave in one area might be considered normal summer weather in another. However, the World Meteorological Organization (WMO) generally defines a heatwave as a period of at least five consecutive days where the daily maximum temperature exceeds the average maximum temperature by at least 5°C (9°F).

2. Global Trends in Extreme Heat

The frequency, duration, and intensity of heatwaves have increased globally over the past several decades, a trend that is closely linked to the overall warming of the planet. According to the Intergovernmental Panel on Climate Change (IPCC), heatwaves that would have been considered rare in the pre-industrial era are now becoming increasingly common. For example, in many parts of the world, the number of extreme heat days—days with temperatures exceeding the local threshold for dangerous heat—has doubled or even tripled since the mid-20th century.

This trend is expected to continue, with climate models projecting a substantial increase in the occurrence and severity of heatwaves as global temperatures rise. By the end of the century, under a high-emission scenario, many regions could experience heatwaves that are unprecedented in both their intensity and duration. In some cases, the combination of heat and humidity could exceed the physiological limits of human tolerance, posing a severe risk to human health and survival.

3. Urban Heat Island Effect

The Urban Heat Island (UHI) effect is a phenomenon where urban or metropolitan areas experience significantly higher temperatures with dense urban centers anywhere from 1-7 degrees warmer than their rural counterparts.[6] This temperature difference is most pronounced during the nighttime and is primarily due to human activities and the dense concentration of buildings, roads, and other infrastructure that absorb and retain heat. Today, researchers think of the heat island as more of an archipelago, where hot spots are heterogeneously distributed throughout a city in locations with higher concentrations of concrete and asphalt, whereas cooler temperatures can be found around trees, parks, or other open space.[7]

The UHI effect exacerbates the impact of heatwaves in cities, contributing to higher energy consumption, elevated emissions of air pollutants and greenhouse gases, and adverse health outcomes, particularly for vulnerable populations.

Several factors contribute to the formation and intensification of the UHI effect:

Impervious Surfaces: Urban areas are characterized by a high density of impervious surfaces such as asphalt, concrete, and buildings. These materials absorb and store heat during the day, releasing it slowly at night, leading to higher nighttime temperatures compared to rural areas, which have more vegetation and open spaces that cool down more rapidly.

Lack of Vegetation: Vegetation plays a crucial role in cooling the environment through the processes of shading and evapotranspiration. However, urban areas often have limited green spaces, and the removal of trees and vegetation for development further reduces these natural cooling mechanisms. The lack of vegetation not only contributes to higher temperatures but also reduces air quality and increases stormwater runoff.

Waste Heat: Cities are hubs of energy consumption, with buildings, vehicles, and industrial activities generating significant amounts of waste heat. This waste heat, released into the atmosphere from air conditioning units, vehicles, and factories, contributes to the overall warming of urban environments.

Urban Geometry: The design and layout of cities, with their tall buildings and narrow streets, can create "urban canyons" that trap heat and limit air circulation. This urban geometry reduces the ability of cities to cool down at night and exacerbates the UHI effect.

Air Pollution: Urban areas tend to have higher levels of air pollution, including particulates and ozone, which can absorb and re-radiate heat. This not only contributes to higher temperatures but also exacerbates the health impacts of heatwaves by reducing air quality. While the overall trend is clear, the impact of extreme heat is not uniform across the globe. Some regions are more vulnerable than others, depending on factors such as geographical location, local climate patterns, and socio-economic conditions.

4. Implications for Human Health

The health impacts of extreme heat are profound and can be deadly. Heat-related illnesses range from mild conditions like heat rash and heat cramps to more severe conditions such as heat exhaustion and heatstroke, which can be fatal if not treated promptly.

Heat Exhaustion and Heatstroke: Heat exhaustion occurs when the body loses too much water and salt through sweating, leading to symptoms such as weakness, dizziness, nausea, and fainting. If left untreated, heat exhaustion can progress to heatstroke, a life-threatening condition where the body's core temperature rises to dangerous levels, causing confusion, seizures, and, in severe cases, organ failure and death.

Vulnerable Populations: Certain groups are more vulnerable to the health impacts of extreme heat, including the elderly, young children, people with pre-existing health conditions, and those who work outdoors. In many cities, heatwaves disproportionately affect low-income communities and people of color, who may lack access to air conditioning or live in neighborhoods with fewer green spaces and higher levels of pollution.

Public Health Response: Public health systems must adapt to the increasing frequency of extreme heat events. This includes improving early warning systems, expanding access to cooling centers, and promoting public awareness of the dangers of heat exposure and the importance of staying hydrated and cool.

5. Impacts on Infrastructure and the Economy

Beyond the direct effects on human health, extreme heat has significant implications for infrastructure and the economy.

Energy Demand: During heatwaves, the demand for electricity often spikes as people rely on air conditioning to stay cool. This can strain power grids, leading to blackouts and higher energy costs. In some cases, extreme heat can reduce the efficiency of power generation and transmission, exacerbating the risk of outages.

Transportation Infrastructure: Extreme heat can damage infrastructure, such as roads, railways, and bridges. High temperatures can cause asphalt to soften and buckle, rail tracks to warp, and bridges to expand, leading to costly repairs and disruptions to transportation networks.

Agriculture: Agriculture is particularly vulnerable to extreme heat, which can stress crops, reduce yields, and exacerbate water scarcity. Heatwaves during critical growing periods can lead to crop failures and reduced food security, with significant economic and social implications.

Labor Productivity: Extreme heat can reduce labor productivity, especially in outdoor and manual labor sectors such as construction and agriculture. This can have a significant economic impact, particularly in regions where a large proportion of the workforce is employed in these sectors.

6. Ecosystem and Biodiversity Impacts

Extreme heat events also have profound effects on ecosystems and biodiversity.

Wildfires: Prolonged periods of extreme heat can increase the risk of wildfires, which can devastate ecosystems, destroy homes, and endanger lives. In recent years, regions such as Australia, California, and the Mediterranean have experienced some of the most severe wildfire seasons on record, driven in part by extreme heat and dry conditions.

Aquatic Systems: Aquatic ecosystems are particularly sensitive to temperature changes. Extreme heat can lead to higher water temperatures, reduced oxygen levels, and algal blooms, all of which can have detrimental effects on fish and other aquatic life. In some cases, extreme heat can cause mass die-offs of aquatic species, disrupting ecosystems and affecting livelihoods that depend on fishing and aquaculture.

Terrestrial Ecosystems: Terrestrial ecosystems are also affected by extreme heat, which can lead to shifts in species distribution, changes in phenology, and increased mortality of heat-sensitive species. In some cases, entire ecosystems may be at risk of collapse if they are unable to adapt to the changing climate.

7. Adaptation and Mitigation Strategies

Addressing the increasing frequency of extreme heat requires a combination of adaptation and mitigation strategies (more on this in Chapter 02).

Urban Planning and Design: Cities can be redesigned to reduce the urban heat island effect and improve resilience to heatwaves. This includes increasing green spaces, planting trees, using reflective materials in buildings and pavements, and designing buildings that promote natural ventilation.

Nature-Based Solutions: Nature-based solutions, such as restoring wetlands, forests, and other natural ecosystems, can help mitigate the impacts of extreme heat by providing shade, cooling the air through evapotranspiration, and reducing the overall temperature of urban and rural areas.

Public Awareness and Education: Educating the public about the dangers of extreme heat and promoting behaviors that reduce heat exposure can save lives. Public awareness campaigns, early warning systems, and community outreach are essential components of a comprehensive heat adaptation strategy.

Policy and Regulation: Governments can play a key role in addressing extreme heat by implementing policies and regulations that promote energy efficiency, reduce GHG emissions, and protect vulnerable populations. This includes setting building codes that require heat-resilient design, mandating the use of cool roofs and other heat-mitigation technologies, and providing financial assistance to low-income households for energy costs.

Research and Innovation: Continued research is needed to better understand the impacts of extreme heat and develop innovative solutions to mitigate its effects. This includes improving climate models, developing new materials and technologies for heat mitigation, and exploring the potential of geoengineering as a last-resort option.

8. Conclusion

Climate change is driving an increase in the frequency, intensity, and duration of extreme heat events, with significant implications for human health, infrastructure, ecosystems, and the economy. As the planet continues to warm, the urgency of addressing these challenges grows.

Effective adaptation and mitigation strategies are essential to protect vulnerable populations, safeguard ecosystems, and ensure the resilience of urban and rural communities. This requires a multi-faceted approach that includes rethinking urban design to minimize heat exposure, implementing nature-based solutions to create cooler environments, and fostering public awareness about the dangers of extreme heat.

Policymakers and planners have a crucial role to play in guiding the development and implementation of these strategies. By integrating thermal data and visualization tools into decision-making processes, they can better understand the spatial and temporal dynamics of extreme heat and take informed actions to mitigate its impacts. The challenge of extreme heat is a clear reminder of the broader risks posed by climate change, underscoring the need for global cooperation and local innovation to build a more sustainable and resilient future.

Through a combination of immediate action and long-term planning, we can address the growing threat of extreme heat and contribute to a more livable world for current and future generations.

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Photo by Mel Melcon / Los Angeles Times, featured in the article, "The 'Sombrita' bus shade controversy obscures an important story about women and transit"

THERMAL COMFORT/DISPARITY

What is Thermal Comfort?

Thermal comfort refers to the condition of mind that expresses satisfaction with the surrounding environment's temperature. It is a subjective state influenced by various factors, including air temperature, humidity, air movement, and personal factors such as clothing and metabolic rate. In urban environments, achieving thermal comfort is essential for the well-being of residents, as it directly impacts health, productivity, and quality of life.

In practical terms, thermal comfort occurs when the human body can maintain its core temperature without expending too much energy on heating or cooling itself. This balance is delicate and can be easily disrupted by external factors, leading to discomfort or even heat-related illnesses.

Achieving thermal comfort in urban areas is challenging due to the Urban Heat Island (UHI) effect and the variation in how different parts of the city experience and manage heat. Factors such as building density, lack of green spaces, and the presence of heat-retaining materials like asphalt and concrete can significantly influence thermal comfort. The increasing intensity, duration, and frequency of heat waves have been found to disproportionately impact underserved populations. In a study of 108 urban areas nationwide, the formerly redlined neighborhoods of nearly every city studied were hotter than the non-redlined neighborhoods, some by nearly 13 degrees Fahrenheit.[1] Redlining is the historical discriminatory practice of refusing home loans or insurance to whole neighborhoods based on a racially-motivated perception of safety for investment.

Who is Disproportionately Impacted?

Thermal comfort is not experienced equally across all populations, leading to disparities that can exacerbate existing social and economic inequalities. Several groups are disproportionately impacted by extreme heat and are more likely to experience thermal discomfort:

1. Low-Income Communities: Individuals in lower-income neighborhoods often live in areas with fewer trees and green spaces, higher building density, and older, less energy-efficient housing. These factors contribute to higher ambient temperatures and less access to cooling resources such as air conditioning, making it more difficult for residents to achieve thermal comfort.

2. Elderly and Young Children: The elderly and young children are particularly vulnerable to extreme heat due to their reduced ability to regulate body temperature. Older adults often have pre-existing health conditions that can be aggravated by heat, while young children have a higher metabolic rate and generate more body heat relative to their size.

3. Outdoor Workers: Individuals who work outdoors, such as construction workers, landscapers, and street vendors, are regularly exposed to high temperatures. Their prolonged exposure to heat increases the risk of heat-related illnesses and makes it difficult to maintain thermal comfort throughout the workday.

4. People with Pre-existing Health Conditions: Those with cardiovascular, respiratory, and other chronic health conditions are at greater risk during extreme heat events. Their bodies are often less efficient at dissipating heat, making them more susceptible to heat stress and related health complications.

5. Residents of Dense Urban Areas: People living in densely populated urban neighborhoods are often surrounded by impervious surfaces like roads, parking lots, and buildings that absorb and retain heat. The lack of shade and green spaces further exacerbates thermal discomfort, particularly during heatwaves.

6. Marginalized Communities: Racial and ethnic minorities, as well as marginalized communities, often reside in neighborhoods with higher exposure to heat due to historical and systemic inequalities, such as redlining and discriminatory urban planning practices. These communities may have less access to resources like cooling centers or energy-efficient housing, increasing their vulnerability to heat stress.

How Do We Measure Thermal Comfort?

Measuring thermal comfort involves assessing both environmental and personal factors that influence how individuals perceive and respond to heat. In the context of this toolkit, measuring thermal comfort is different than visualizing the impacts of extreme heat, where we will discuss these methods in greater detail in Chapter 03. Several methods and indices that are commonly used to evaluate thermal comfort in urban environments include:

1. Wet Bulb Globe Temperature (WBGT): The WBGT index measures heat stress in direct sunlight, taking into account temperature, humidity, wind speed, and solar radiation. It is particularly useful for assessing outdoor thermal comfort and is commonly used in occupational health and safety guidelines.

2. Mean Radiant Temperature (MRT): MRT represents the average temperature of all surrounding surfaces that contribute to radiant heat exchange with the human body. It is a key factor in determining thermal comfort, especially in urban environments with significant heat absorption and reflection from buildings and pavement.

3. Universal Thermal Climate Index (UTCI): The UTCI is a comprehensive index that incorporates air temperature, wind speed, humidity, and radiation to assess outdoor thermal comfort. It provides a standardized measure of how various weather conditions impact human thermal stress.

4. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD): The PMV and PPD indices are widely used in indoor environments to predict thermal comfort based on a combination of environmental variables (temperature, humidity, air velocity) and personal factors (clothing insulation, metabolic rate). PMV predicts the mean thermal sensation vote on a scale from cold to hot, while PPD estimates the percentage of people likely to be

dissatisfied with their thermal environment.

5. Heat Index: The heat index combines air temperature and relative humidity to estimate the apparent temperature or "feels-like" temperature. It provides a quick assessment of how hot it feels to the human body and is commonly used in weather reports to inform the public about heat risks.

6. Thermal Imaging: Thermal imaging cameras and sensors can visualize temperature variations across different surfaces and environments. By capturing detailed thermal data, these tools help identify heat hotspots and areas of thermal discomfort.

7. Questionnaires and Surveys: Subjective assessments through questionnaires and surveys can provide valuable insights into how people perceive thermal comfort in different environments. These tools are often used in conjunction with objective measurements to gain a comprehensive understanding of thermal comfort.

8. Thermal Comfort Models: Advanced models, such as the Fanger model and the Adaptive Comfort model, predict thermal comfort based on environmental inputs and human responses. These models are useful for simulating and assessing thermal comfort in both existing and proposed urban environments.

Addressing Thermal Disparity

Recognizing and addressing thermal disparities is critical for creating equitable and resilient urban environments. Strategies to improve thermal comfort and reduce disparities include increasing green spaces, implementing reflective building materials, enhancing access to cooling resources, and promoting public awareness of heat risks.

By incorporating these measures into urban planning and design, cities can work towards ensuring that all residents, regardless of their socio-economic status or location, have the opportunity to experience thermal comfort, even as the climate continues to warm.

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01

HEAT, DESIGN, ACTION!

In the “Heat, Design, Action!” section, we provide a simple primer and broad overview of the key concepts and resources that are essential for planning heat resilience in urban environments. This is not an exhaustive guide, but a starting point to help you think about the crucial elements needed for designing effective heat action plans. By considering scientific insights, community input, and practical design strategies, this section will guide you through the basics of enhancing urban resilience against extreme heat, with a focus on improving thermal comfort across our urban environments.

"Engaging Heat" community engagement exercise with residents of the South Omaha neighborhood. Photo by Salvador Lindquist.

PLANNING FOR URBAN HEAT RESILIENCE

The Emergence of Heat Action Plans

As climate change intensifies, cities around the world are grappling with increasingly frequent and severe heatwaves. These extreme heat events pose significant risks to public health, infrastructure, and overall quality of life. In response, the concept of heat action plans has emerged as a vital tool for cities to prepare for, mitigate, and respond to the challenges posed by extreme heat.[1, 2]

Heat action plans are strategic frameworks designed to reduce the impact of heatwaves on urban populations. They are comprehensive, community-driven strategies that focus on protecting vulnerable populations, improving infrastructure, and enhancing overall urban resilience to heat.

These plans are generally produced through transdisciplinary collaborations, meaning through the leadership of experts, like landscape architects and policy makers, but through community engagement, including their voices as part of the decision-making process.

There are many ways to accomplish this. The methodology used for Heat Action Planning (Figure 1.) was adapted from Semenza et al. who addressed urban blight by increasing social capital and improving well-being through community projects.[3] Beyond building a community Heat Action Plan and completing demonstration projects, this participatory process is designed to develop awareness, agency, and social cohesion in underrepresented communities.

This iterative method builds on strengthening relationships within and between neighborhoods, community-based organizations, decision-makers, and the core team, and it combines storytelling and subjective wisdom and scientific evidence to understand current and future challenges residents face during extreme heat events.The rise of these plans reflects a growing recognition that cities must take proactive measures to address the escalating threat of heat in a warming world.

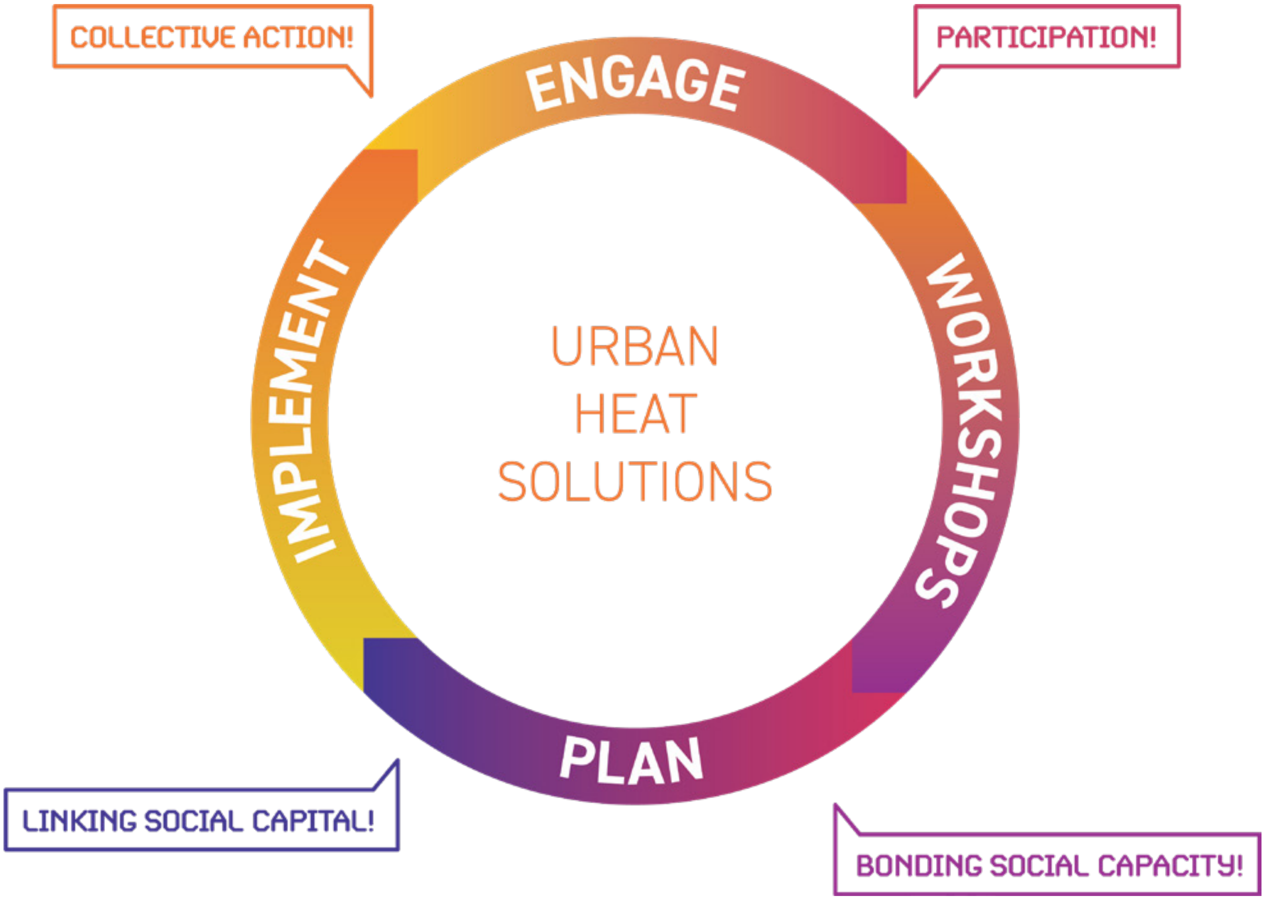

Figure 1. Community-engaged process for heat action planning. Adopted from Semenza et. al. 2006.

The Role of Heat Action Plans

Heat action plans serve multiple roles, all centered around safeguarding communities from the adverse effects of extreme heat. Here are some of the key roles they play:

Public Health Protection: One of the primary roles of heat action plans is to protect public health, particularly for vulnerable populations such as the elderly, children, and those with pre-existing health conditions. These plans often include early warning systems, public awareness campaigns, and emergency response protocols to reduce the risk of heat-related illnesses and deaths.

Urban Planning and Design: Heat action plans play a crucial role in guiding urban planning and design decisions that can mitigate the impact of heat. This includes integrating green infrastructure, enhancing urban canopy cover, and designing buildings and public spaces that promote thermal comfort.

Community Engagement and Empowerment: Effective heat action plans involve the community in both the planning and implementation phases. By engaging with residents, local organizations, and stakeholders, these plans ensure that the needs and perspectives of the community are incorporated, leading to more effective and equitable outcomes.

Climate Adaptation: Heat action plans are a key component of broader climate adaptation strategies. They help cities adapt to the changing climate by implementing measures that reduce vulnerability to heat, such as improving energy efficiency, increasing access to cooling resources, and promoting sustainable urban development.

Emergency Response Coordination: During extreme heat events, heat action plans provide a coordinated response framework that brings together public health agencies, emergency services, and community organizations. This coordination ensures that resources are efficiently deployed and that vulnerable populations receive the support they need.

Data Collection and Analysis: Many heat action plans emphasize the importance of data collection and analysis to inform decision-making. By monitoring temperature trends, heat-related health outcomes, and the effectiveness of implemented strategies, cities can continually refine and improve their heat resilience efforts.

Facilitating Action Through Heat Action Plans

Heat action plans are not just theoretical documents; they are designed to facilitate concrete actions that mitigate the impact of extreme heat. Here's how they translate planning into action:

Early Warning Systems: One of the first lines of defense against heatwaves is an early warning system. Heat action plans often include protocols for monitoring weather forecasts and issuing heat advisories to alert the public and prepare emergency services. These warnings can be tailored to different levels of heat severity, triggering specific actions such as opening cooling centers or distributing water.

Public Awareness Campaigns: Education and communication are critical components of heat action plans. By raising awareness about the risks of extreme heat and providing practical advice on how to stay safe, these campaigns empower individuals and communities to take proactive measures. Information is often disseminated through multiple channels, including social media, radio, and community outreach.

Infrastructure Upgrades: Heat action plans often include recommendations for upgrading urban infrastructure to better withstand extreme heat. This might involve installing cool roofs and pavements, expanding tree canopies, or retrofitting buildings with better insulation and ventilation systems. These actions not only reduce ambient temperatures but also enhance overall urban resilience.

Cooling Centers and Resource Distribution: During heatwaves, providing access to cooling centers and distributing resources such as water, fans, and air conditioners are common actions outlined in heat action plans. These centers offer a refuge for those without adequate cooling at home, helping to prevent heat-related illnesses and deaths.

Policy and Regulation: Heat action plans can also influence policy and regulation to promote heat resilience. For example, cities may adopt building codes that require energy-efficient designs or mandate the inclusion of green spaces in new developments. These policies help institutionalize heat resilience practices, making them a standard part of urban planning.

Community-Based Interventions: Recognizing that heat affects different communities in different ways, heat action plans often include tailored interventions that address local needs. For example, in neighborhoods with high levels of outdoor workers, plans might focus on providing shaded rest areas and ensuring access to hydration. In lower-income areas, efforts might be directed toward improving housing conditions and expanding access to cooling resources.

Partnerships and Collaboration: Implementing a heat action plan requires collaboration across multiple sectors, including public health, urban planning, emergency management, and community organizations. By fostering partnerships and coordinating efforts, heat action plans ensure that all stakeholders are working together toward a common goal.

Evaluation and Iteration: Effective heat action plans are dynamic and evolve over time. After each heatwave, cities can evaluate the effectiveness of their response and identify areas for improvement. This iterative process allows for the continuous refinement of strategies and ensures that the plan remains relevant as conditions change.

Variations in Heat Action Plans

While the core principles of heat action plans are similar, they can vary significantly depending on local context, priorities, and resources. Here are some of the ways in which heat action plans differ:

Geographic and Climatic Factors: The design of a heat action plan is heavily influenced by the geographic and climatic conditions of the area it covers. For instance, a heat action plan for a coastal city with moderate temperatures will differ from one in an inland city that experiences extreme heat. Factors such as humidity levels, average summer temperatures, and the urban heat island effect all shape the specific strategies included in the plan.

Population Demographics: Different cities have different demographic profiles, which influence the focus of their heat action plans. In cities with a large elderly population, there may be a greater emphasis on healthcare and social services, while cities with a high percentage of outdoor workers might prioritize occupational safety measures.

Economic Resources: The level of economic resources available to a city also affects the scope and scale of its heat action plan. Wealthier cities may have the capacity to invest in large-scale infrastructure projects and comprehensive public awareness campaigns, while cities with limited resources might focus on more cost-effective measures, such as community-based interventions and targeted outreach.

Governance Structures: The governance structure of a city or region can impact how a heat action plan is developed and implemented. In some cities, a centralized approach might be taken, with a single agency leading the effort. In others, a more decentralized approach might involve multiple agencies and community organizations working together. The level of stakeholder involvement and the mechanisms for coordination can vary widely.

Cultural and Social Factors: Cultural and social factors also play a role in shaping heat action plans. In some communities, traditional knowledge and practices may be integrated into the plan, while in others, the focus may be on modern scientific approaches. Understanding local customs, values, and social networks is important for ensuring that the plan resonates with the community and is effectively implemented.

Technological Capabilities: The availability and use of technology can vary widely between heat action plans. Some cities may employ advanced technologies such as GIS mapping, real-time temperature monitoring, and predictive analytics to inform their strategies. Others may rely on more basic tools, such as manual data collection and simple communication channels.

Focus Areas: Different heat action plans may prioritize different focus areas based on local needs and vulnerabilities. For example, one city might prioritize improving housing conditions and energy efficiency, while another might focus on expanding green spaces and reducing the urban heat island effect. The specific focus areas are determined by the unique characteristics and challenges of the community.

Integration with Other Plans: Heat action plans can be stand-alone documents or integrated into broader climate adaptation and disaster preparedness plans. In some cases, cities may choose to develop comprehensive plans that address multiple climate-related risks, such as flooding, drought, and heatwaves. In other cases, the heat action plan may be more narrowly focused, with specific actions targeting extreme heat events.

Case Studies of Heat Action Plans

To better understand the diversity and impact of heat action plans, it is helpful to look at some case studies from cities that have implemented successful strategies:

1. Ahmedabad, India: Ahmedabad was one of the first

cities in South Asia to develop a comprehensive heat action plan, launched in 2013. The plan includes an early warning system, public awareness campaigns, training for healthcare professionals, and the creation of cooling spaces in slum areas. This plan has been credited with significantly reducing heat-related deaths in the city.

2. Phoenix, Arizona, USA: Phoenix, a city known for its extreme heat, has developed a detailed heat action plan that includes measures to increase tree canopy coverage, install cool roofs and pavements, and expand access to cooling centers. The plan also involves partnerships with local businesses and community organizations to reach vulnerable populations.

3. Paris, France: In response to the deadly heatwave of 2003, Paris developed a heat action plan that focuses on protecting the elderly and other vulnerable groups. The plan includes a system for registering at-risk individuals who receive regular check-ins during heatwaves, as well as the creation of cool rooms in public buildings and the expansion of green spaces across the city.

4. Melbourne, Australia: Melbourne's heat action plan is part of its broader climate adaptation strategy. The plan emphasizes community engagement, with a focus on educating residents about heat risks and promoting neighborhood-based resilience initiatives. Melbourne has also invested in urban greening projects to reduce the urban heat island effect.

5. Toronto, Canada: Toronto's heat action plan includes a heat alert and response system, with specific actions triggered at different heat alert levels. The plan also focuses on increasing access to cooling centers, providing support for low-income residents, and retrofitting public housing with energy-efficient cooling systems.

Conclusion

Heat action plans have become an essential tool for cities to navigate the challenges of extreme heat in a warming world. By integrating scientific data, community input, and strategic planning, these plans facilitate proactive measures that protect public health, enhance urban resilience, and improve quality of life. While the core principles of heat action plans are consistent, they are also highly adaptable, allowing cities to tailor their strategies to local conditions, priorities, and resources. As climate change continues to intensify, the role of heat action plans in safeguarding urban populations will only become more critical, underscoring the importance of continued innovation, collaboration, and investment in heat resilience.

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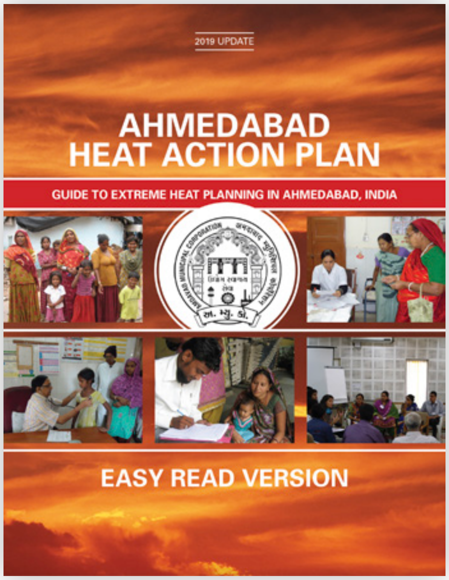

2019 UPDATE

AHMEDABAD HEAT ACTION PLAN

GUIDE TO EXTREME HEAT PLANNING IN AHMEDABAD, INDIA

EASY READ VERSION

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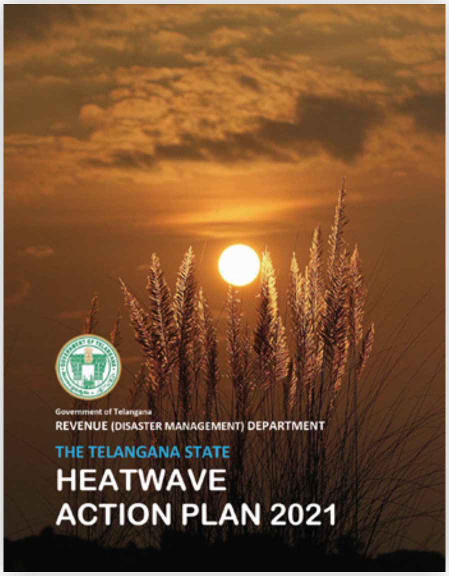

Government of Telangana

REVENUE (DISASTER MANAGEMENT) DEPARTMENT

THE TELANGANA STATE

HEATWAVE ACTION PLAN 2021

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WSROC

TURN DOWN THE HEAT

TURN DOWN THE HEAT

STRATEGY AND ACTION PLAN

2018

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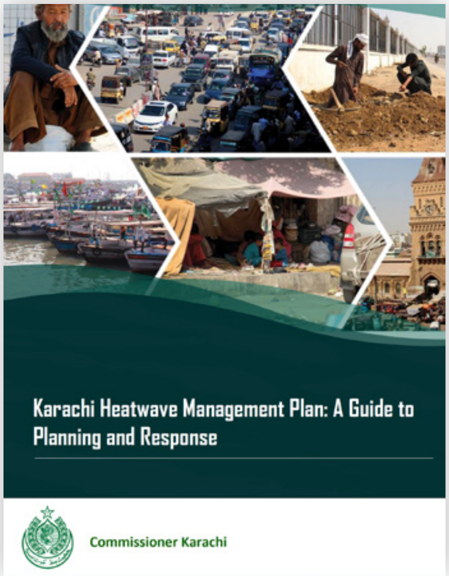

Karachi Heatwave Management Plan: A Guide to Planning and Response

Commissioner Karachi

E

Heat Action Plan Toolkit

Guidance and resources to help North Carolina communities prepare for extreme heat

Published April 2024 | Version 1.0

NCORR DPS

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EXTREME HEAT ACTION PLAN

MIAMI-DADE COUNTY

OFFICE OF RESILIENCE

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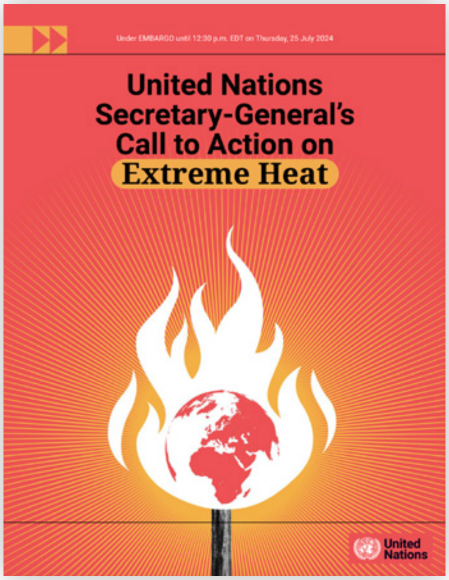

Under EMBARGO until 12:30 p.m. EDT on Thursday, 25 July 2024

United Nations Secretary-General's Call to Action on Extreme Heat

United Nations

H

Heat Mitigation & Adaptation Guidebook

Strategies for Sedona

Prepared for the City of Sedona by CAPA Strategies, LLC

April 2024

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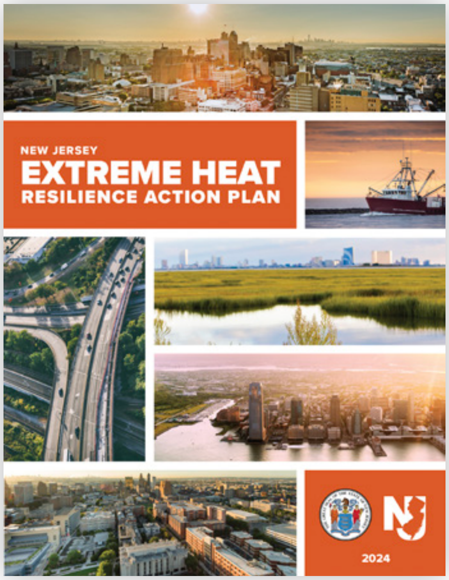

NEW JERSEY

EXTREME HEAT RESILIENCE ACTION PLAN

NJ

2024

Examples of existing heat action plans in various locations around the world. Key available on page 33.

HEAT RESILIENCE RESOURCES

A Ahmedabad Heat Action Plan
B The Telangana State Heatwave Action Plan
C Western Sydney Heat Strategy and Action Plan
D Karachi Heatwave Management Plan
E North Carolina Heat Action Plan Toolkit
F Miami-Dade Extreme Heat Action Plan
G UN Call to Action on Extreme Heat
H Sedona Heat Mitigation & Adaptation Guidebook
I New Jersey Extreme Heat Resilience Action Plan

Heat resilience has become an essential focus in urban planning and design, with resources available to help professionals incorporate climate adaptation strategies into their work. These resources provide valuable guidance, tools, and frameworks for understanding and mitigating the impacts of extreme heat on urban environments. Below is a detailed overview of some key resources available for designers, planners, and policymakers, along with a summary of the Adrienne Arsht-Rockefeller Foundation Resilience Center's Heat Action Platform.

1. U.S. Climate Resilience Toolkit

The U.S. Climate Resilience Toolkit[1] is a comprehensive resource developed by the federal government to assist communities in preparing for and adapting to the impacts of climate change, including extreme heat. It offers a wide array of tools, information, and case studies that can help planners and designers understand the specific challenges posed by climate change in their regions.

Steps to Resilience Framework: One of the core features of the Toolkit is the “Steps to Resilience” framework. This five-step process guides users through assessing vulnerability, identifying adaptation options, prioritizing actions, and implementing and monitoring solutions. For urban heat resilience, this framework can help communities develop targeted strategies to reduce heat exposure and protect vulnerable populations.

Interactive Tools and Data: The Toolkit includes interactive tools like the Climate Explorer, which allows users to visualize climate projections and historical data. This can be particularly useful for planners and designers looking to assess future heat risks and incorporate climate data into their planning processes.

Case Studies and Success Stories: The Toolkit also provides access to a wealth of case studies and success stories that highlight effective climate adaptation strategies from around the country. These examples can serve as inspiration and guidance for professionals working to enhance heat resilience in their communities.

2. Urban Sustainability Directors Network (USDN)

The Urban Sustainability Directors Network (USDN)[2] is a collaborative platform that brings together sustainability leaders from local governments across North America. USDN provides a space for knowledge sharing, collaboration, and the development of innovative solutions to sustainability challenges, including those related to extreme heat.

Climate Action Planning: USDN offers resources specifically tailored to creating and implementing climate action plans. These plans often include components focused on reducing urban heat islands, enhancing green infrastructure, and promoting energy efficiency. USDN’s resources help local governments integrate these components into their broader sustainability strategies.

Peer-to-Peer Learning: One of the key strengths of USDN is its emphasis on peer-to-peer learning. Members can connect with other sustainability directors to share experiences, challenges, and best practices. This collaborative approach fosters innovation and helps communities learn from one another’s successes and setbacks.

Grants and Funding Opportunities: USDN also provides access to grants and funding opportunities that support the development and implementation of heat resilience projects. These financial resources are crucial for local governments seeking to invest in infrastructure improvements and community-based interventions to combat extreme heat.

3. National Integrated Heat Health Information System (NIHHIS)

The National Integrated Heat Health Information System (NIHHIS)[3] is a partnership between multiple U.S. federal agencies aimed at managing the health risks associated with extreme heat. NIHHIS provides critical data, tools, and resources to help communities prepare for and respond to heat events.

Heat-Health Monitoring Tools: NIHHIS offers a range of monitoring tools that track heat-related health outcomes, such as hospital admissions and mortality rates. These tools help public health officials and planners understand the real-time impacts of heat on their communities and make informed decisions about emergency response and mitigation strategies.

Guidance for Developing Heat Action Plans: NIHHIS provides detailed guidance on creating heat action plans, including how to identify vulnerable populations, develop early warning systems, and implement public health interventions. This guidance is invaluable for communities looking to protect their residents from the dangers of extreme heat.

Collaborative Research and Partnerships: NIHHIS fosters collaboration between researchers, public health officials, and local governments to advance the understanding of heat-health risks and develop innovative solutions. This collaborative approach ensures that the latest scientific knowledge is integrated into public health practices and urban planning.

4. World Health Organization (WHO) - Heat and Health

The World Health Organization is a specialized agency within the United Nations system, focused on improving health and well-being for all people globally. On their website, there are resources that address the public health impacts of urban heat islands and provides recommendations for policymakers and urban planners on how to mitigate these effects.

Health Impacts of Urban Heat Islands: The WHO document, "Heat-waves: risks and responses"[4] outline the various health risks associated with urban heat islands, including increased rates of heat-related illnesses and exacerbation of chronic health conditions. They emphasize the importance of integrating public health considerations into urban planning to reduce these risks.

Mitigation Strategies: The WHO documents a range of mitigation strategies that can be implemented at the city level, such as increasing urban green spaces, enhancing building energy efficiency, and promoting the use of cool roofs and pavements. These strategies not only reduce temperatures but also improve the overall livability of urban environments.

Policy Recommendations: The WHO targets policy recommendations that encourage the adoption of urban heat island mitigation measures at the local, national, and international levels. These recommendations are designed to support the development of comprehensive heat resilience strategies that protect public health and enhance urban sustainability.

5. American Planning Association (APA)

The American Planning Association (APA) is a professional organization that supports planners through education, advocacy, and the development of best practices. The APA offers a range of resources on climate resilience and adaptation, with a focus on addressing the challenges posed by urban heat.

Guidance on Urban Heat Island Mitigation: The APA released a report, "Planning for Urban Heat Resilience,"[6] which offers comprehensive guidance to help planners enhance urban heat resilience while ensuring equity in the communities they serve. It thoroughly explores the factors contributing to urban heat and the associated equity issues. The report also introduces a framework and a variety of strategies that practitioners can use to address and manage urban heat through different plans, policies, and actions, enabling a more resilient and inclusive approach to urban planning.

Professional Development and Training: The APA offers professional development opportunities, including webinars, workshops, and conferences that focus on climate resilience and adaptation. These training sessions equip planners with the knowledge and skills needed to address the impacts of extreme heat in their communities.

Policy Advocacy: The APA advocates for policies that support sustainable urban development and climate resilience. This includes lobbying for federal and state policies that promote green infrastructure, energy efficiency, and other strategies that reduce urban heat and enhance community resilience.

6. The Heat Action Platform by the Adrienne Arsht-Rockefeller Foundation Resilience Center

The Heat Action Platform[7], developed by the Adrienne Arsht-Rockefeller Foundation Resilience Center, is a comprehensive tool designed to help cities and communities build resilience to extreme heat. The platform provides a structured approach to assessing, planning, and implementing heat resilience strategies at the local level.

Assessment Modules: The platform includes modules for conducting baseline assessments of heat risk, identifying vulnerable populations, and assessing current levels of heat awareness within the community. These assessments provide a critical foundation for developing targeted heat action plans.

Planning and Implementation Tools: The Heat Action Platform offers tools for developing education strategies, exploring adaptation solutions, and securing funding for heat resilience projects. It emphasizes the importance of community engagement and collaboration in the planning process, ensuring that solutions are both effective and equitable.

Monitoring and Evaluation: The platform also provides resources for monitoring the effectiveness of heat action plans and evaluating their impact over time. This continuous feedback loop allows cities to refine their strategies and ensure that they remain responsive to changing conditions and emerging challenges.

Global Expertise and Collaboration: The Heat Action Platform connects users with global experts in heat resilience, offering opportunities for collaboration and co-development of solutions. This access to international expertise and best practices makes the platform a valuable resource for cities looking to enhance their heat resilience efforts.

The Heat Action Platform is designed to be a living resource, continually updated with new insights, tools, and strategies. It serves as a critical resource for cities aiming to reduce the human and economic impacts of extreme heat and build a more resilient future.

7. Tree Equity Score (TES)

The Tree Equity Score tool, developed by American Forests, assesses neighborhoods across the United States to identify disparities in tree canopy coverage. It integrates demographic and socioeconomic factors, including income, employment, race, and age, with environmental data like existing tree cover and surface temperature. Each neighborhood is assigned a score from 0 to 100, reflecting its tree equity status: higher scores indicate adequate tree coverage relative to the community's needs, while lower scores point to areas in urgent need of greening efforts.

This tool is vital for targeting urban forestry initiatives effectively, helping to mitigate urban heat islands, enhance public health, and improve resilience against climate change. By increasing tree cover in underserved areas, cities can reduce heat-related risks, lower energy costs, and improve air quality. Additionally, the TES promotes environmental justice by ensuring equitable distribution of green infrastructure, thereby enhancing urban livability and biodiversity. Cities use the Tree Equity Score to guide tree planting projects, integrate urban forestry into climate action plans, and secure funding for greening initiatives.

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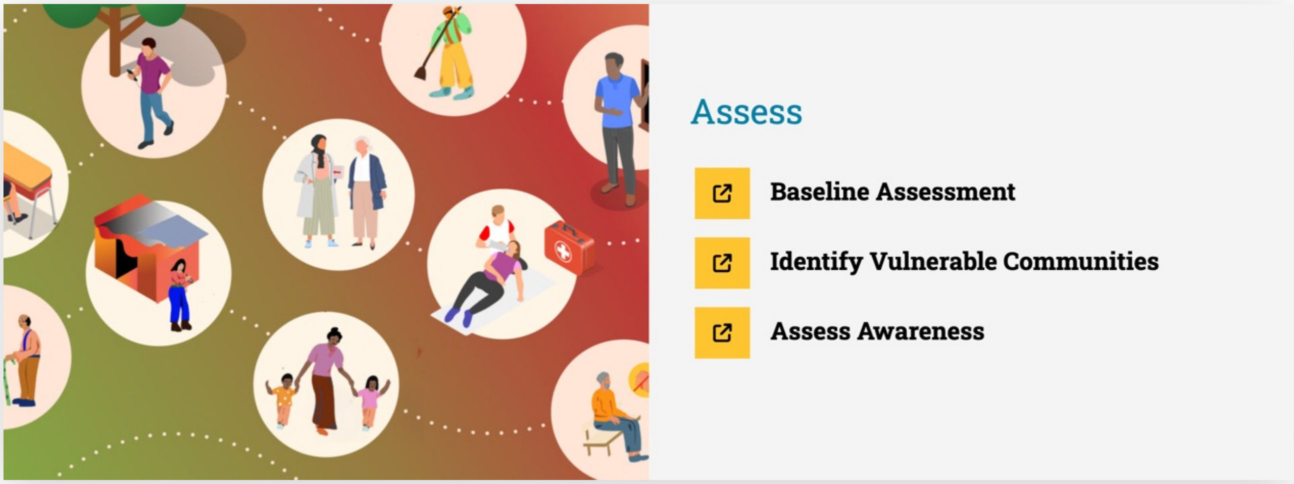
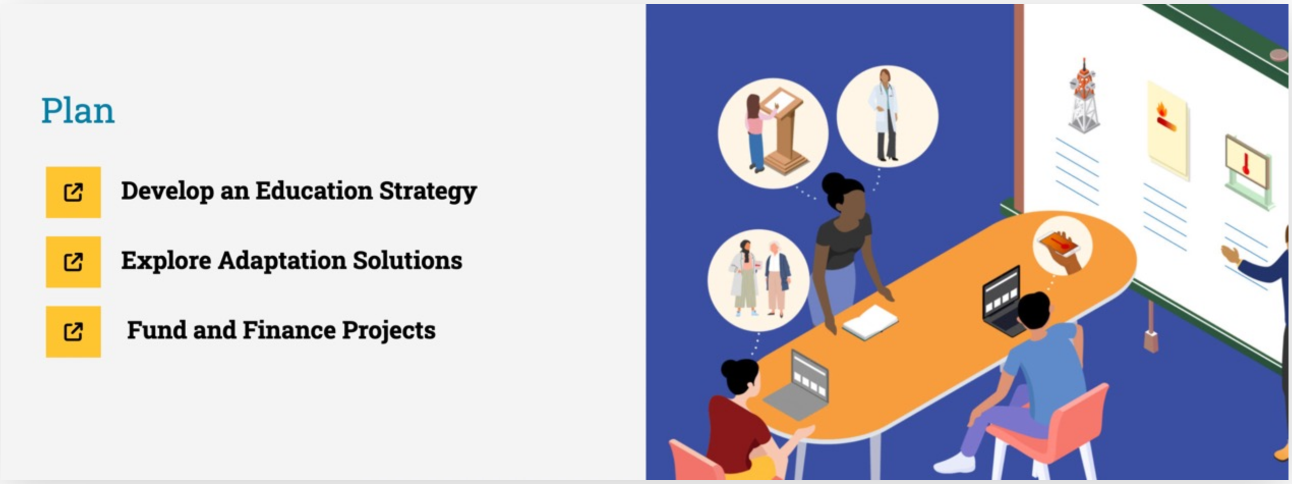


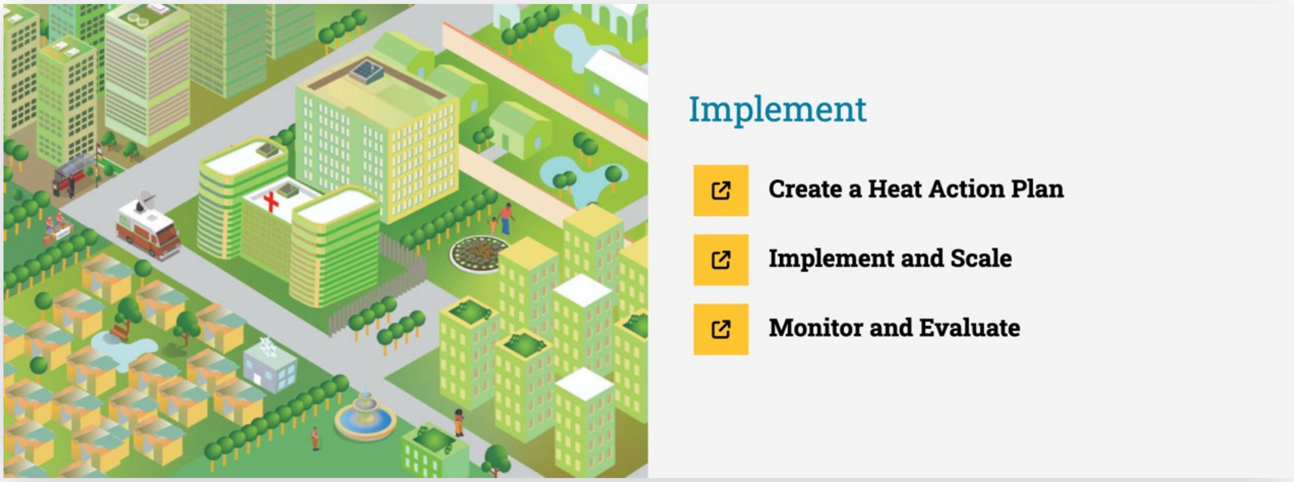
Assess

- Baseline Assessment
- Identify Vulnerable Communities
- Assess Awareness



Plan

- Develop an Education Strategy
- Explore Adaptation Solutions
- Fund and Finance Projects



Implement

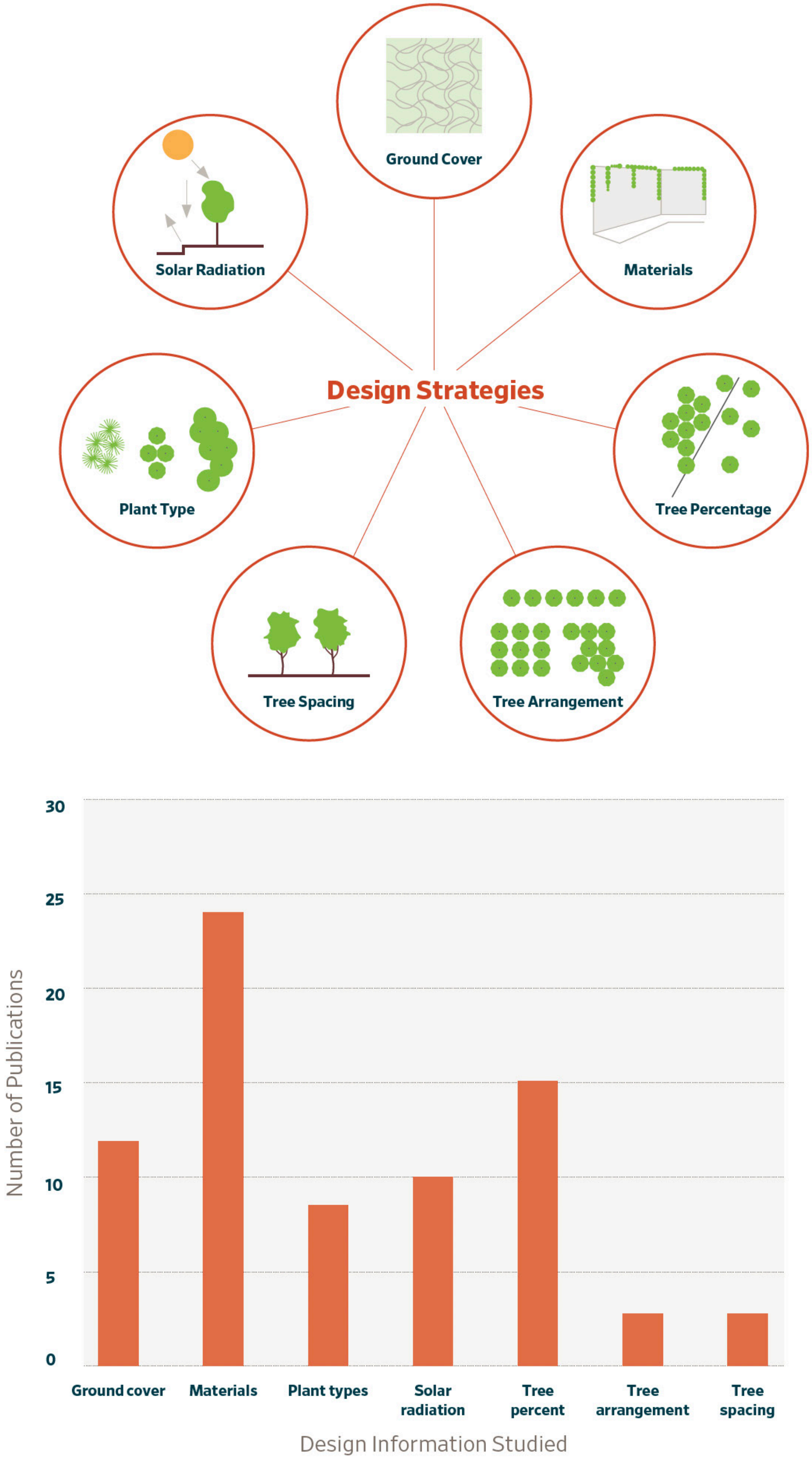
- Create a Heat Action Plan
- Implement and Scale
- Monitor and Evaluate

Education modules on the Resilence Center's "Heat Action Platform." [6]

02

ADAPTATION AND MITIGATION TACTICS

Many of us want an answer to what will solve extreme heat, but the reality is that adequately designing heat resilient cities requires a complex tapestry of a variety of different approaches at a multitude of scales. There is no, "one-size-fits-all," and requires us as designers, planners, and researchers to understand the unique urban conditions that constitute a specific place. There are many different approaches to "solving" extreme heat and they generally fall into two categories, adaptation and mitigation. We included 40 different strategies documented as part of the Heat Action Platform's Policy Tool, but there are as many as 50 or more approaches available online that we did not include. Be sure to check those out too! At the bottom of each "Tactic Card" are benefits (cost-benefit, public good, and GHG reduction), which are a direct reference to the Policy Tool's classification. The case studies corresponding to the selected tactics were compiled by third-year Landscape Architecture students at the University of Nebraska-Lincoln (Humaid Al Hinai, Sarah Cope, Parker Hamling, and Kyle Riley).



Seven typologies of design interventions featured by number of publications. Diagrams from Daniella Hirchfelds "Landscape Architecture Solutions to Extreme Heat," a systematic literature review (2024).

SOLUTIONS TO EXTREME HEAT

The recent publication by the American Society of Landscape Architects (ASLA), titled “Landscape Architecture Solutions to Extreme Heat,” highlights the crucial role that landscape architecture can play in mitigating the impacts of extreme heat. The report, compiled by Dr. Daniella Hirschfeld and her team, synthesizes findings from over 100 peer-reviewed studies and provides practical strategies for reducing heat through nature-based solutions (NbS).

Key findings from the research emphasize the importance of incorporating NbS and optimizing its distribution within urban environments. The report underscores that more greenery, especially trees, can significantly lower temperatures in urban areas. However, it is not just the presence of green spaces that matters, but how they are interconnected and distributed across neighborhoods. Well-connected green spaces provide greater temperature-reduction benefits than isolated patches.

The report outlines seven key landscape architecture strategies to combat extreme heat:

1. Ground Cover

Heat Mitigation Role: Ground cover, including grass, low-lying plants, and green roofs, plays a crucial role in reducing heat absorption and lowering surface temperatures. Permeable ground cover helps in cooling by allowing water infiltration and reducing the heat-island effect caused by non-permeable surfaces like asphalt and concrete.

Application: Utilizing grass or other ground covers in place of traditional concrete or asphalt surfaces in urban areas can significantly reduce localized temperatures. This is particularly effective in parking lots, rooftops, and other large surface areas.

2. Materials

Heat Mitigation Role: The choice of materials in urban design can either contribute to or mitigate the heat island effect. Materials with high albedo (reflectivity) like light-colored pavements and reflective coatings help in reducing heat absorption, while materials that absorb less heat help keep surface temperatures lower.

Application: Replacing traditional dark asphalt with lighter, more reflective materials, or using cool pavements and permeable pavements that allow water infiltration, can help lower temperatures. These materials not only reduce heat but also help manage stormwater.

3. Plant Types

Heat Mitigation Role: The selection of plant types is crucial for managing extreme heat. Native and drought-resistant plants are particularly effective as they require less water and are more resilient to heat. Vegetation with broad leaves provides more shade and contributes to cooling through evapotranspiration.

Application: Landscape designs that incorporate a variety of plant types, including shrubs, groundcovers, and trees, create a more thermally comfortable environment. Using native plant species adapted to the local climate can maximize the effectiveness of these green infrastructures.

4. Solar Radiation

Heat Mitigation Role: Reducing the amount of solar radiation that reaches surfaces is essential for lowering temperatures. This can be achieved through the strategic placement of shade structures, the use of reflective materials, and the design of landscapes that minimize direct sunlight exposure.

Application: Implementing shade structures like pergolas, awnings, or green walls in areas with high pedestrian traffic can reduce the heat load. Additionally, using reflective materials in building exteriors and paving can help deflect solar radiation away from urban areas.

5. Tree Percentage

Heat Mitigation Role: The percentage of tree canopy cover in an area is directly correlated with temperature reduction. Higher tree cover leads to more shade and a significant decrease in ambient temperatures, making it a critical component in heat mitigation.

Application: Increasing the percentage of tree cover in urban spaces, especially in areas lacking green space, can greatly enhance thermal comfort. Urban forestry programs that aim to increase tree canopy coverage are essential for long-term urban heat mitigation.

6. Tree Arrangement and Spacing

Heat Mitigation Role: The arrangement and spacing of trees influence their effectiveness in cooling an area. Properly spaced and arranged trees provide maximum shade coverage and improve air circulation, both of which are vital for reducing heat.

Application: Strategic tree planting, such as lining streets with trees or creating clusters of shade in public spaces, optimizes their cooling benefits. Avoiding overly dense planting ensures trees have adequate space to grow and remain healthy, which in turn sustains their ability to cool effectively.

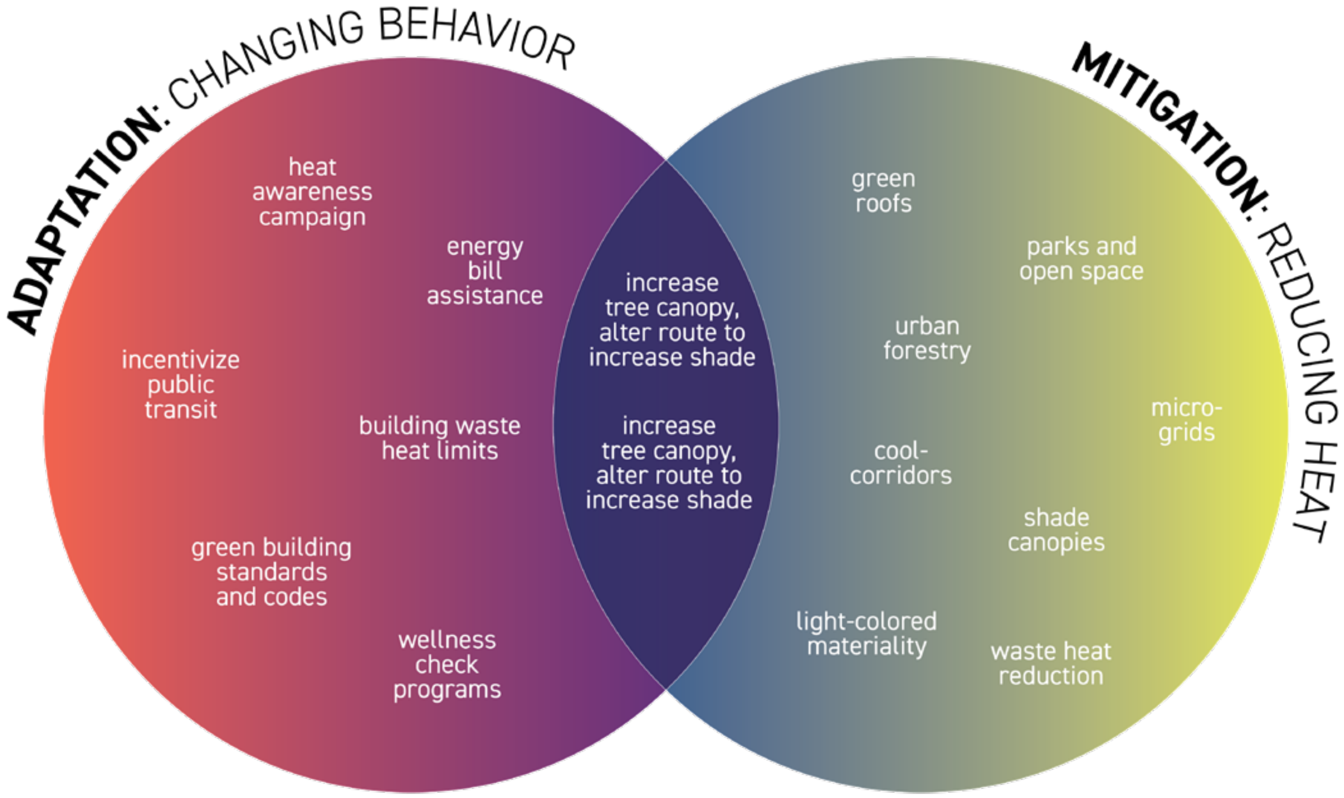
These strategies are supported by case studies and project examples that demonstrate their effectiveness in real-world applications. The research aims to provide landscape architects, policymakers, and community planners with authoritative evidence to advocate for nature-based solutions as essential components of urban design and climate adaptation efforts.

Adaptation and Mitigation

Urban heat solutions generally fall into two categories, adaptation and mitigation. Adaptation and mitigation are two key strategies for addressing climate change, particularly when dealing with challenges like extreme heat. They serve different purposes and focus on different aspects of the problem.

Summary of Differences

Goal: Adaptation seeks to reduce the impacts of climate change by making adjustments to existing systems, while mitigation seeks to reduce the causes of climate change by lowering Greenhouse Gas (GHG) emissions.



Urban heat solutions generally fall into two categories, adaptation and mitigation. Diagram adapted from The Nature Conservancy's "Heat Action Planning Guide For Neighborhoods of Greater Phoenix" (TNC, 2019).

Timeframe: Adaptation addresses both immediate and future impacts, whereas mitigation focuses on long-term prevention of further climate change.
Scope: Adaptation is often localized and context-specific, tailored to the vulnerabilities of a specific area. Mitigation has a broader, often global, focus on reducing overall emissions.
Impact: Adaptation reduces the harm from climate change, making communities more resilient. Mitigation reduces the extent of climate change, aiming to prevent it from worsening.

Heat Action Platform Policy Tool

Building on the detailed analysis presented in Hirschfeld's study, it becomes evident that while the science and principles behind urban heat management are well-documented, the translation of these findings into actionable strategies requires further exploration. This is where the Heat Action Platform's Policy Tool comes into play. It bridges the gap between theoretical research and practical application by offering a comprehensive collection of adaptation and mitigation strategies that can be tailored to specific urban contexts. The platform organizes these solutions into categories that reflect real-world implementation scenarios, making it an essential resource for professionals looking to address urban heat effectively.

In the following section, we will delve into these adaptation and mitigation strategies, categorized into themes such as community, emergency preparedness, and infrastructure, as demonstrated by the Heat Action Platform's Policy Tool. These examples provide a practical guide for cities aiming to integrate these strategies into their planning processes. By exploring how different cities have successfully implemented these solutions, we can draw valuable lessons and inspiration for future projects aimed at combating urban heat and enhancing resilience.

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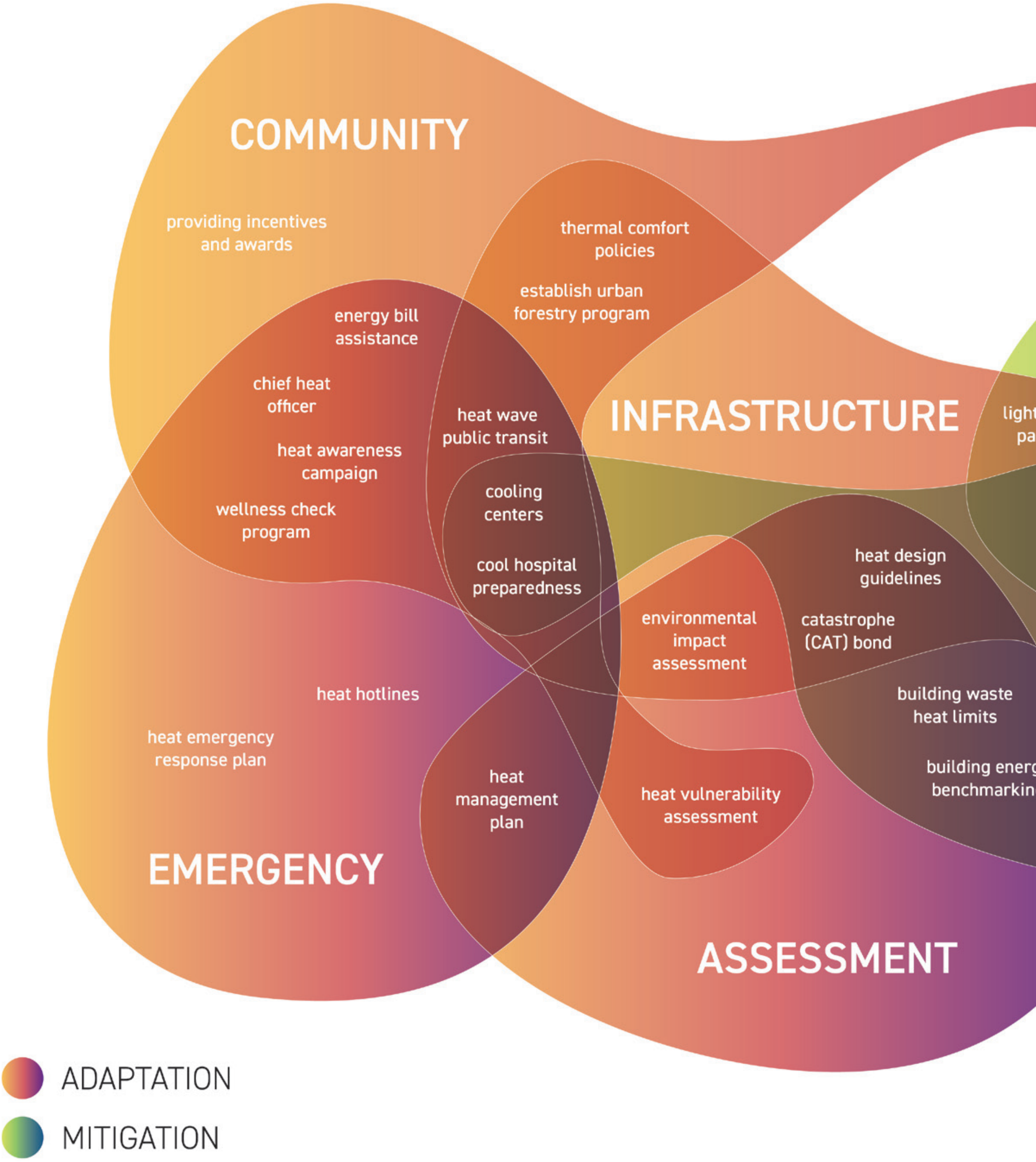
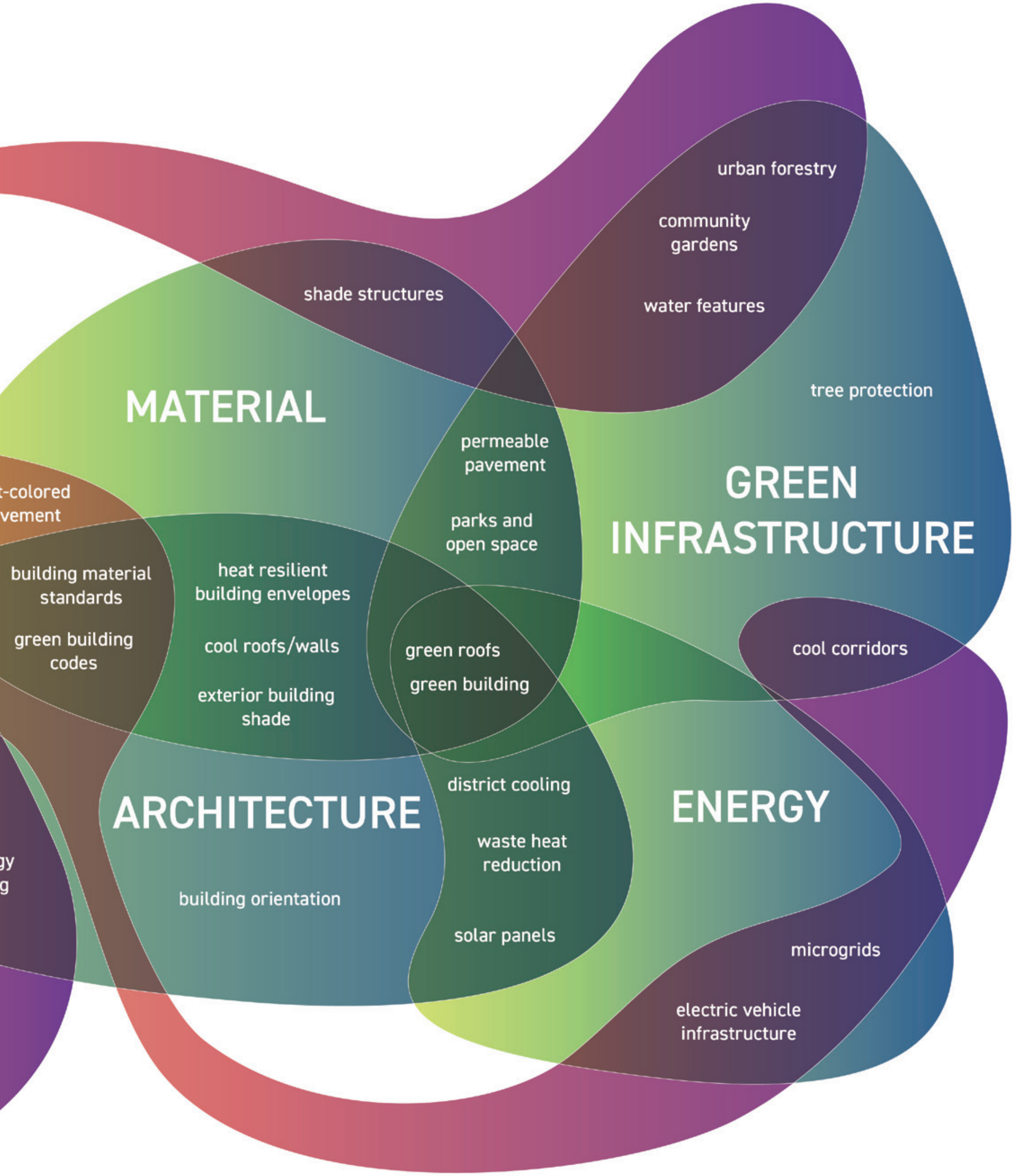
1. Hirschfeld, D., & Guenther, A. (2024, March). *Landscape architecture solutions to extreme heat: Research study*. American Society of Landscape Architects Fund (ASLA Fund). https://www.asla.org/evidence


COMMUNITY
providing incentives and awards
thermal comfort policies
establish urban forestry program
energy bill assistance
chief heat officer
heat awareness campaign
wellness check program
heat wave public transit
INFRASTRUCTURE
light
pa
cooling centers
cool hospital preparedness
heat design guidelines
environmental impact assessment
catastrophe (CAT) bond
heat hotlines
building waste heat limits
heat emergency response plan
building energ
benchmarkin
heat management plan
heat vulnerability assessment
EMERGENCY
ASSESSMENT
ADAPTATION
MITIGATION



Selected adaptation and mitigation strategies. Diagram by Authors.

ADAPTATION

Noun: \ ˌa-dap-ˌtā-shən
Definition: The process of adjusting to new conditions or environments, particularly in response to changing climate or external factors. In the context of climate change, adaptation refers to the actions taken to manage the impacts of climate change on human and natural systems.

Purpose:

Adaptation strategies are designed to adjust and prepare communities, infrastructure, and ecosystems to cope with the current and anticipated impacts of climate change. These strategies aim to reduce vulnerability and enhance resilience against the changes that are already occurring or are expected to occur.

Focus:

Short-term and Long-term Adjustments: Adaptation involves both immediate actions to deal with current climate impacts and long-term planning to prepare for future changes.

Local and Context-Specific: Adaptation measures are often tailored to the specific needs and vulnerabilities of a community or region.

Enhancing Resilience: These strategies focus on making systems and communities more robust so they can withstand climate impacts. Examples include creating cooling centers for heatwaves, developing urban green spaces, or altering agricultural practices to cope with changing weather patterns.

Categories:

Community: This category focuses on initiatives and strategies that directly engage and support communities in adapting to extreme heat.

Emergency: The emergency category addresses immediate and urgent responses to extreme heat events.

Infrastructure: This category deals with long-term resilience by focusing on the built environment.

Assessment: Assessment strategies involve the evaluation and analysis of heat vulnerabilities and resilience within communities and environments.

ENERGY BILL ASSISTANCE

Description:
Local governments can provide financial assistance for people that have difficulties paying their utility bills. Extreme heat waves result in the increased use of air conditioning, causing household energy bills to rise. These costs may already cause low-income communities to struggle, and the increased cost will only add to the burden, making the assistance even more important during extreme heat.

Consideration:
Accompanying this initiative with community outreach can inform residents on how to apply for this program and educate them on low-cost ways to conserve energy.

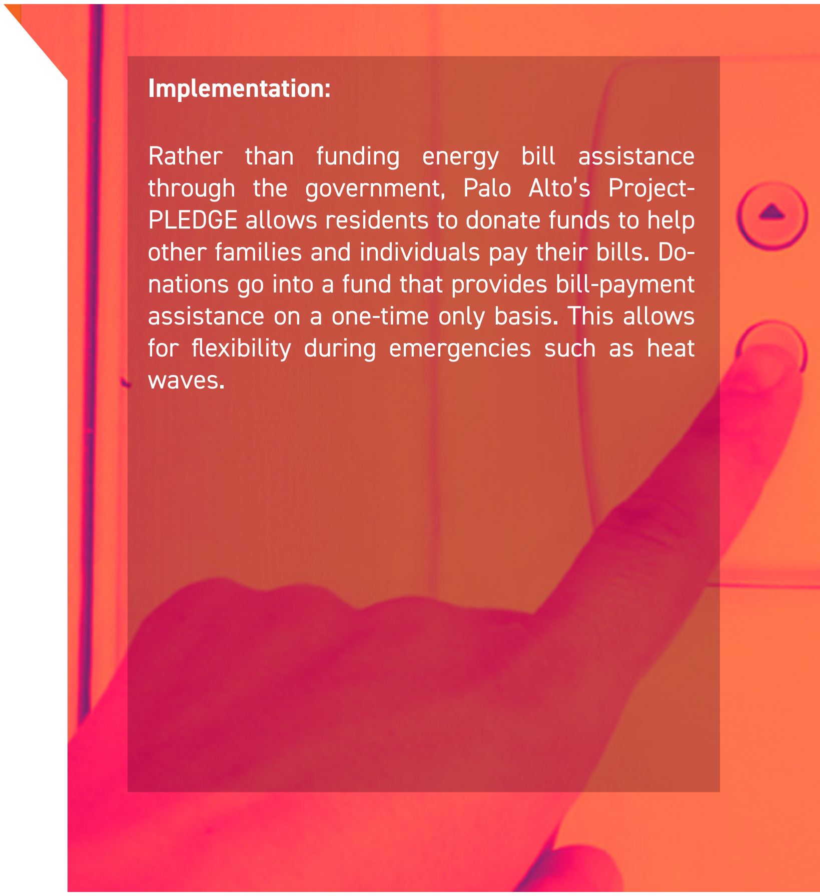
Impact:
Energy bill assistance can greatly benefit heat-vulnerable communities and residents. Metrics on numbers of families served by the energy assistance program as well as the number of power outages per heat wave or year should be measured to understand where discrepancies lie.

Benefits:

cost: ● low ○ mid ○ high

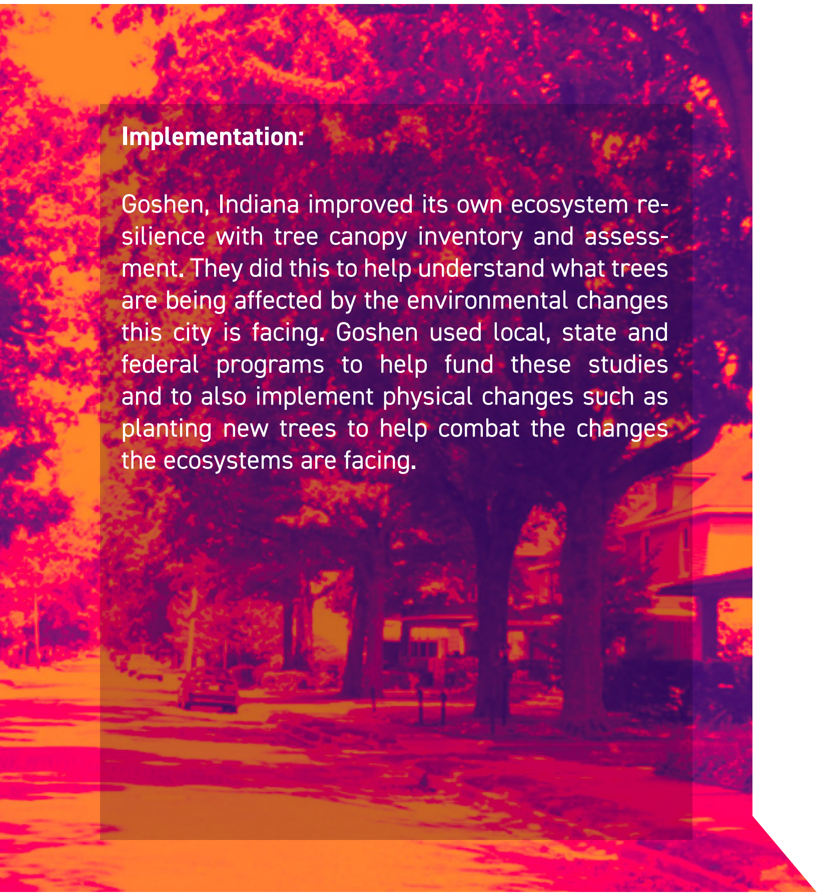
public good: ○ low ○ mid ● high

GHG reduction: ○ low ○ mid ○ high



Implementation:

Rather than funding energy bill assistance through the government, Palo Alto's Project-PLEDGE allows residents to donate funds to help other families and individuals pay their bills. Donations go into a fund that provides bill-payment assistance on a one-time only basis. This allows for flexibility during emergencies such as heat waves.



Implementation:

Goshen, Indiana improved its own ecosystem resilience with tree canopy inventory and assessment. They did this to help understand what trees are being affected by the environmental changes this city is facing. Goshen used local, state and federal programs to help fund these studies and to also implement physical changes such as planting new trees to help combat the changes the ecosystems are facing.

ESTABLISHING URBAN FOREST PROGRAMS

Decription:
These programs generally have broad goals that emphasize the multiple benefits trees can provide, including helping to cool cities. Moreover, many states give grants to communities and organizations that promote or maintain urban forests. Many local governments have enacted tree and landscape ordinances, which can ensure public safety, protect trees or views, and provide shade.

Consideration:
Three types of ordinances, in particular, are most useful from a heat island perspective: tree protection, street trees, and parking lot shade.

Impact:
Incentivized green roofs can impact the community in diverse ways through area cooling, efficient energy consumption, and reclaiming unused space.

Benefits:

cost
○ low ● mid ○ high

public good
○ low ○ mid ● high

GHG reduction
● low ○ mid ○ high

HEAT AWARENESS CAMPAIGN

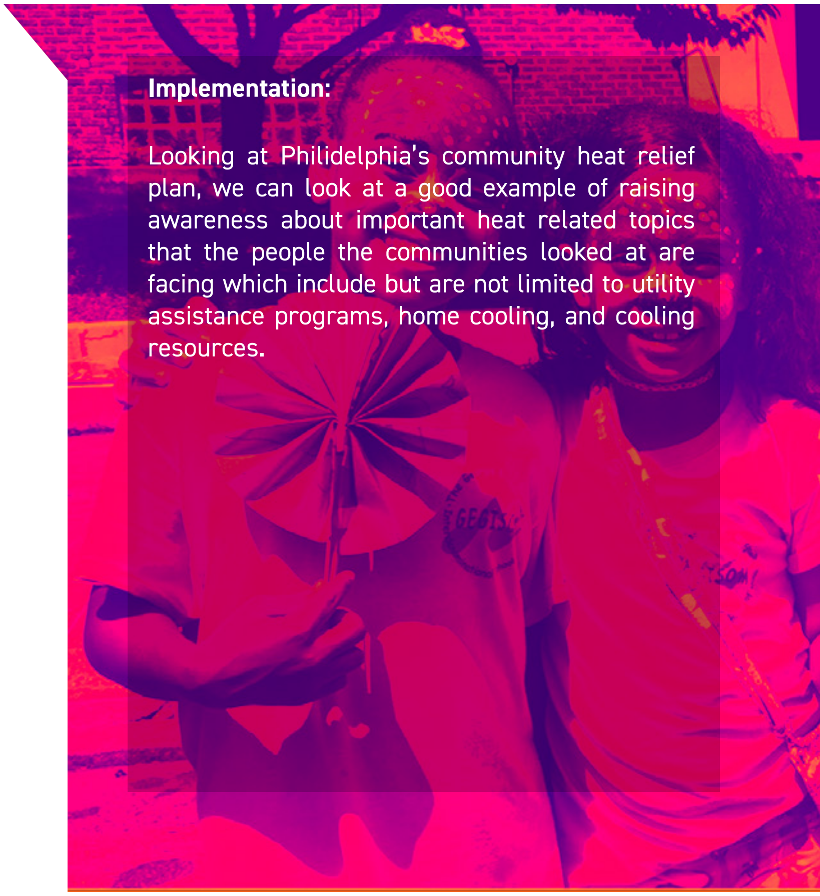
Description:
Many communities do not realize the wide-ranging impacts of extreme heat or options to mitigate their risk. Outreach campaigns can raise awareness about why heat is a priority, how rising temperatures intersect with different social and climate issues, and share existing resources for community members to participate in cooling solutions to protect human health.

Consideration:
Public spaces and spaces where vulnerable populations frequent are great locations for events such as schools and senior centers. Program managers should consider barriers to online communication for vulnerable populations and prioritize sharing information in highly visible public places.

Impact:
Heat awareness can greatly benefit heat-vulnerable communities, and all other residents of the targeted community. This will impact the way we move foreward to reduce the rising temperature and to help lessen the risk with heat related problem. Metrics on the number of people reached and topics that are most unknown and know should be measured to understand how the community feels about these heat related risks.

Benefits:

	low	mid	high
cost	●	○	○
public good	○	○	●
GHG reduction	○	○	○



Implementation:

Looking at Philidelphia's community heat relief plan, we can look at a good example of raising awareness about important heat related topics that the people the communities looked at are facing which include but are not limited to utility assistance programs, home cooling, and cooling resources.

PROVIDING INCENTIVES AND AWARDS

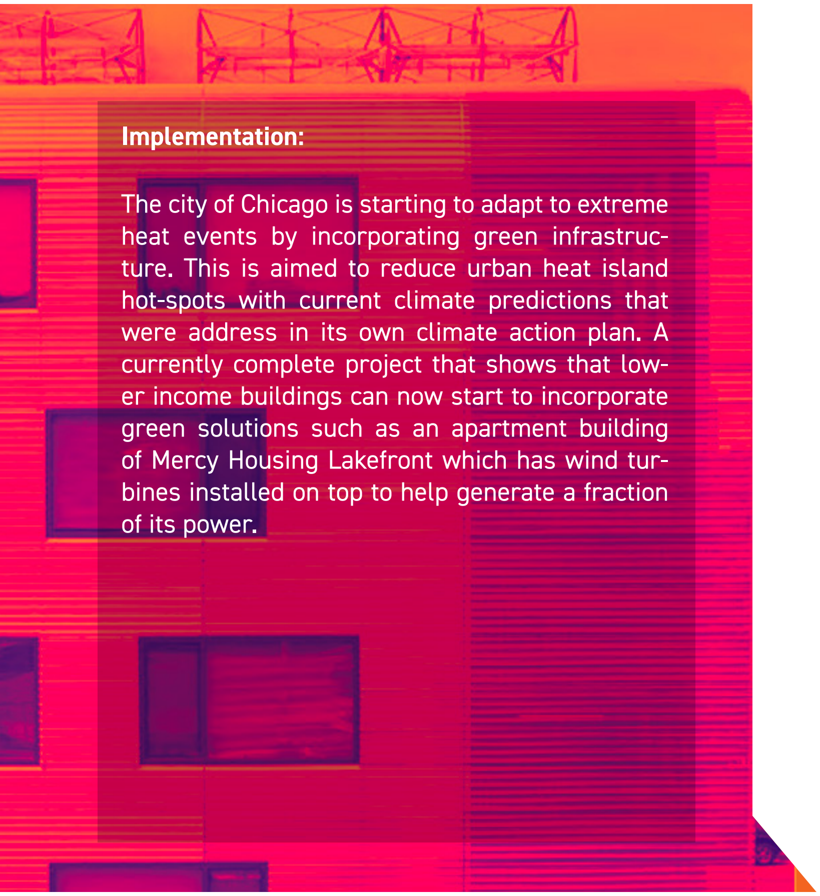
Decription:
Incentives and awards from governments, utilities, and other organizations can be an effective way to spur individual heat island reduction actions. These might include below-market loans, tax breaks, product rebates, grants, and giveaways. Awards can reward exemplary work, highlight innovation, and promote solutions across the public and private sectors.

Consideration:
Providing incentives can help raise awareness and to help benefit those who are working with the community to improve and reduce heat mitigation.

Impact:
Providing incentives can help to raise awareness and help locals who typically choose the cheaper option explore more heat mitigation tactics when dealing with day to day operations of there lives. Metrics on the amount of incentives given out and along with how many people that were reached should be looked at.

Benefits:

	low	mid	high
cost	○	●	○
public good	○	○	●
GHG reduction	○	○	○



Implementation:

The city of Chicago is starting to adapt to extreme heat events by incorporating green infrastructure. This is aimed to reduce urban heat island hot-spots with current climate predictions that were address in its own climate action plan. A currently complete project that shows that lower income buildings can now start to incorporate green solutions such as an apartment building of Mercy Housing Lakefront which has wind turbines installed on top to help generate a fraction of its power.

THERMAL COMFORT POLICIES

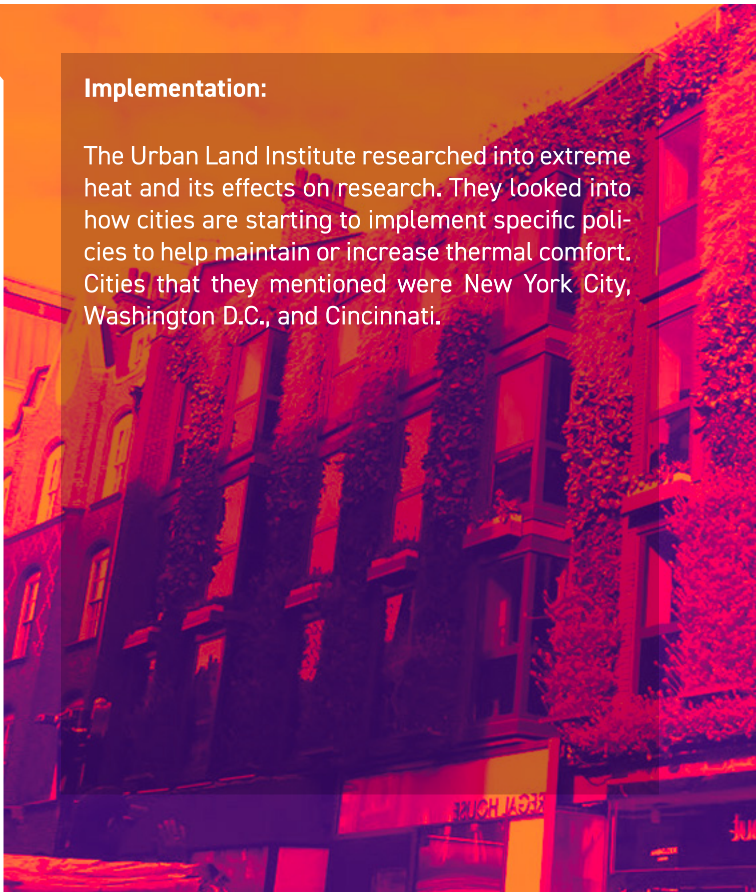
Description:
Maximum allowable indoor temperatures for buildings can increase awareness and encourage property managers to adjust cooling standards to avoid excessive cooling, reduce energy loads, and as a result reduce the associated waste heat.

Consideration:
This policy could build on or add to existing minimum indoor temperature, energy, or other efficiency standards for interior conditions.

Impact:
Thermal comfort policies can help residents and property owners of the targeted community. This will mitimize energy usage and help to lower the risk and strain on the power grid. Metrics on the number of community members served by this should be measured.

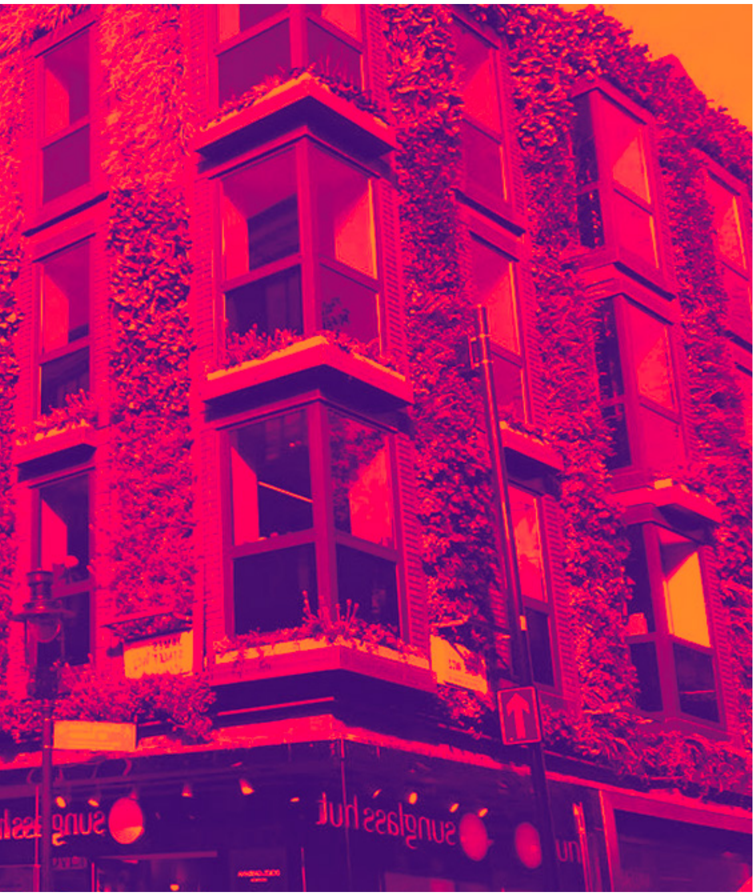
Benefits:

cost	public good	GHG reduction
● low ○ mid ○ high	● low ○ mid ○ high	○ low ○ mid ○ high



Implementation:

The Urban Land Institute researched into extreme heat and its effects on research. They looked into how cities are starting to implement specific policies to help maintain or increase thermal comfort. Cities that they mentioned were New York City, Washington D.C., and Cincinnati.



Implementation:

On June 3, 2022 Marta Segura will start to coordinate the city of LA's response to extreme heat. This is the first heat officer that the city has hired. She will be the key to organizing all heat related issues aimed at efficiently takling heat related problems different LA communities are facing.

CHIEF HEAT OFFICER

Description:
One of the challenges of protecting people from heat is that the responsibility for heat-related issues is spread across many agencies and positions. A Chief Heat Officer can serve as a unifying leader for this work, responsible for addressing rising temperatures through short- and long-term interventions and raising awareness about heat risks.

Consideration:
Ensure the Chief Heat Officers are supported within their government functions and have both jurisdiction and funding to implement meaningful solutions.

Impact:
All residents will be beneficiaries along with heat vulnerable communities, who would be benefited the most. This would be aimed at risk reduction and mitigation. Metrics on number of projects initiated and completed should be recorded.

Benefits:

cost
○ low ● mid ○ high

public good
○ low ● mid ○ high

GHG reduction
○ low ○ mid ○ high

COOL HOSPITAL PREPAREDNESS MANDATE

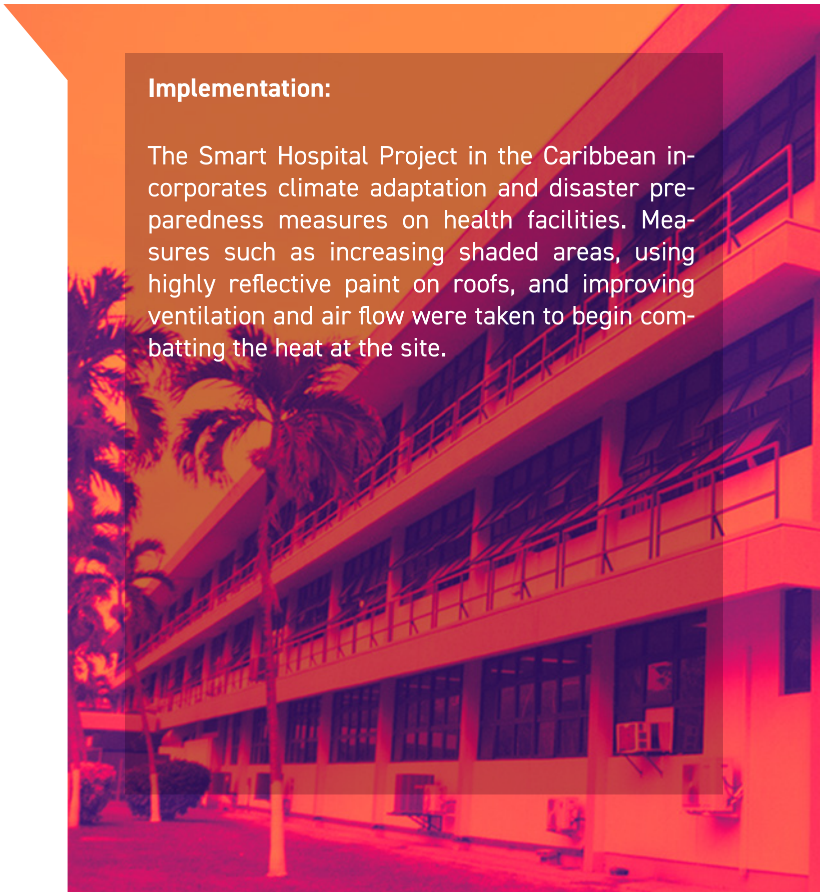
Description:
During heat waves, hospitals can become overwhelmed with the sudden influx of patients, and those hospitals connected to the grid may lose power for other essential equipment. Hospitals should be prepared for these increased admissions and power outages in order to ensure they can continue treating patients. By requiring hospitals to prepare plans for extreme heat waves, such as installing generators, and training staff to respond, they can be better prepared.

Consideration:
By properly preparing for extreme heat events, hospitals can also be better equipped for other environmental hazards.

Impact:
Better prepared hospitals directly impact heat-vulnerable communities and residents. Preparation should occur during the emergency response and management phase, and collecting data on the reduction in heat-related deaths provides insight on how well-prepared hospitals are or have become.

Benefits:

cost			public good			GHG reduction		
●	○	○	●	○	○	○	○	○
low	mid	high	low	mid	high	low	mid	high



Implementation:

The Smart Hospital Project in the Caribbean incorporates climate adaptation and disaster preparedness measures on health facilities. Measures such as increasing shaded areas, using highly reflective paint on roofs, and improving ventilation and air flow were taken to begin combatting the heat at the site.

HEAT EMERGENCY RESPONSE PLAN

Description:
Creating a heat emergency response plan can help governments anticipate heat waves and minimize loss of life. A heat emergency response plan will identify vulnerable populations, set standards to forecast and categorize heat waves, and identify roles and responsibilities for different stakeholders during high-heat events.

Consideration:
Emergency response plans should be regularly tested and updated. Preventative and emergency communication plans and materials should be included.

Impact:
All city residents and particularly heat-vulnerable communities will be greatly impacted by having a heat emergency response plan. It helps reduce heat-related death and other serious issues.

Benefits:

	low	mid	high
cost	●	○	○
public good	○	○	●
GHG reduction	○	○	○

Implementation:

The city of Ahmedabad in Gujarat, India developed a heat action plan with a focus on emergency heat waves and the roles various agencies play on these days of extreme heat. It is estimated that 2,380 deaths were avoided in the years after implementation.

HEAT HOTLINES

Description:
Heat hotines are telephone helplines that can provide information during a heat wave to members of the public. Hotline operators can share information on how to access cooling resources like cooling centers, identify symptoms of heat-related illness in real-time, and connect users with emergency services as necessary. Heat hotlines can prevent heat-related illness and death by connecting users with resources.

Consideration:
Depending on climate, hotlines can be active year-round or at select high-risk times of year (e.g. seasonally or during a heat wave).

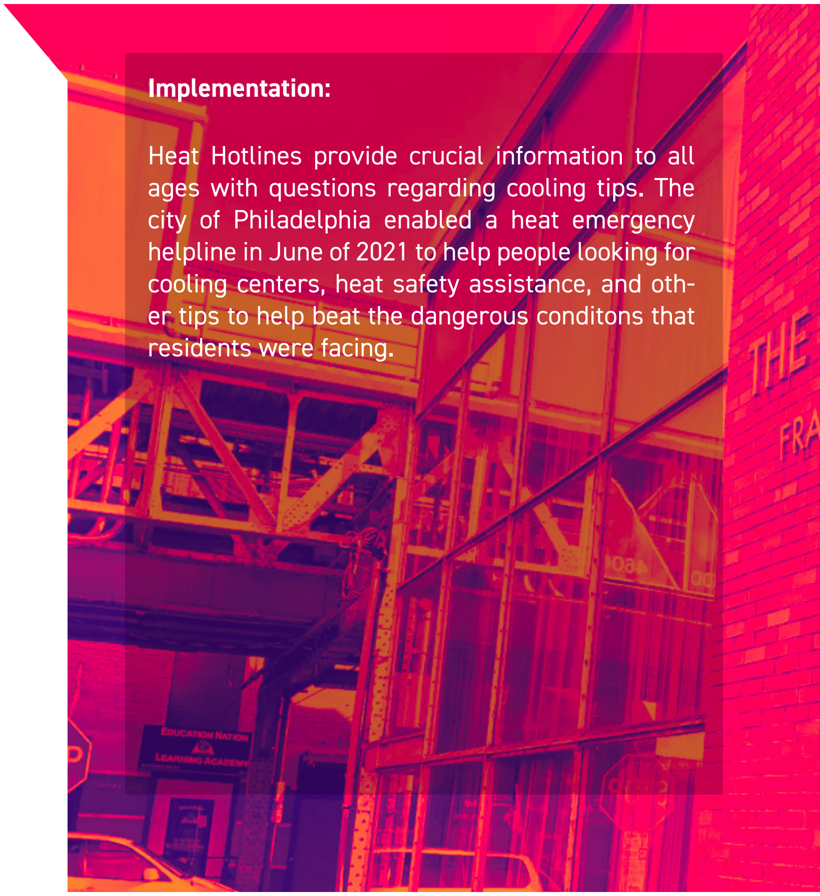
Impact:
Heat awareness can greatly benefit heat-vulnerable communities, and all other residents of the targeted community. This will be aimed at impacting the eergenc response and management. Metrics of number of calls received should be recorded.

Benefits:

cost
● ○ ○
low mid high

public good
○ ○ ●
low mid high

GHG reduction
○ ○ ○
low mid high



Implementation:

Heat Hotlines provide crucial information to all ages with questions regarding cooling tips. The city of Philadelphia enabled a heat emergency helpline in June of 2021 to help people looking for cooling centers, heat safety assistance, and other tips to help beat the dangerous conditons that residents were facing.

PUBLIC TRANSIT DURING HEAT WAVES

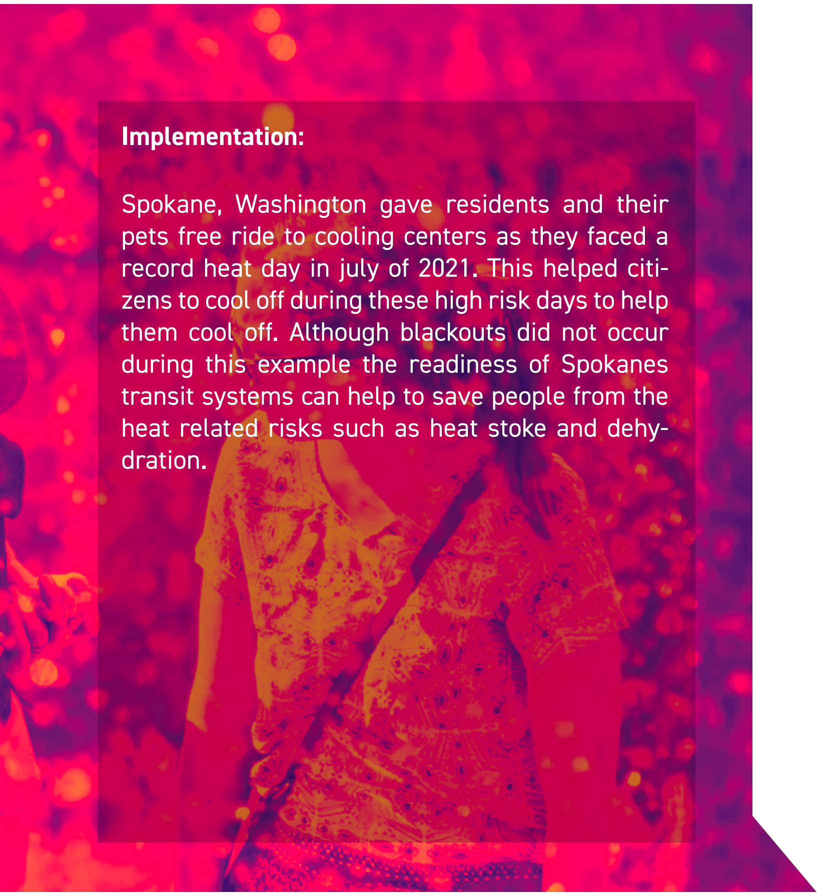
Description:
Provide transit to cooling centers during heat waves can help protect communities. In particular, this can suppport vulnerable populations, especially older adults, that are isolated and/or may not have access to cooling at home.

Consideration:
Providing incentives can help raise awareThis intervention will have the greatest impact with targeted outreach to make sure community members know about public transportation options during heat waves. Additionally, cooling centers should be located in areas that are accessible to public transit.

Impact:
PAll residents will be beneficiaries but heat vulnerable communities would benefit the most. This would be aimed at risk reduction and mitigation. Metrics on number of riders should be recorded.

Benefits:

cost	public good	GHG reduction
● low ○ mid ○ high	○ low ○ mid ● high	● low ○ mid ○ high



Implementation:

Spokane, Washington gave residents and their pets free ride to cooling centers as they faced a record heat day in july of 2021. This helped citizens to cool off during these high risk days to help them cool off. Although blackouts did not occur during this example the readiness of Spokanes transit systems can help to save people from the heat related risks such as heat stoke and dehydration.

WELLNESS CHECK PROGRAMS

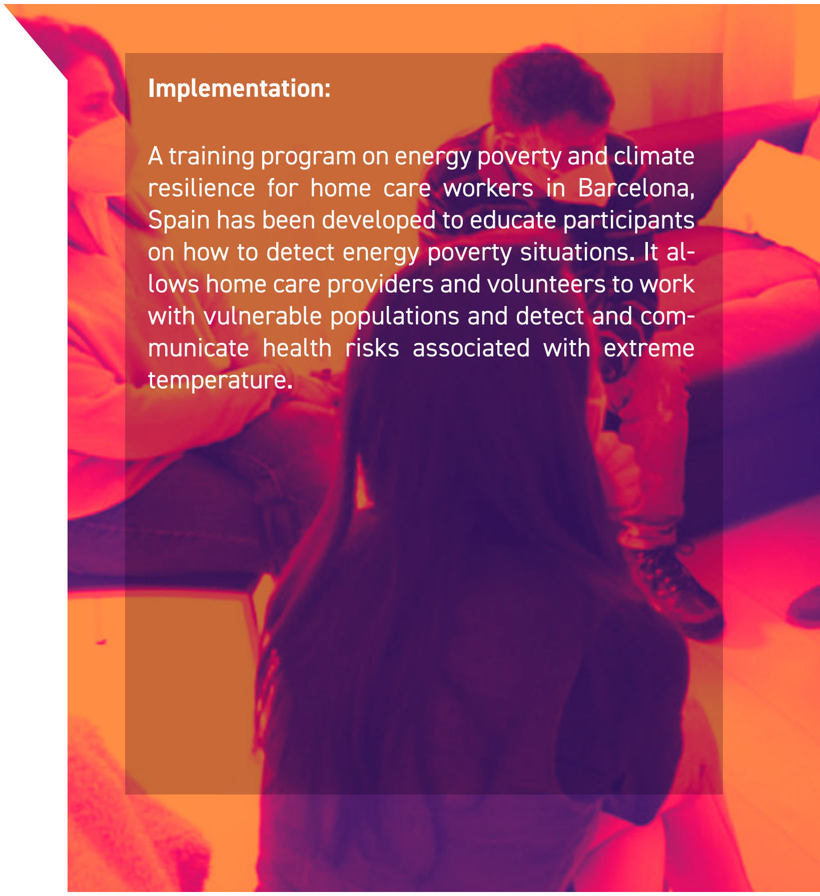
Description:
Socially isolated and other vulnerable populations are at greater risk of health emergencies during heat waves. Programs to check in on these populations can reduce heat-related illness and emergencies by having people designated to check in on individuals. Establish a wellness check program with three steps: 1) create a voluntary registry supported by targeted outreach for individuals to sign up to be checked on during extreme heat events; 2) train members of the community to recognize heat stress symptoms and check-in on vulnerable populations during heat waves; and 3) launch a campaign; which can be paired with a heat wave alert system.

Consideration:
The list of program participants should be updated on an annual basis. Government can partner with community-based organizations to support outreach to hard-to-reach populations.

Impact:
Wellness check programs help all community members in a time of need and help monitor health risks before they become serious. Collecting data on the number of community members reached through these programs is important in order to strive to impact more residents.

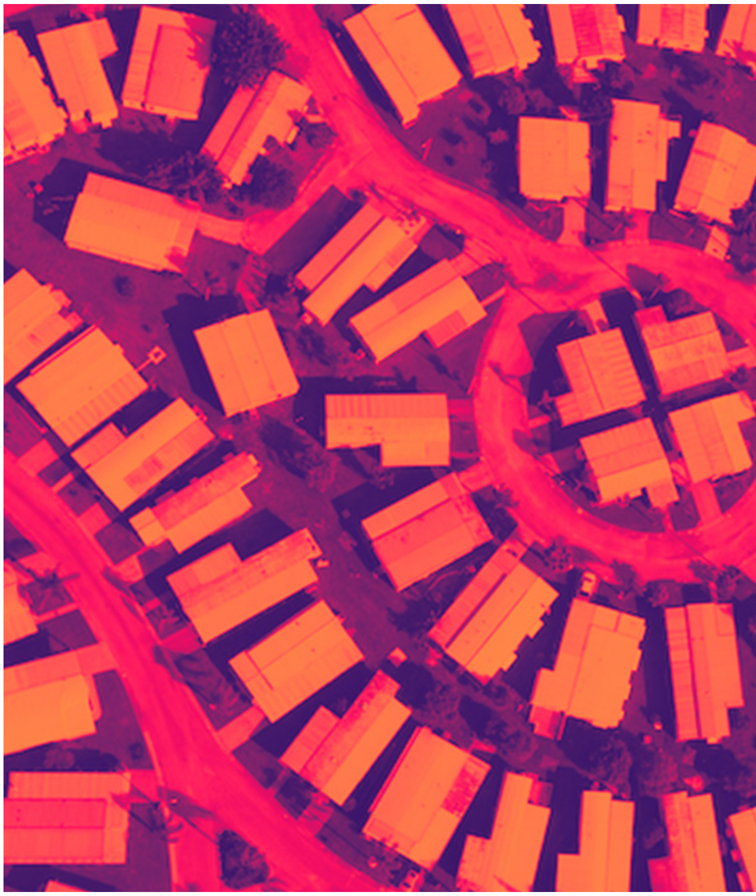
Benefits:

cost	public good	GHG reduction
● ○ ○	○ ○ ●	○ ○ ○
low mid high	low mid high	low mid high



Implementation:

A training program on energy poverty and climate resilience for home care workers in Barcelona, Spain has been developed to educate participants on how to detect energy poverty situations. It allows home care providers and volunteers to work with vulnerable populations and detect and communicate health risks associated with extreme temperature.



BUILDING MATERIAL STANDARDS

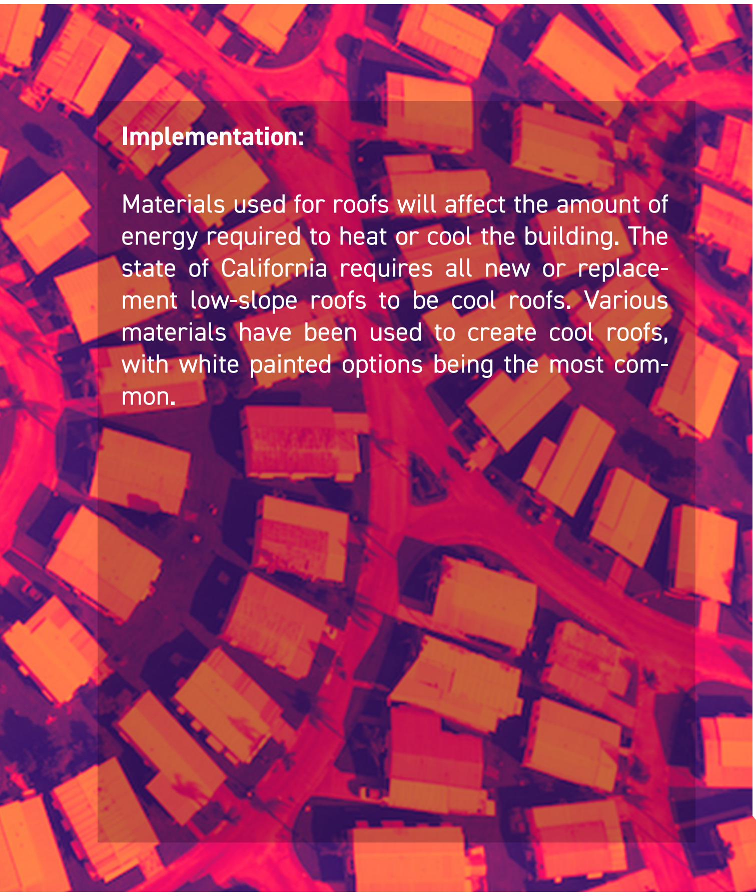
Description:
Converting vacant, non-vegetated land into community gardens can provide social and economic benefits in addition to mitigating local temperatures. Soil in garden spaces or raised beds can trap sunlight and heat during warmer months.

Consideration:
This is most applicable to new developments. Improving existing building envelopes is often cost prohibitive, but owners can consider improving insulation and airtightness during major renovations.

Impact:
Building material standards help property owners to create an energy efficient building during construction. Data collection of building temperature changes and energy savings should be done in order to assess the impact.

Benefits:

cost	public good	GHG reduction
○ low ● mid ○ high	● low ○ mid ○ high	○ low ○ mid ● high



Implementation:

Materials used for roofs will affect the amount of energy required to heat or cool the building. The state of California requires all new or replacement low-slope roofs to be cool roofs. Various materials have been used to create cool roofs, with white painted options being the most common.

BUILDING WASTE HEAT LIMITS

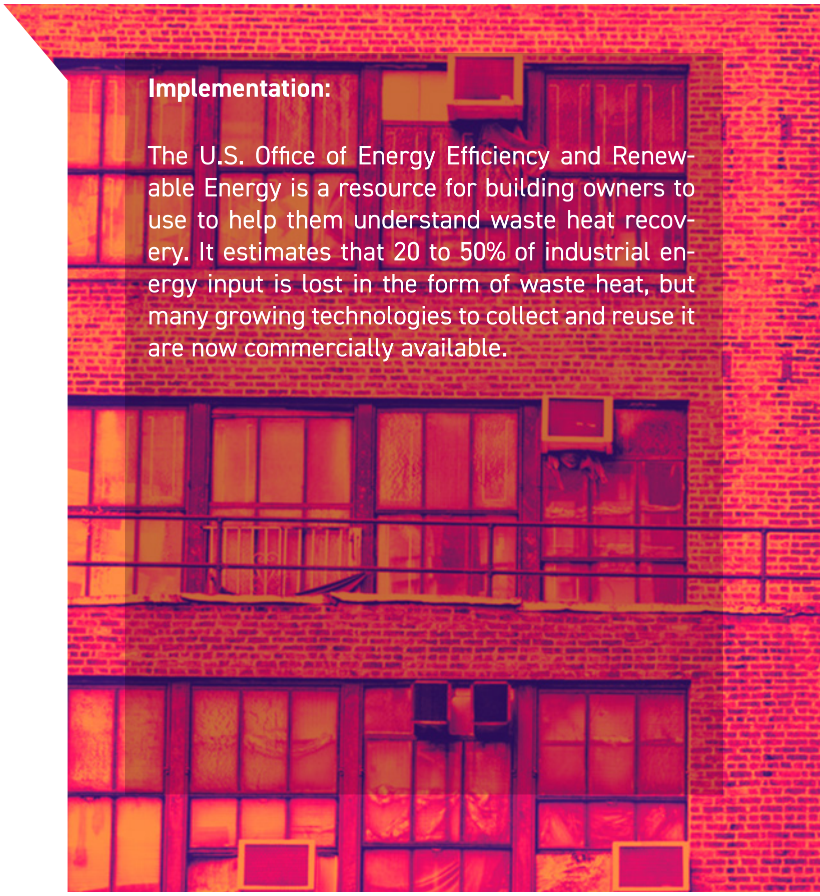
Description:
Certain air conditioning units, such as window units, emit heat to the outside, which can increase outdoor temperatures. By evaluating and setting a maximum amount of heat waste a building can produce, warming emissions can be reduced. Owners of buildings that exceed the maximum heat waste allowance can be required to improve the building's ventilation or install heat recovery systems. In other cases, waste heat can be recovered and reused to power other areas.

Consideration:
Rather than requiring specific systems for buildings outside of the maximum, building owners can be directed to various resources for retrofitting and other building improvements.

Impact:
Building waste heat limits reduce risks and mitigate heat emissions in the outdoor environment. By measuring energy use by area, building, use, and more, specific spaces can be targeted, benefiting residents in the area.

Benefits:

	low	mid	high
cost	●	○	○
public good	○	○	○
GHG reduction	○	●	○



Implementation:

The U.S. Office of Energy Efficiency and Renewable Energy is a resource for building owners to use to help them understand waste heat recovery. It estimates that 20 to 50% of industrial energy input is lost in the form of waste heat, but many growing technologies to collect and reuse it are now commercially available.

GREEN BUILDING STANDARDS & CODES

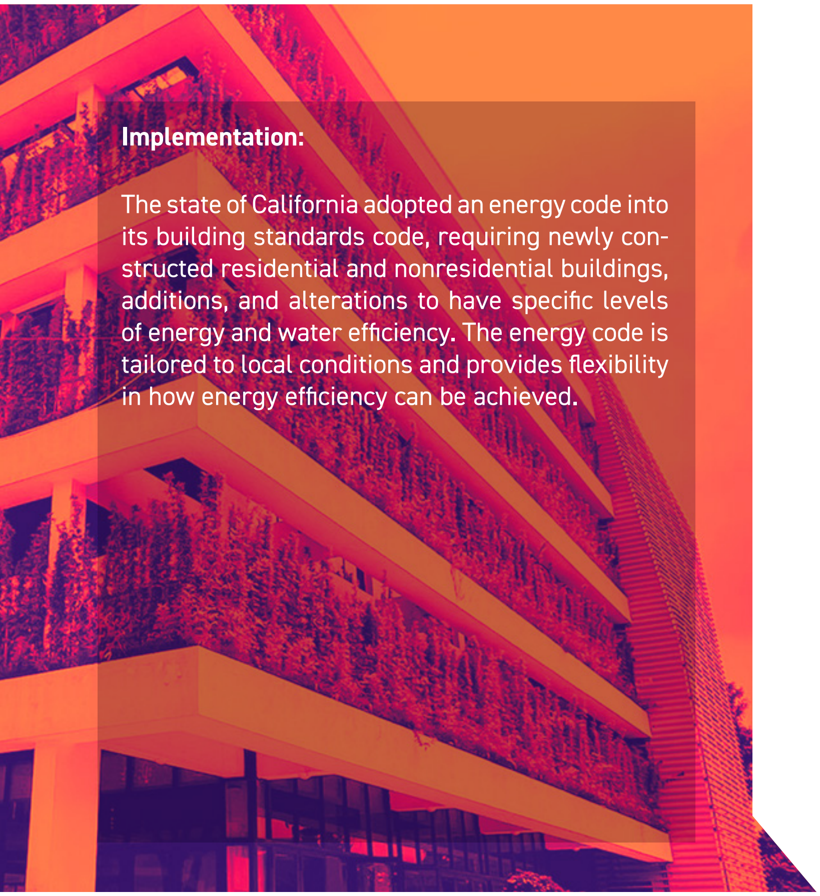
Description:
Converting vacant, non-vegetated land into community gardens can provide social and economic benefits in addition to mitigating local temperatures. Soil in garden spaces or raised beds can trap sunlight and heat during warmer months.

Consideration:
Community gardens require basic infrastructure to operate (e.g. water supply) and provide opportunities for community engagement, partnership, and education.

Impact:
Green building standards help property owners and residents achieve energy efficient buildings and save money. Numbers and scores or levels of certification for buildings that receive ratings should be collected to ensure codes are being upheld.

Benefits:

cost	public good	GHG reduction
● low ○ mid ○ high	○ low ○ mid ○ high	○ low ○ mid ● high



Implementation:

The state of California adopted an energy code into its building standards code, requiring newly constructed residential and nonresidential buildings, additions, and alterations to have specific levels of energy and water efficiency. The energy code is tailored to local conditions and provides flexibility in how energy efficiency can be achieved.

HEAT DESIGN GUIDELINES

Description:
Green roofs cool the surrounding air and reduce building heat through a layer of vegetation or other plants. Green roofs can also serve as additional green space. There are two main types of green roofs: intensive and extensive.

Consideration:
Green roofs need sufficient structural support and do not work on steep-sloped roofs. Green roofs require maintenance and upkeep every year. Roofs that are open to the public require safety precautions. Intensive green roofs provide more co-benefits (such as stormwater management) are much heavier than extensive roofs and require more structural support, irrigation, and fertilization as well as additional maintenance. Green roofs are generally more feasible and cost-effective in new construction versus retrofits. Given the costs required to install and maintain green roofs, requirements to install them must be carefully considered.

Impact:
Heat design guidelines benefit both property owners and residents. They can be implemented to reduce risk and act as a form of heat mitigation. It is important to measure the change in cost over the lifetime of a specific asset as well as how surface temperature decreases over time.

Benefits:

cost	public good	GHG reduction
● low ○ mid ○ high	● low ○ mid ○ high	○ low ● mid ○ high

Implementation:

New York City currently has heat design guidelines for buildings, infrastructure, and landscapes. They have been found to reduce damage and stress to materials, plantings, and electrical and mechanical systems as well as reduce operational costs.

Implementation:

The city of Chicago is starting to adapt to extreme heat events by incorporating green infrastructure. This is aimed to reduce urban heat island hot-spots with current climate predictions that were address in its own climate action plan. A currently complete project that shows that lower income buildings can now start to incorporate green solutions such as an apartment building of Mercy Housing Lakefront which has wind turbines installed on top to help generate a fraction of its power.

BUILDING ENERGY BENCHMARKING

Description:
Converting vacant, non-vegetated land into community gardens can provide social and economic benefits in addition to mitigating local temperatures. Soil in garden spaces or raised beds can trap sunlight and heat during warmer months.

Consideration:
Community gardens require basic infrastructure to operate (e.g. water supply) and provide opportunities for community engagement, partnership, and education.

Impact:
Community based gardens have both educational and social impacts on a community. Produce from community gardens may be used by impoverished households, elementary schools, or sold at community markets. Working together in urban agriculture can teach youth in the community about self-sufficiency and patience.

Benefits:

cost			public good			GHG reduction		
●	○	○	○	○	○	○	●	○
low	mid	high	low	mid	high	low	mid	high

CATASTROPHE (CAT) BONDS

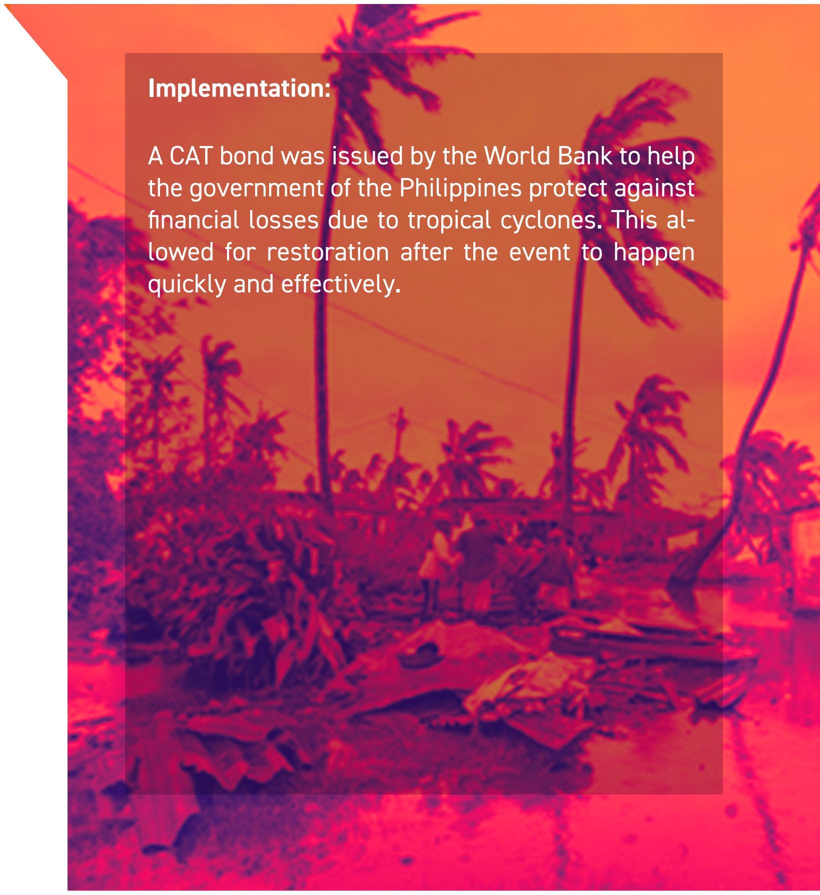
Description:
Catastrophe bonds or CAT bonds are funds that are paid to an insurer when a predetermined index such as an extreme weather event is triggered. The proceeds from the bond are put into an account and can only be released if the trigger occurs (i.e. a heat wave). They allow for long-term financial protection against climate-related risks.

Consideration:
Interest or repayment discounts to governments investing in risk-mitigation infrastructure can be included in a CAT bond.

Impact:
CAT bonds can benefit business and property owners as well as renters and residents and allows for the reduction and mitigation of risks in the event of a heat wave.

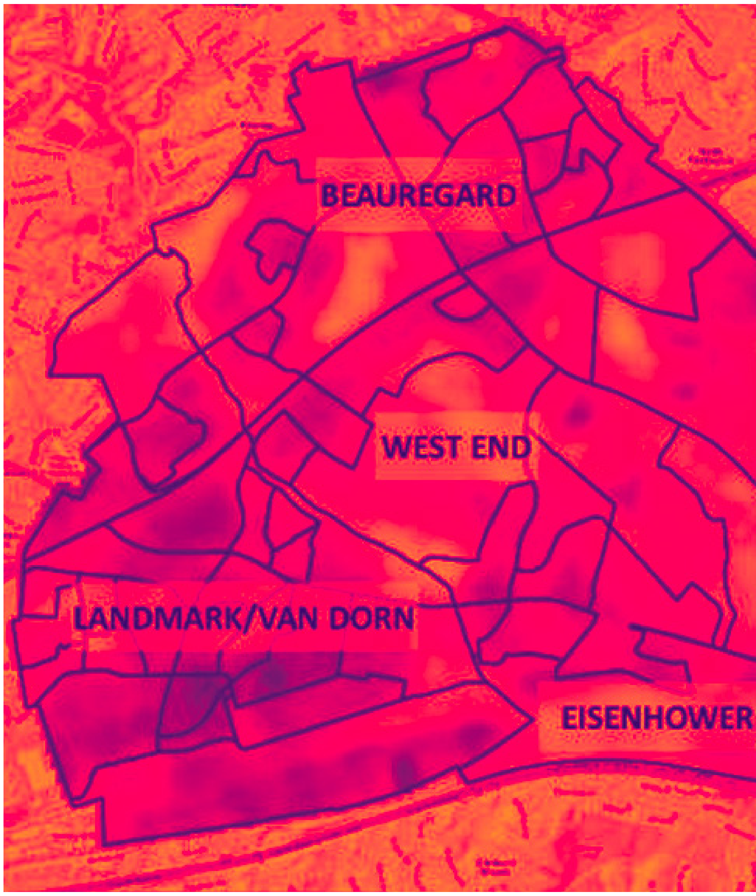
Benefits:

cost	public good	GHG reduction
○ ● ○	● ○ ○	○ ○ ○
low mid high	low mid high	low mid high



Implementation:

A CAT bond was issued by the World Bank to help the government of the Philippines protect against financial losses due to tropical cyclones. This allowed for restoration after the event to happen quickly and effectively.



CONDUCT A HEAT VULNERABILITY ASSESSMENT

Decription:
A heat vulnerability assessment uses available data to quantify and map the heat risk throughout the community. This data can then be used to address the risk. Factors addressed include, most exposure, the highest population sensitivity, and the least ability to adapt. These groups will be considered as the priority for intervention.

Consideration:
This assessment combines health, economic, governmental, community, and environmental indicators together to create a vulnerability score for each census tract.

Impact:
Heat vulnerability assessments can help define where heat vulnerable communities are and in return can help these residents that are experiencing more of heat related risks. This is used for risk reduction and mitigation within these communities. Metrics on the community members reached should be measured.

Benefits:

cost	public good	GHG reduction
● ○ ○	● ○ ○	○ ○ ○
low mid high	low mid high	low mid high

Implementation:

The city of Alexandria, Virginia completed a heat vulnerability assessment in july of 2022 and looked at numerous different data sets to determine a heat vulnerability index score along with different components such as exposure, sensitivity, and adaptive capacity.

DEVELOP A HEAT MANAGEMENT PLAN

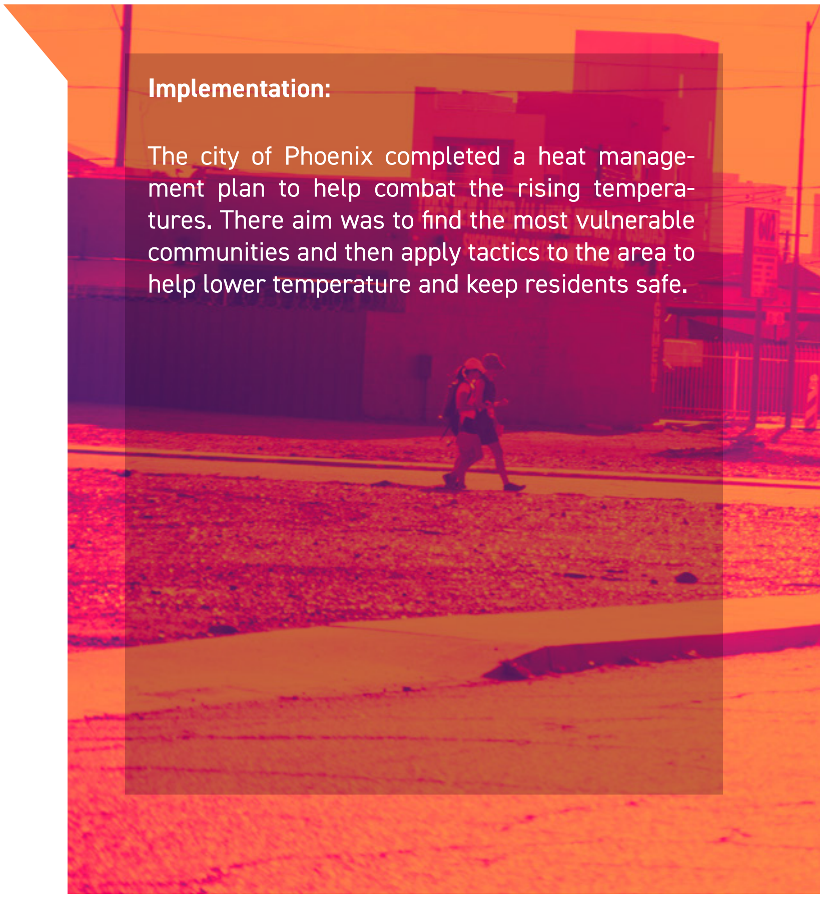
Description:
A heat response plan can include strategies and procedures to respond to extreme heat-related emergencies. Plans could also include other measures (or "non-emergency measures") such as increasing the availability and affordability of air conditioning, encouraging or requiring heat-sensitive building techniques such as green or white roofs, increasing tree coverage, and addressing urban heat islands.

Consideration:
A key component is cooling centers and access to them for vulnerable populations.

Impact:
All residents of the community involved will be impacted. Metrics of those who are positivley afected should be recorded. This could mean looking at statistics of heat related risks.

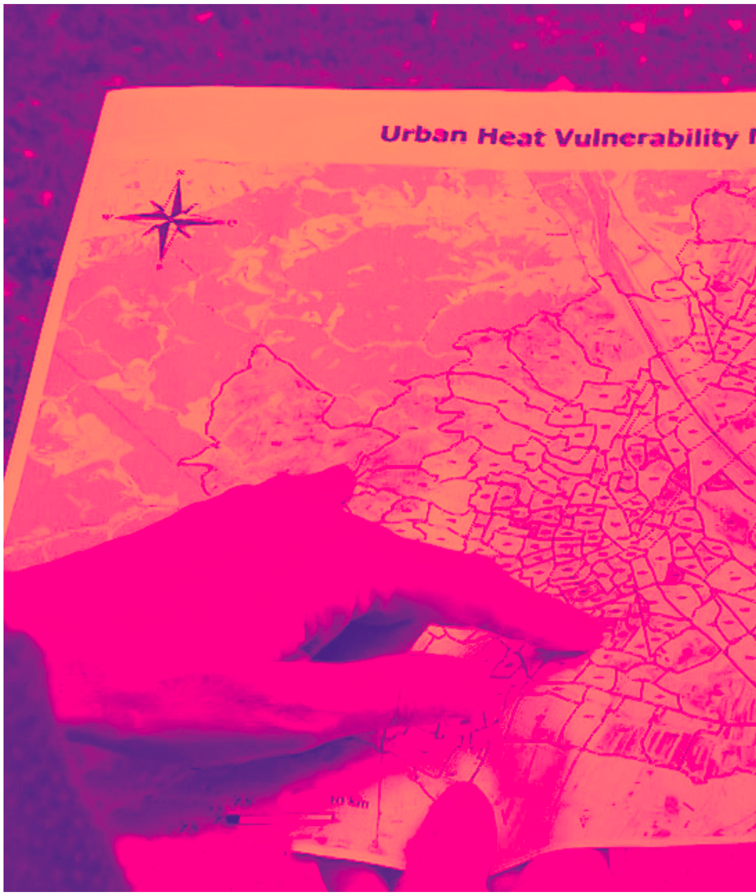
Benefits:

cost	public good	GHG reduction
● low ○ mid ○ high	● low ○ mid ○ high	○ low ● mid ○ high



Implementation:

The city of Phoenix completed a heat management plan to help combat the rising temperatures. There aim was to find the most vulnerable communities and then apply tactics to the area to help lower temperature and keep residents safe.



HEAT-RESILIENT ENVIRONMENTAL IMPACT ASSESSMENT

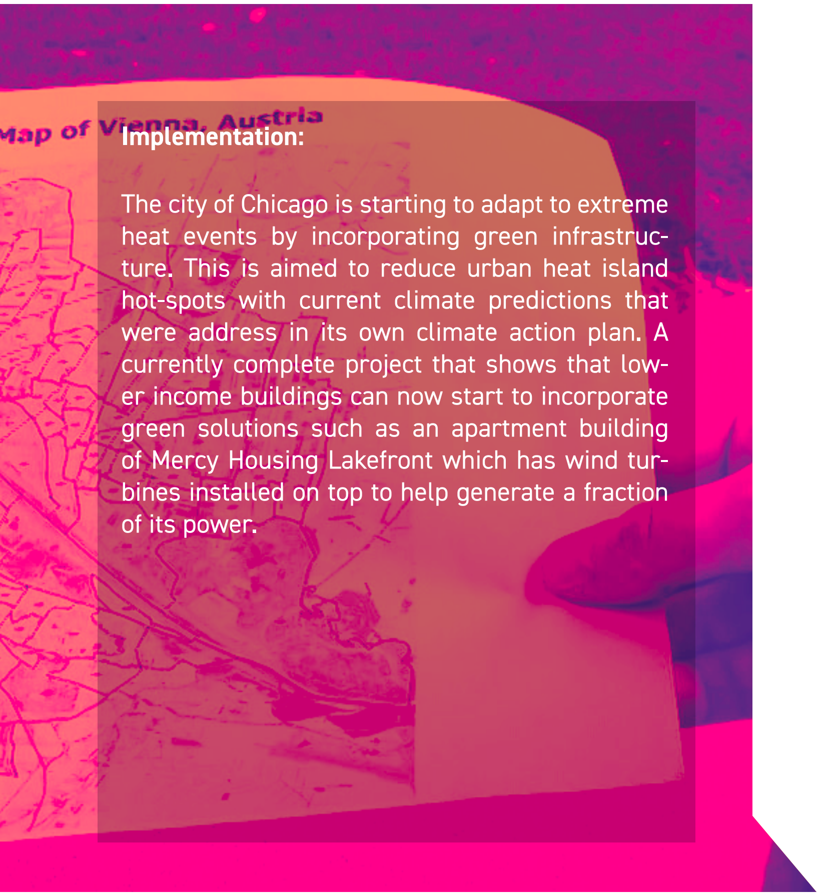
Decription:
Most Environmental Impact Assessments (EIAs) do not take impacts on the urban heat island effect into consideration. Governments should incorporate a new development's adverse effects on its surrounding environment in the context of heat (e.g. building mass, increased pedestrian temperatures, greenhouse gas emissions, etc.) in environmental impact assessments.

Consideration:
To support the transition to an amended EIA, host trainings to educate staff and stakeholders on updated EIA methodologies.

Impact:
Residents will be at the forefront, aiming at risk reduction and mitigation. Metrics of number of people who incorporate heat-resilient considerations.

Benefits:

cost	public good	GHG reduction
● low ○ mid ○ high	● low ○ mid ○ high	○ low ○ mid ○ high



Implementation:

The city of Chicago is starting to adapt to extreme heat events by incorporating green infrastructure. This is aimed to reduce urban heat island hot-spots with current climate predictions that were address in its own climate action plan. A currently complete project that shows that lower income buildings can now start to incorporate green solutions such as an apartment building of Mercy Housing Lakefront which has wind turbines installed on top to help generate a fraction of its power.

MITIGATION

Noun: \ ˌmi-tə-ˌgā-shən
Definition: The action of reducing the severity, seriousness, or painfulness of something. In the context of climate change, mitigation refers to efforts to reduce or prevent the emission of greenhouse gases in order to limit the extent of global warming and its impacts.

Purpose:

Mitigation strategies aim to reduce or prevent the emission of greenhouse gases (GHGs) in order to slow down or halt the progression of climate change or to provide an immediate impact to the improvement of thermal comfort in the built environment.

Focus:

Long-term and Global Impact: Mitigation focuses on actions that have a global benefit, as reducing GHG emissions anywhere in the world helps mitigate climate change overall.

Systemic Changes: This often involves significant changes in energy production, transportation, industry, and land use. Mitigation strategies require shifts toward renewable energy sources, improving energy efficiency, and protecting or restoring carbon sinks like forests.

Preventing Future Damage: While adaptation deals with managing current impacts, mitigation seeks to prevent or lessen future impacts by addressing the cause of climate change.

Categories:

Material: This category focuses on using advanced materials to reduce the absorption and retention of heat in the built environment.

Architecture: Architectural design plays a crucial role in heat mitigation.

Green Infrastructure: Green infrastructure is essential for creating cooler urban environments by using natural systems to combat heat.

Energy: Energy strategies aim to reduce heat production and enhance efficiency.

SHADE STRUCTURES

Description:
Shading structures can provide comfort for pedestrians and also serve as public space. Shade can come from nature-based solutions like trees or manmade structures. Shade can also extend to public transportation lanes and stops (see "Cooled transit stations").

Consideration:
Shade in the form of tree canopy and public space is often disproportionately distributed throughout neighborhoods and areas with vulnerable populations should be prioritized for pilot programs.

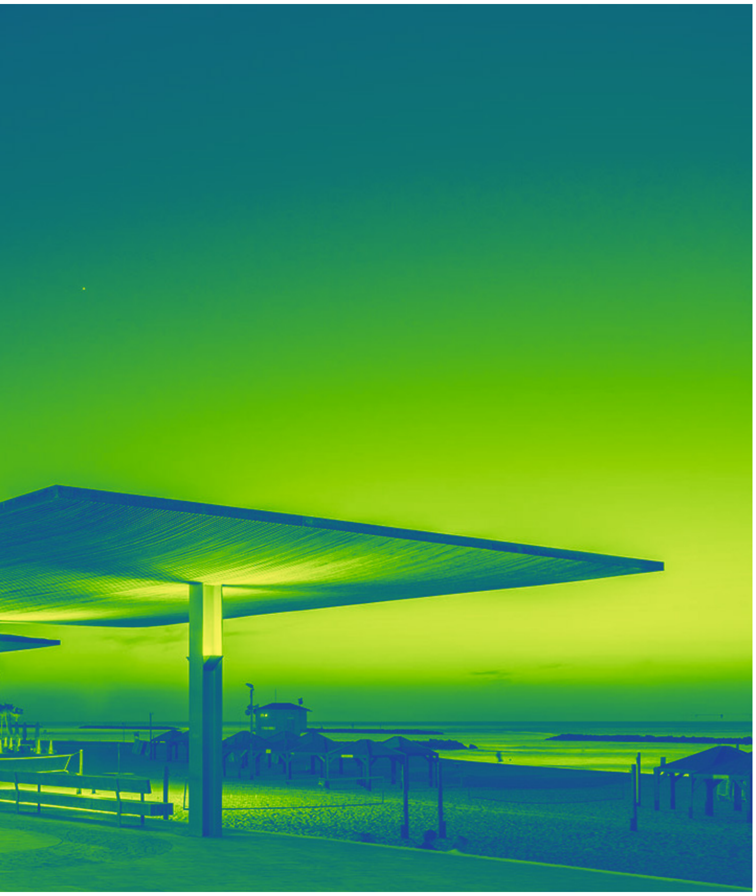
Impact:
Target Beneficiaries: Heat-vulnerable communities, Residents
Phase of Impact: Risk reduction and mitigation
Metrics: Area of increased shading

Benefits:

cost			public good			GHG reduction		
●	○	○	○	○	●	●	○	○
low	mid	high	low	mid	high	low	mid	high

Implementation:

The Central Promenade Renewal project in Tel Aviv, Israel, was designed by Mayslits Kassif Architects. The promenade was extended towards the beach with terraced sitting platforms and large shaded areas, as well as new recreational areas which hold sports facilities, various game courts, playgrounds, and relaxation areas under the palms



PERMEABLE PAVEMENT

Description:
Permeable pavement cools surfaces as stormwater evaporates and decreases the surrounding air temperature. Pavements can be built with vegetation to be attractive to users. Example materials include: porous asphalt, pervious concrete, and permeable paver blocks.

Consideration:
Permeable pavement works best in areas of the public realm with lower traffic and low-to-no polluted water runoff. Cold climates must select permeable pavement carefully to avoid cracking porous pavements. Areas with clay or fine soils may not provide adequate drainage and may require more frequent maintenance than traditional materials. Plants can be grown alongside or in between permeable surfac

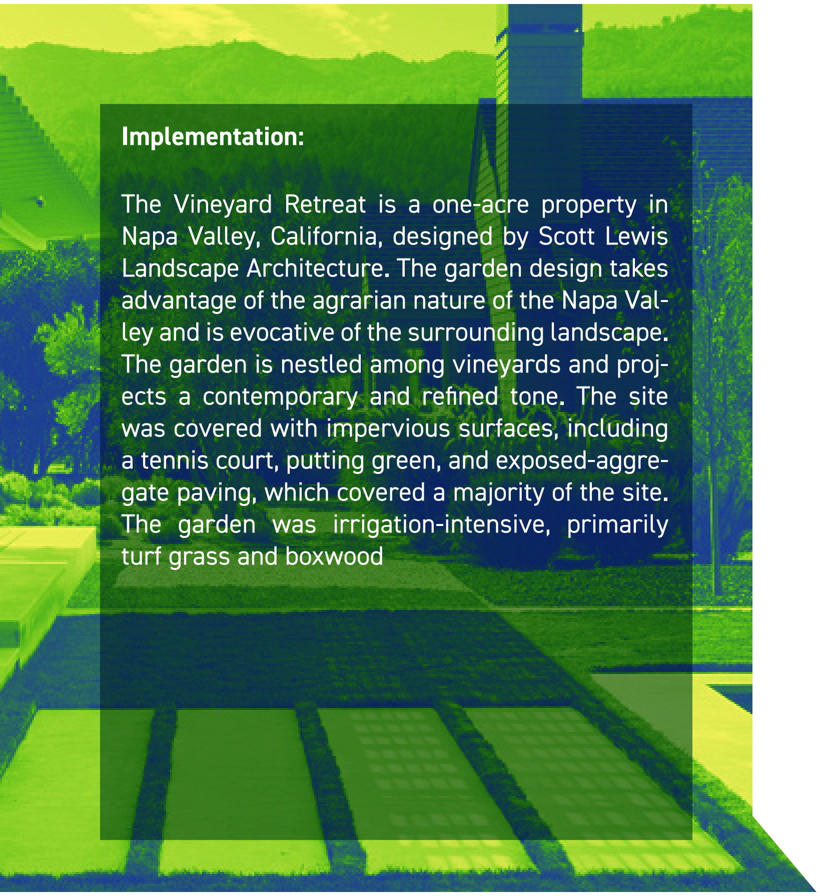
Impact:
Target Beneficiaries: Property owners, Residents
Phase of Impact: Risk reduction and mitigation
Metrics: Total area of permeable paving

Benefits:

cost
● low ○ mid ○ high

public good
○ low ● mid ○ high

GHG reduction
○ low ○ mid ○ high



Implementation:

The Vineyard Retreat is a one-acre property in Napa Valley, California, designed by Scott Lewis Landscape Architecture. The garden design takes advantage of the agrarian nature of the Napa Valley and is evocative of the surrounding landscape. The garden is nestled among vineyards and projects a contemporary and refined tone. The site was covered with impervious surfaces, including a tennis court, putting green, and exposed-aggregate paving, which covered a majority of the site. The garden was irrigation-intensive, primarily turf grass and boxwood

BUILDING ENVELOPES

Description:
High performing building envelopes reduce heat gain as well as heat loss, lowering energy requirements. Materials commonly used to keep buildings warm in colder months also store heat in warmer months (e.g. concrete, tiles, brick, and stone).

Consideration:
This is most applicable to new developments. Improving existing building envelopes is often cost prohibitive, but owners can consider improving insulation and airtightness during major renovations.

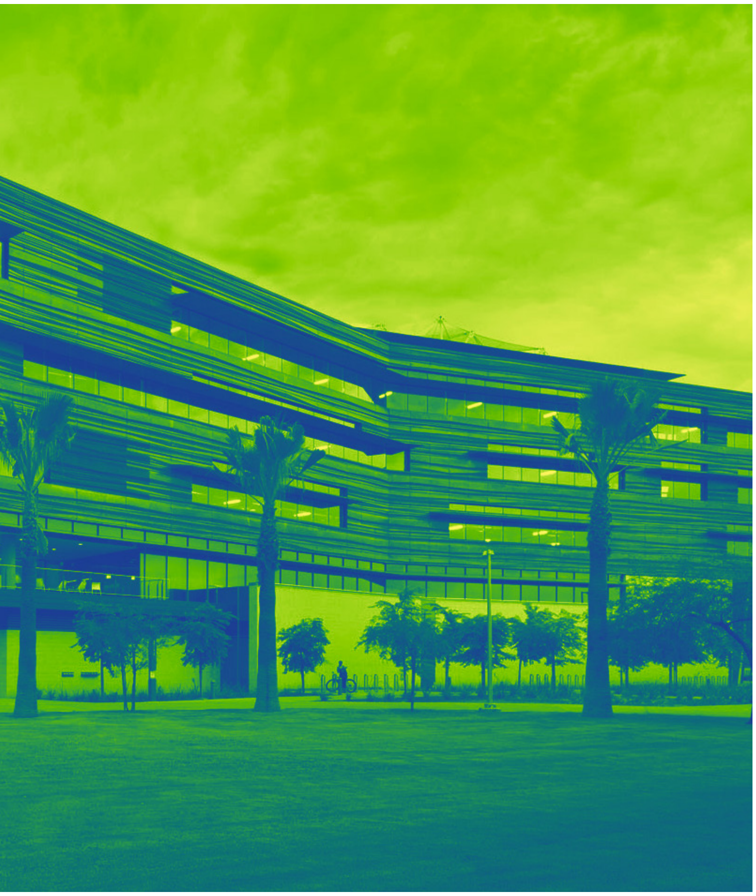
Impact:
Target Beneficiaries: Property owners
Phase of Impact: Risk reduction and mitigation
Metrics: Decrease in building temperatures, Energy savings

Benefits:

cost	public good	GHG reduction
○ ● ○	● ○ ○	○ ○ ●
low mid high	low mid high	low mid high

Implementation:

The Health Sciences Education Building is a building designed by CO Architects located in downtown Phoenix, Arizona. The building's north and south façades feature glazed curtainwalls with sunshades to reduce heat gain inside the building.



Implementation:

Maraya Concert Hall in Al Atheeb, Saudi Arabia, is a famous building with reflective coatings and light-colored materials. It is the world's largest mirror-clad building and was constructed by The Royal Commission for AlUla (RCU) using a first-of-its-kind solution, designed specifically for the project, by Guardian Glass1. The building's name, Maraya, means reflection or mirror in Arabic

LIGHT-COLORED MATERIAL

Description:
Light-colored materials and reflective coatings or overlays serve to reflect heat instead of absorbing and retaining it. In addition to decreasing temperatures, these treatments can also extend the pavement lifetime.

Consideration:
Consider who uses the pavements, how, and what is surrounding the area to determine if reflective pavements are appropriate to implement. Local technology and product availability may also determine implementation cost.

Impact:
Target Beneficiaries: Heat-vulnerable communities, Property owners, Residents
Phase of Impact: Risk reduction and mitigation
Metrics: Total area repaved

Benefits:

cost			public good			GHG reduction		
●	○	○	○	●	○	●	○	○
low	mid	high	low	mid	high	low	mid	high

COOL ROOFS AND WALLS

Description:
Cool walls and roofs apply treatments to building facades to reduce the solar absorption of a building's walls, which can reduce the urban heat island effect.

Consideration:
Cool walls are less effective in colder climates that have greater heating needs in the colder months. Cool walls are best suited to buildings with low roof-to-wall and window-to-wall ratios. Additional research is needed to evaluate effectiveness of cool walls in dense areas.

Impact:
Target Beneficiaries: Property owners, Residents
Phase of Impact: Risk reduction and mitigation
Metrics: Energy savings by building, Indoor air temperature reductions, Number of buildings compliant with provision, Outdoor ambient air temperature

Benefits:

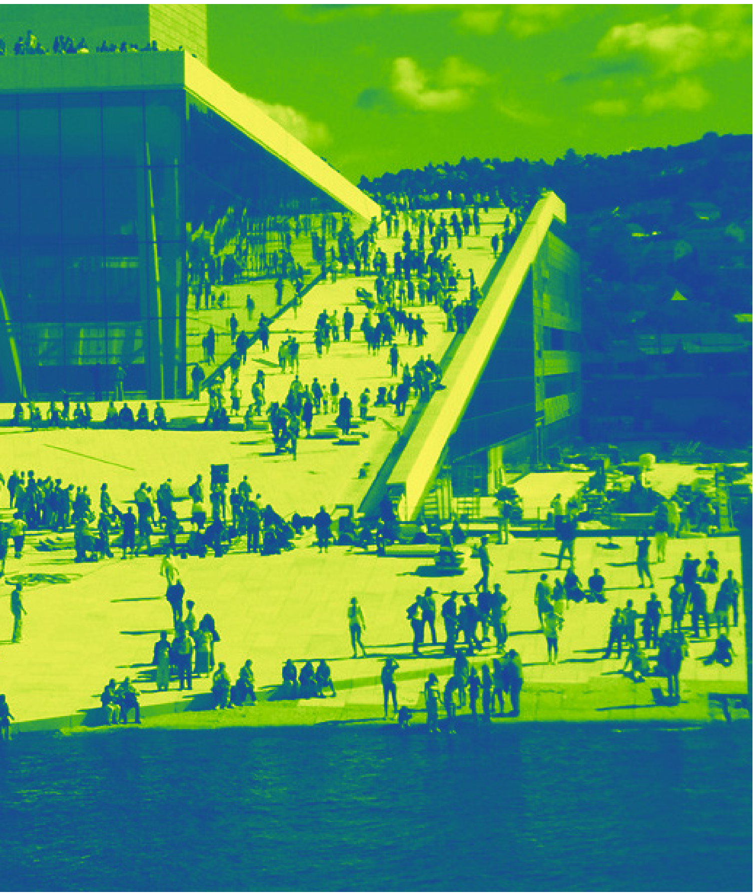
cost
● low ○ mid ○ high

public good
● low ○ mid ○ high

GHG reduction
○ low ● mid ○ high

Implementation:

Oslo Opera House uses cool roofs and walls to reduce temperature. The walk to reach the highest point of the Oslo Opera House roof is a series of gently-sloping ramps, all laid out with interlocking blocks of white, light gray or pale salmon marble, and lined with generous, low walls that serve as resting points and places to just take a moment to take in all the surrounding beauty .



BUILDING ORIENTATION

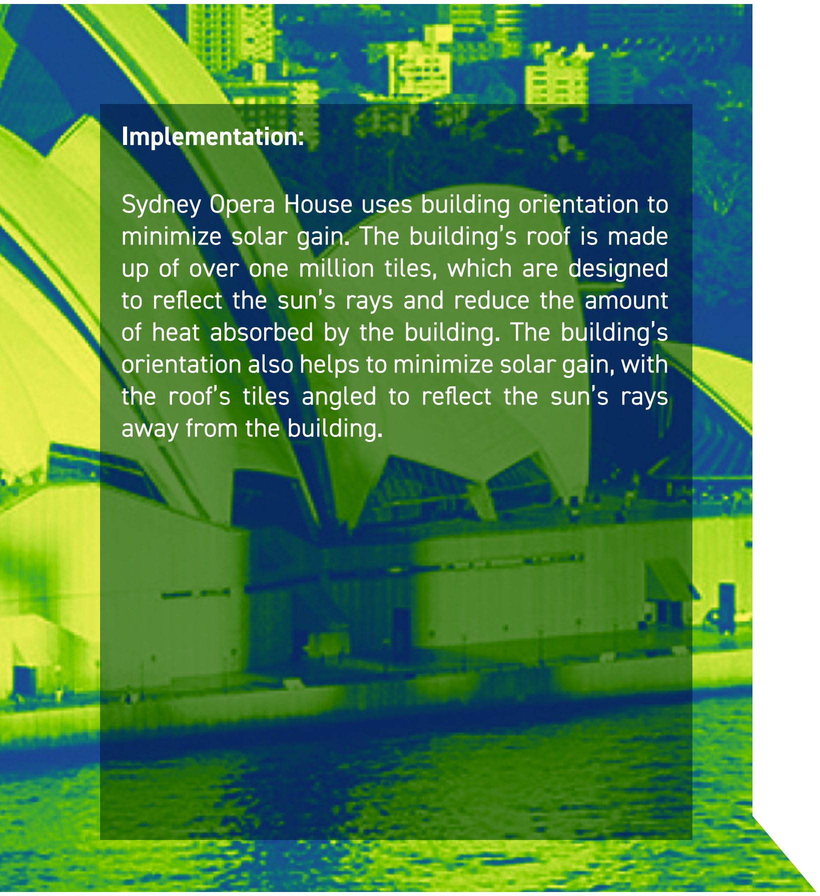
Description:
Doors and windows can be oriented to minimize solar heat gain, increase ventilation, and provide strategic shade for outdoor public spaces.

Consideration:
This is only applicable to new developments.
Policy Levers: Mandate
Trigger Points: City planning processes Introducing new or updated zoning/codes
Intervention Type: Buildings and Built Form
Sectors: Buildings

Impact:
Target Beneficiaries: Property owners, Residents
Phase of Impact: Risk reduction and mitigation
Metrics: Decrease in surface temperature, Energy savings

Benefits:

cost			public good			GHG reduction		
●	○	○	●	○	○	●	○	○
low	mid	high	low	mid	high	low	mid	high



Implementation:

Sydney Opera House uses building orientation to minimize solar gain. The building's roof is made up of over one million tiles, which are designed to reflect the sun's rays and reduce the amount of heat absorbed by the building. The building's orientation also helps to minimize solar gain, with the roof's tiles angled to reflect the sun's rays away from the building.

EXTERIOR BUILDING SHADE

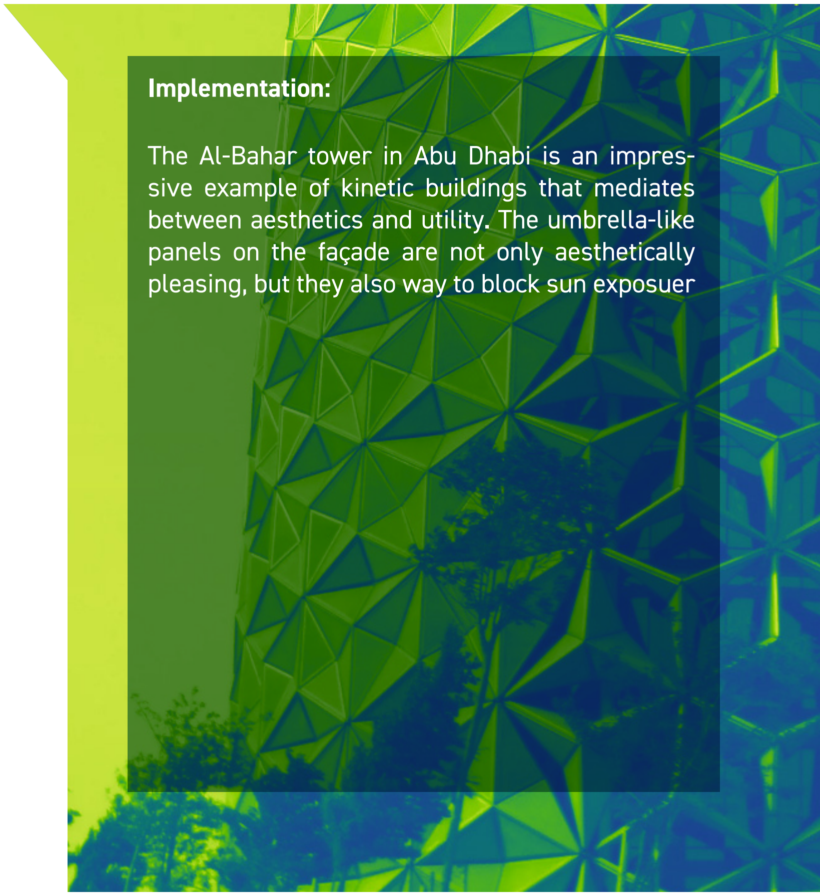
Description:
Exterior shading block solar exposure and can lower building temperatures and reduce the need for air conditioning. Examples include awnings or window attachments.

Consideration:
Shadings can be permanent or mobile depending on the climate and constraints.

Impact:
Target Beneficiaries: Property owners, Residents
Phase of Impact: Risk reduction and mitigation
Metrics: Number of buildings with shading structures

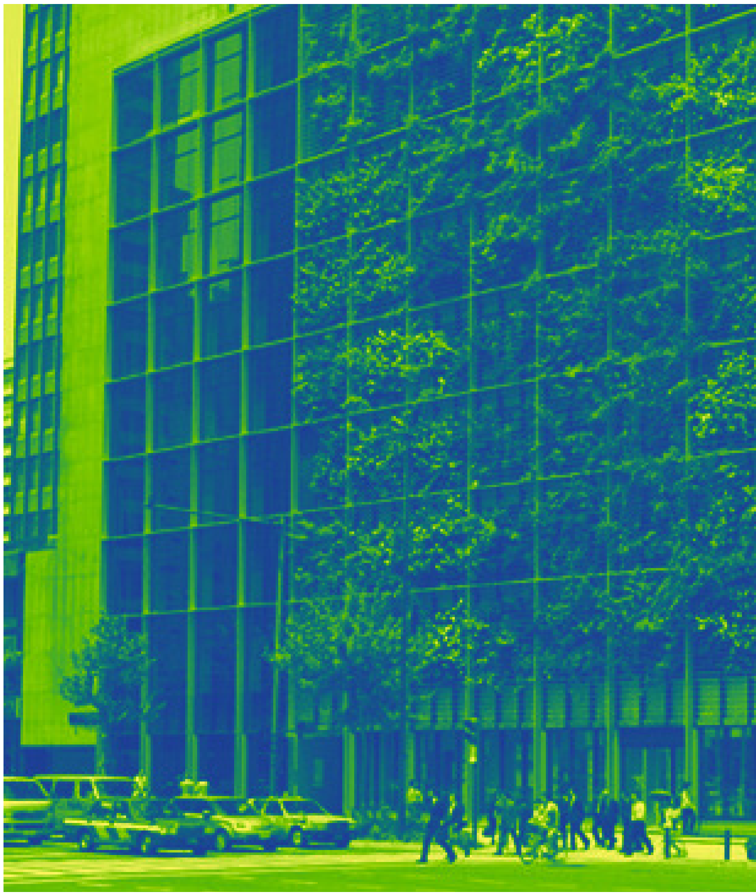
Benefits:

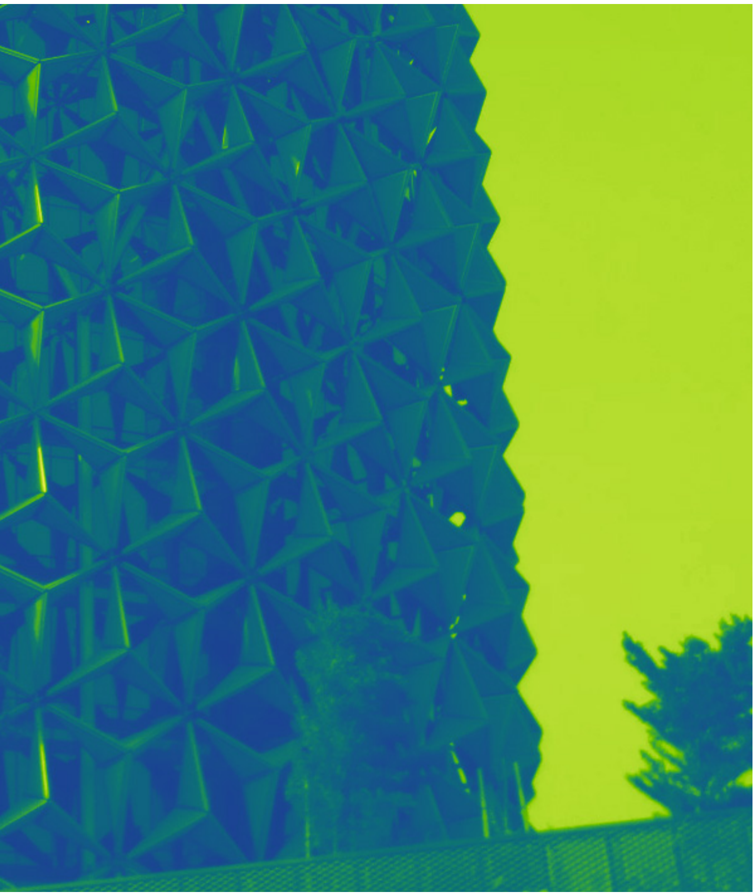
	low	mid	high
cost	●	○	○
public good	●	○	○
GHG reduction	●	○	○

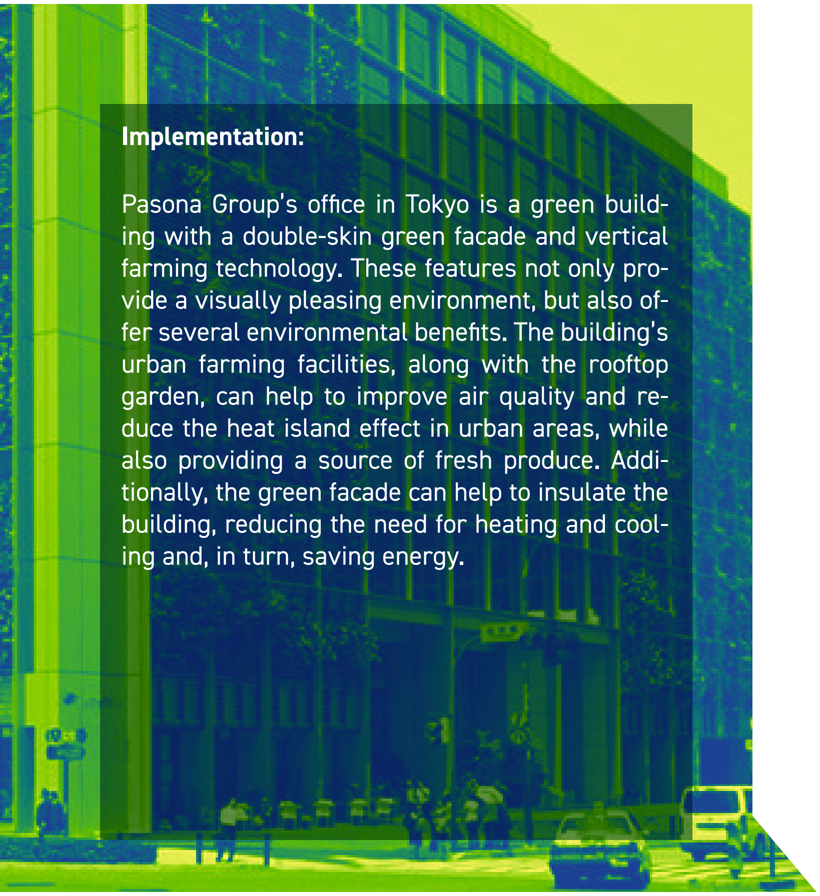


Implementation:

The Al-Bahar tower in Abu Dhabi is an impressive example of kinetic buildings that mediates between aesthetics and utility. The umbrella-like panels on the façade are not only aesthetically pleasing, but they also way to block sun exposuer







Implementation:

Pasona Group's office in Tokyo is a green building with a double-skin green facade and vertical farming technology. These features not only provide a visually pleasing environment, but also offer several environmental benefits. The building's urban farming facilities, along with the rooftop garden, can help to improve air quality and reduce the heat island effect in urban areas, while also providing a source of fresh produce. Additionally, the green facade can help to insulate the building, reducing the need for heating and cooling and, in turn, saving energy.

GREEN BUILDING

Description:
Green building practices and energy efficiency standards improve building performance that reduce solar gains, energy consumption, and urban heat islands.

Consideration:
Resources associated with ratings and certifications can provide upgrade recommendations that are applicable to all buildings not only participating buildings.

Impact:
Target Beneficiaries: Property owners, Residents
Phase of Impact: Risk reduction and mitigation
Metrics: Number and scores or levels of certification for buildings that receive ratings

Benefits:

cost
● low ○ mid ○ high

public good
○ low ○ mid ○ high

GHG reduction
○ low ○ mid ● high

URBAN FORESTRY

Description:
Trees provide cooling through evapotranspiration and shading that decreases temperatures along walkways. Increasing vegetation provides numerous co-benefits like reducing pollution, improving the public realm, and decreasing energy costs. The goals of an urban forestry plan is to look at existing tree canopy coverage and identify strategies to expand coverage. Creating an urban forestry plan is an important step to align different departments to address possible disparities in tree canopy coverage, protect biodiversity, and provide efficient maintenance.

Consideration:
Urban forestry plans need to select native species that recognize local context's water needs. Trees can increase fire risk depending on climate and environmental context. Plantings require ongoing maintenance with associated costs and staffing. Urban forestry and street plans can be piloted in high priority neighborhoods or neighborhoods undergoing rezonings.

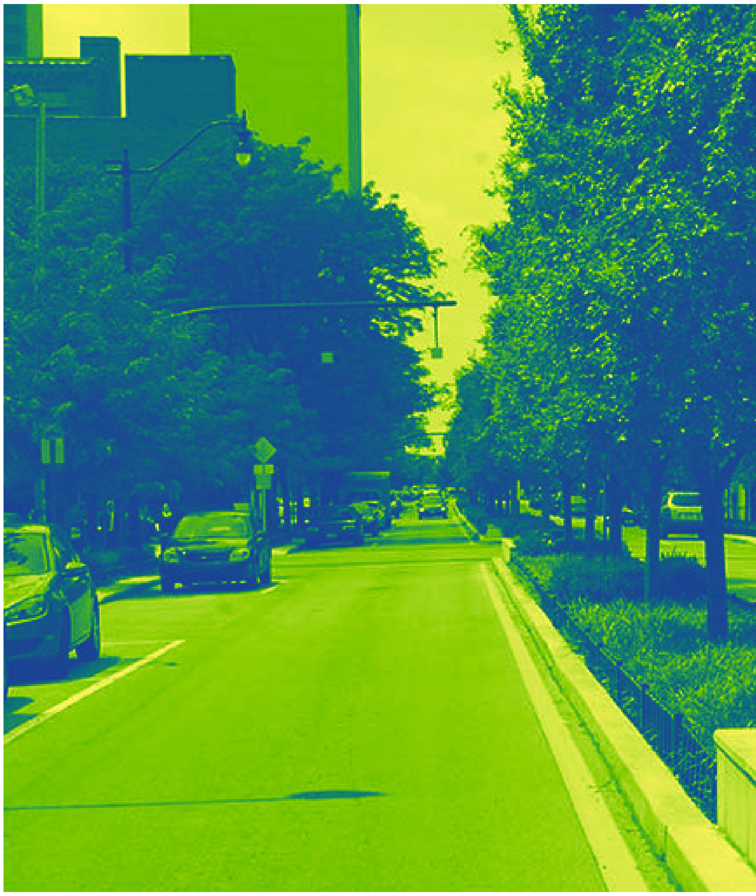
Impact:
The change in urban canopy catalyzed by this commitment would help residents in a community, property owners, and heat-vulnerable communities in general. Heat risk reduction and mitigation would improve overall safety, comfort, maintenance costs, and increase property value.

Benefits:

cost	public good	GHG reduction
○ low ● mid ○ high	○ low ○ mid ● high	● low ○ mid ○ high

Implementation:

As Melbourne, Australia faces significant challenges due to global climate change, they have continued to develop an urban forestry strategy for the city. The strategy aims to mitigate heat island effect, create healthy ecosystems, and engage the community, among other things. Goals in this strategy include an 18% increase in canopy cover by 2040 and other biodiversity metric goals, all while informing and consulting with the community.



TREE PROTECTION

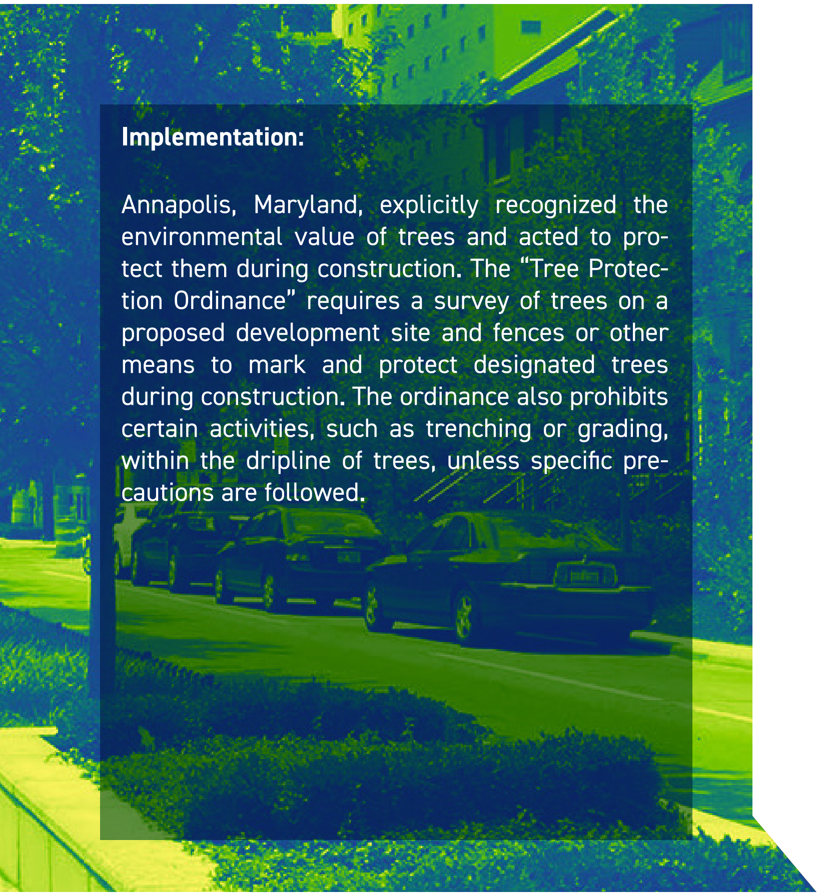
Description:
Trees provide cooling through evapotranspiration and shading that decreases temperatures along walkways. Increasing vegetation provides numerous co-benefits like reducing pollution; improving the public realm; and decreasing energy costs. A tree protection program protects the relocation and replacement of specific trees through the building code. The code can require documentation of existing trees and requiring permitting or fees for removal.

Consideration:
This mandate is most effective in areas with high property turnover rates to protect existing trees from the change in stylistic ideals.

Impact:
This mandate would improve the odds of trees in our communities reaching maturity, even when urban development around them is constantly changing. This would help protect heat-vulnerable communities through reducing the heat island effect caused by gray infrastructure, ultimately creating a more comfortable environment along streets and trails.

Benefits:

cost	public good	GHG reduction
● low ○ mid ○ high	○ low ○ mid ● high	○ low ● mid ○ high



Implementation:

Annapolis, Maryland, explicitly recognized the environmental value of trees and acted to protect them during construction. The “Tree Protection Ordinance” requires a survey of trees on a proposed development site and fences or other means to mark and protect designated trees during construction. The ordinance also prohibits certain activities, such as trenching or grading, within the dripline of trees, unless specific precautions are followed.

PARKS AND OPEN SPACE

Description:
Converting vacant, non-vegetated land into parks and open spaces is a heat mitigation strategy that cools the surrounding temperature and also provides social co-benefits.

Consideration:
Parks can be capitally intensive to design and construct; but offer many opportunities for funding through increased property values and financing solutions. Parks require ongoing maintenance.

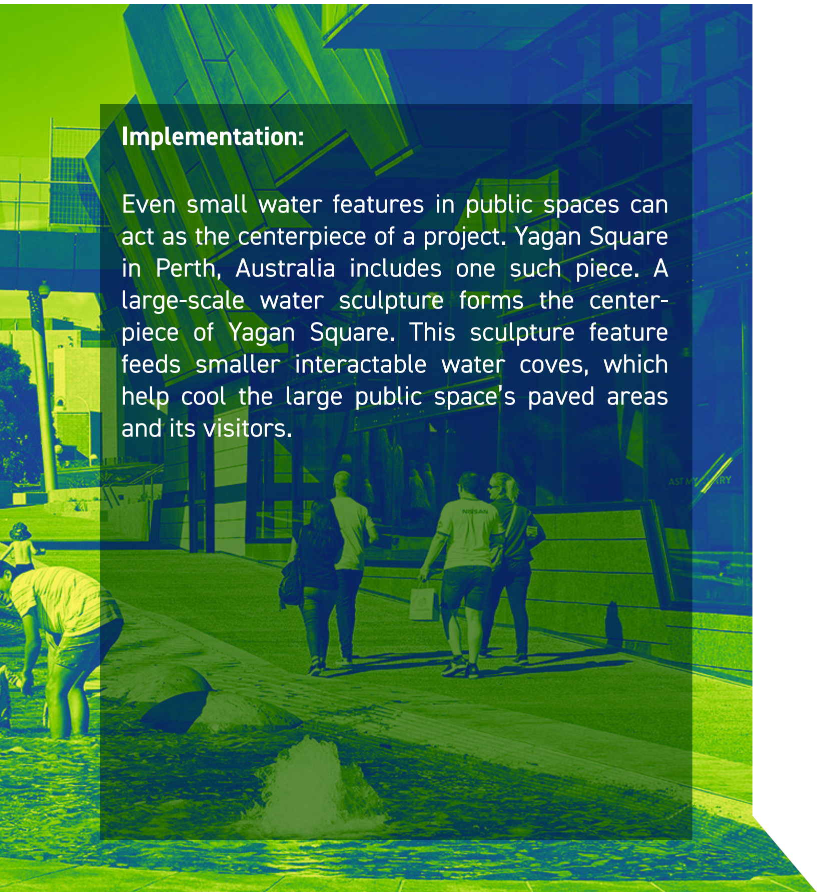
Impact:
Increased number of parks and publicly available green space within urban environments will help with urban heat island effect. This would also provide vital gathering spaces, that are free of charge, for community members and groups.

Benefits:

cost	public good	GHG reduction
○ low ● mid ○ high	○ low ○ mid ● high	○ low ● mid ○ high

Implementation:

In 2019, London became the first national park city, having around 50% green and blue space throughout the city. The London National Park City movement aimed to improve the lives of residents through public park space, biodiversity, and ecological outreach programs. This was accomplished through cooperation between citizens, visitors, and partners, all in the hopes that everybody can enjoy London's great outdoors.



Implementation:

Even small water features in public spaces can act as the centerpiece of a project. Yagan Square in Perth, Australia includes one such piece. A large-scale water sculpture forms the centerpiece of Yagan Square. This sculpture feature feeds smaller interactable water coves, which help cool the large public space's paved areas and its visitors.

PUBLIC WATER FEATURES

Description:
Public water features provide cooling and hydration to people during heatwaves. Examples include hydration stations, drinking fountains, urban rivers, and recreational water features.

Consideration:
Water features may raise humidity. Building water features is ideal for areas with air movement and dry air. Areas that are drought-sensitive may consider spray parks over pools/larger bodies of water. Cities that use sprinklers to irrigate parks can publicize times to allow children to play. Regular maintenance and monitoring is required in order to manage water quality and consumption. Cities should conduct water quality checks, safety reviews, and provide adequate signage. Create a map to identify public water structures and share relevant information.

Impact:
The implementation of public water features within public space can help reduce risk during heat waves. The cooling effect water features have their surroundings can increase attraction, resiliency, and productivity in large public spaces devoid of shade or air flow.

Benefits:

cost	public good	GHG reduction
○ low ● mid ○ high	○ low ● mid ○ high	○ low ○ mid ○ high

COMMUNITY GARDENS

Description:
Converting vacant, non-vegetated land into community gardens can provide social and economic benefits in addition to mitigating local temperatures. Soil in garden spaces or raised beds can trap sunlight and heat during warmer months.

Consideration:
Community gardens require basic infrastructure to operate (e.g. water supply) and provide opportunities for community engagement, partnership, and education.

Impact:
Community based gardens have both educational and social impacts on a community. Produce from community gardens may be used by impoverished households, elementary schools, or sold at community markets. Working together in urban agriculture can teach youth in the community about self-sufficiency and patience.

Benefits:

	low	mid	high
cost	●	○	○
public good	○	○	●
GHG reduction	○	●	○

Implementation:

Measuring a total of 5,000 square feet, one of New York city's largest urban farm is located in the Urby Staten island residential development. The garden is run by growNYC, an organization that provides free tools and services for DIY gardeners. Produce from the farm, included 50 varieties, is used by residents, served in the kitchen, and sold at the local farmer's market and in the bodega.

GREEN ROOFS

Description:
Green roofs cool the surrounding air and reduce building heat through a layer of vegetation or other plants. Green roofs can also serve as additional green space. There are two main types of green roofs: intensive and extensive.

Consideration:
Green roofs need sufficient structural support and do not work on steep-sloped roofs. Green roofs require maintenance and upkeep every year. Roofs that are open to the public require safety precautions. Intensive green roofs provide more co-benefits (such as stormwater management) are much heavier than extensive roofs and require more structural support, irrigation, and fertilization as well as additional maintenance. Green roofs are generally more feasible and cost-effective in new construction versus retrofits. Given the costs required to install and maintain green roofs, requirements to install them must be carefully considered.

Impact:
Incentivized green roofs can impact the community in diverse ways through area cooling, efficient energy consumption, and reclaiming unused space.

Benefits:

	low	mid	high
cost	○	○	●
public good	○	●	○
GHG reduction	○	●	○

Implementation:

The green roof company LiveRoof specializes in installing fully grown green roof modules. These modules arrive have soil depths ranging from 2.5 to 8 inches, depending on module size. Designers and contractors have creatively used LiveRoof for instant intensive-extensive green roofs.Contractors may place LiveRoof modules inside of precast concrete, fiberglass or sheet metal planters to provide the visual effect of a much deeper green roof, but without adding excessive weight load to the roof.

WALKABILITY AND COOL CORRIDORS

Description:
Green and blue infrastructure immediately adjacent and parallel to prevailing winds cools corridors. Incorporating additional urban design principles in zoning can be used to optimize natural wind flow for cooling and prevent heat from radiating from other buildings. Combining this with pathway shading makes walking a more feasible mode of transit in an urban environment.

Consideration:
This is most applicable to new developments and is harder to implement in existing, highly dense areas. Natural landscape features like hills, valleys, or bodies of water can also function as ventilation corridors. The 'greenway' typology is one way in which areas such as abandoned streets and railways can be transformed into a pedestrian network that meets with key zones of a city.

Impact:
Cool corridors decrease the surface temperature of paved areas, creating a compromise between efficiency and comfort. Having shorter walks in dense urban settings be more comfortable, the use of public transport systems that drop off at one station is likely to see an increase.

Benefits:

cost			public good			GHG reduction		
○	○	●	○	○	●	●	○	○
low	mid	high	low	mid	high	low	mid	high

Implementation:

The "Goods Line" project in Sydney, Australia is an elevated pathway and park space that acts as a key connection point within the area. It acts as an overpass for pedestrians, with the heat radiated from streets below being mitigated by its green space and encompassing canopies. The 'social infrastructure' of the Goods Line makes the space into an energized civic spine of Sydney's most densely populated area.

MICROGRIDS

Description:
During extreme heat waves, electric grids are often pushed to their limits because of increased demand for mechanical cooling causing power outages. Microgrids are decentralized electricity grids that can supply energy to the main grid or directly to communities. Microgrids help reduce strain on the main grid while providing a reliable and renewable source of energy.

Consideration:
Microgrids need to be maintained regularly to protect equipment. Consider partnering with CBOs to explore different ownership and operational models.

Impact:
This strategy aims to increase the amount of energy provided by microgrids and the number of buildings served by a microgrid. This will effectively reduce the risk of full city power shutdowns, ensuring the issue is contained and solved efficiently. During severe heat events, this will limit the amount of time where air ventilation and conditioning if shut down.

Benefits:

cost
○ low ○ mid ● high

public good
○ low ● mid ○ high

GHG reduction
○ low ● mid ○ high

Implementation:

California's Microgrid Incentive Program's (MIP) implementation program was passed in 2021. Through incorporating feedback from previous workshops, MIP developed a system to provide funding for the community to implement microgrid reliability and resilience projects. Benefits for these communities included reduced risk of electrical outages, increased reliability on electricity use in hospitals, schools and firehouses, and reduced greenhouse gas emissions by deploying clean generation technologies.

ELECTRIC VEHICLE INFRASTRUCTURE

Description:
Installing and distributing charging stations throughout an area can aid adoption of electric vehicles among residents. These stations should be easily found within parking lots, near gas stations, and displayed on GPS mapping platforms.

Consideration:
The public and private sector can partner to increase efficiency and expand the reach of efforts to provide electric vehicle chargers.

Impact:
By increasing the number and density of charging stations within a city, the feasibility of owning an electric vehicle increases. This both gives residents the choice to reduce their daily emissions and acts as a reminder of how the city is trying to improve their localized climate through heat island effect mitigation.

Benefits:

	cost	public good	GHG reduction
low	○	○	○
mid	●	●	○
high	○	○	●

Implementation:

In September of 2022, the the National Electric Vehicle Infrastructure (NEVI) program was approved by the United States government. This gives all states funding to build EV chargers, covering approximately 75,000 miles of highway across the country. This funding effort aims to help build a convenient, reliable, and affordable EV charging network throughout the US.

DISTRICT COOLING

Description:
District cooling can replace distributed cooling systems, resulting in up to 50% lower energy and emissions impact. These cooling systems move chilled water to buildings without contributing to the urban heat island effect like mechanical cooling.

Consideration:
There are many trade-offs associated with district cooling. Benefits include lower energy consumption, shifting cooling loads, increased reliability, and reduced capital costs in building development. District cooling requires high upfront capital costs to build the infrastructure and it must be implemented in high-density or new construction zones to be financially feasible.

Impact:
Target Beneficiaries: Property owners, Residents
Phase of Impact: Risk reduction and mitigation
Metrics: Energy savings

Benefits:

cost	○ low	○ mid	● high
public good	○ low	● mid	○ high
GHG reduction	○ low	○ mid	● high

Implementation:

Qatar Cool is the leading district cooling company in Qatar, with The United Development Company (UDC) as the majority shareholder. Since its inception in 2003, Qatar Cool has aimed for operational excellence in every aspect of its business. Qatar Cool provides an invaluable feature to The Pearl-Qatar's advanced infrastructure. The Integrated District Cooling Plant was specially commissioned for this community. With a capacity of 130,000 Tons of Refrigeration, it is the largest district cooling plant in the world

WASTE HEAT REDUCTION

Description:
Waste heat contributes to the urban heat island effect and has been linked to overall warming. Heat pumps and heat recovery chillers can move heat to different locations to be applied to other uses instead of being vented directly onto the street.

Consideration:
Waste heat reduction can happen through many of the solutions in this toolkit like district cooling, weatherization, mechanical cooling, among others.

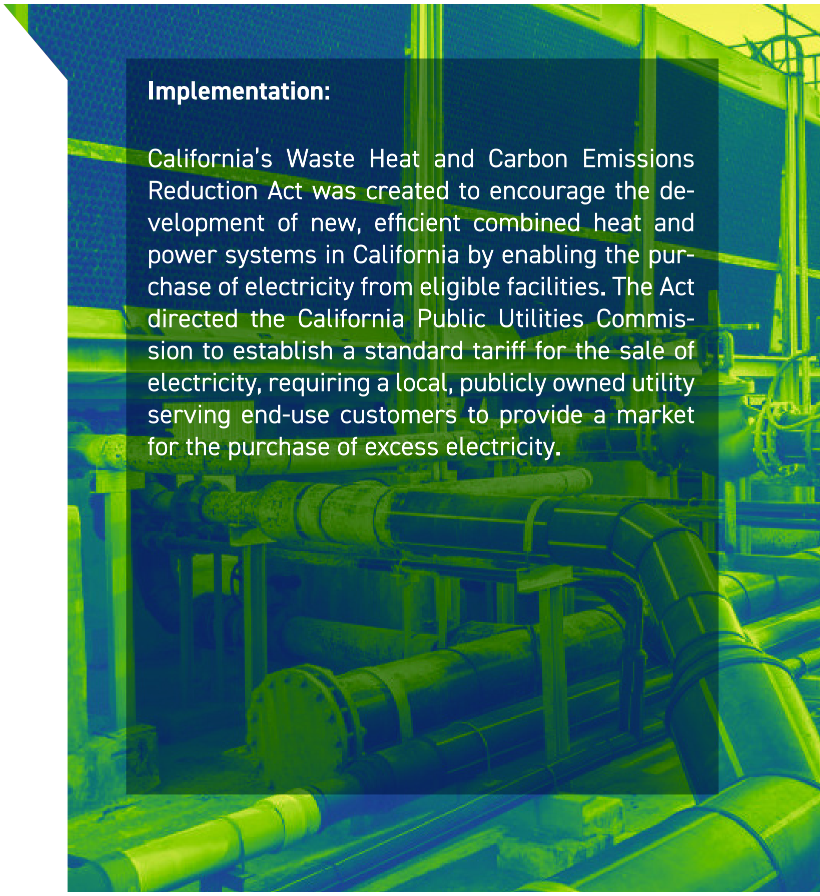
Impact:
Reducing the amount of heat wasted by venting would help save energy consumption costs. As an incentive strategy, manufacturers may be able to acquire funding for heat reuse systems.

Benefits:

cost
○ low ○ mid ● high

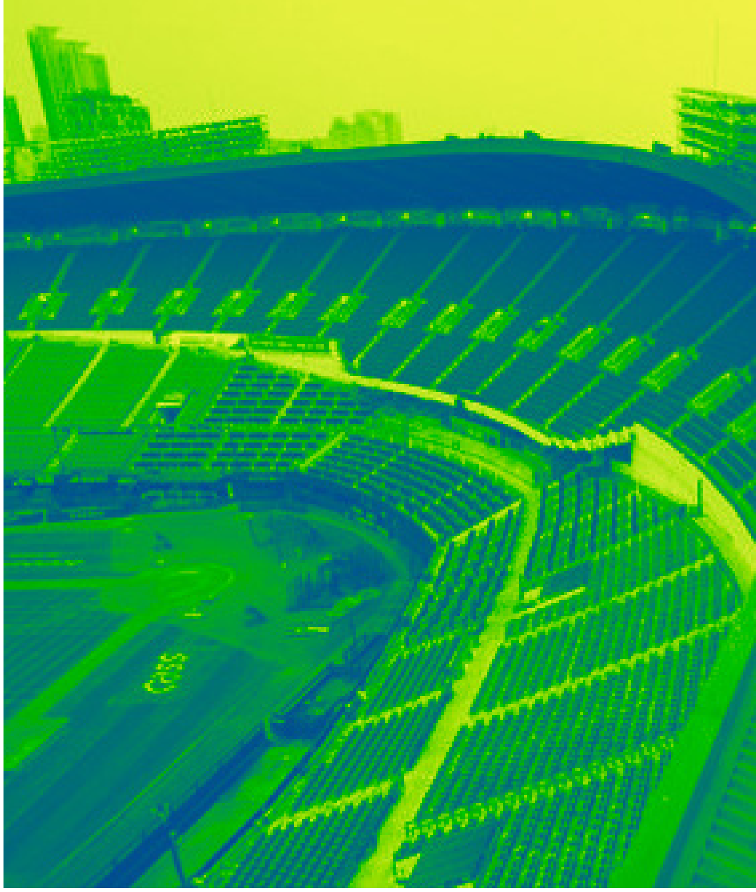
public good
○ low ○ mid ○ high

GHG reduction
○ low ○ mid ● high



Implementation:

California's Waste Heat and Carbon Emissions Reduction Act was created to encourage the development of new, efficient combined heat and power systems in California by enabling the purchase of electricity from eligible facilities. The Act directed the California Public Utilities Commission to establish a standard tariff for the sale of electricity, requiring a local, publicly owned utility serving end-use customers to provide a market for the purchase of excess electricity.



SOLAR PANELS

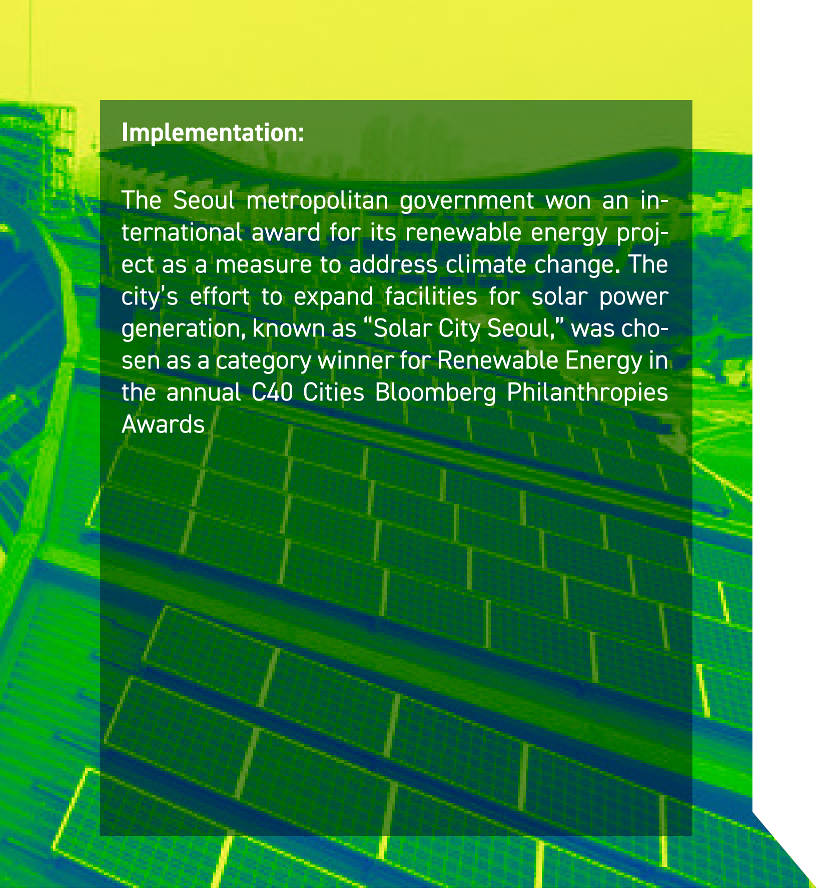
Description:
Installing solar panel systems on rooftops provide the dual benefits of providing renewable energy as well as direct cooling to buildings. The energy produced by solar energy can help offset energy costs for air conditioning.

Consideration:
Solar panels can be applied in a diversity of climates and contexts with low maintenance costs. Upfront capital costs to buy and install solar panels is typically prohibitive or a deterrent for lower-income households.

Impact:
Target Beneficiaries: Property owners, Residents
Phase of Impact: Risk reduction and mitigation
Metrics: Amount of energy produced by solar energy

Benefits:

cost			public good			GHG reduction		
●	○	○	●	○	○	○	●	○
low	mid	high	low	mid	high	low	mid	high



Implementation:

The Seoul metropolitan government won an international award for its renewable energy project as a measure to address climate change. The city's effort to expand facilities for solar power generation, known as "Solar City Seoul," was chosen as a category winner for Renewable Energy in the annual C40 Cities Bloomberg Philanthropies Awards

03

METHODS FOR VISUALIZING HEAT

Understanding and visualizing urban heat is a critical step in addressing the growing challenge of extreme heat in cities. The methods and tools available for this purpose have advanced significantly, enabling planners, designers, and researchers to gain nuanced insights into how heat is distributed and experienced across different urban landscapes. This section, "Methods for Visualizing Heat," provides an overview of various techniques and technologies that can be employed to map, analyze, and communicate thermal patterns in urban environments.

				SCALE			PHASE		
VISUALIZATION TOOL	**DESCRIPTION**	**ASSESSMENT**	**TOOLS**	**REGIONAL**	**NEIGHBORHOOD**	**SITE**	**PRE-DESIGN**	**DESIGN**	**POST-DESIGN**
LANDSAT IMAGERY/GIS DATA	Satellite imagery used to map surface temperature and land cover.	Land surface temperature, Land cover classification	GIS software (e.g., ArcGIS, QGIS), Landsat imagery, Tree Equity Score (TES)	●	●		○		
UAV INFRARED THERMOGRAPHY	Use of drones equipped with infrared cameras to capture high-resolution thermal images.	Material surface temperature, infrared radiation (IR)	UAVs, infrared cameras (e.g., FLIR)		●	●	○		○
HANDHELD THERMOGRAPHY	Portable infrared cameras to measure temperature variations on the ground level.	Material surface temperature, infrared radiation (IR)	Handheld infrared cameras (e.g., FLIR)		●	●	○		○
MOBILE BIOMETEOROLOGICAL INSTRUMENT PLATFORM	Mobile units equipped with sensors to measure various environmental parameters that comprise mean radiant temperature.	Air temperature (°C), humidity (%), wind speed (m/s). Mean Radiant Temperature, 6-directional method for obtaining average temperature of all surfaces surrounding a person, including walls, floors, and objects.	Mobile meteorological stations (e.g. MaRTy)			●	○		
VEHICLE-TRAVERSE COLLECTION	Thermocouples mounted on vehicles to measure temperature while driving through different areas.	Air temperature	Vehicles, thermocouple sensors		●	●	○		
ENVIRONMENTAL SIMULATION	Simulation software to model and predict microclimatic conditions in urban environments.	Temperature (°C), wind flow (m/s), humidity (%)	ENVI-met software, Grasshopper plugins (e.g. Ladybug, Honeybee)		●	●	○	○	
COMMUNITY ENGAGEMENT/HEAT WALKS	Engaging with the community to collect temperature data and identify heat-affected areas.	Perceived temperature, community feedback, qualitative data	Surveys, mobile apps, handheld thermometers		●	●	○	○	○

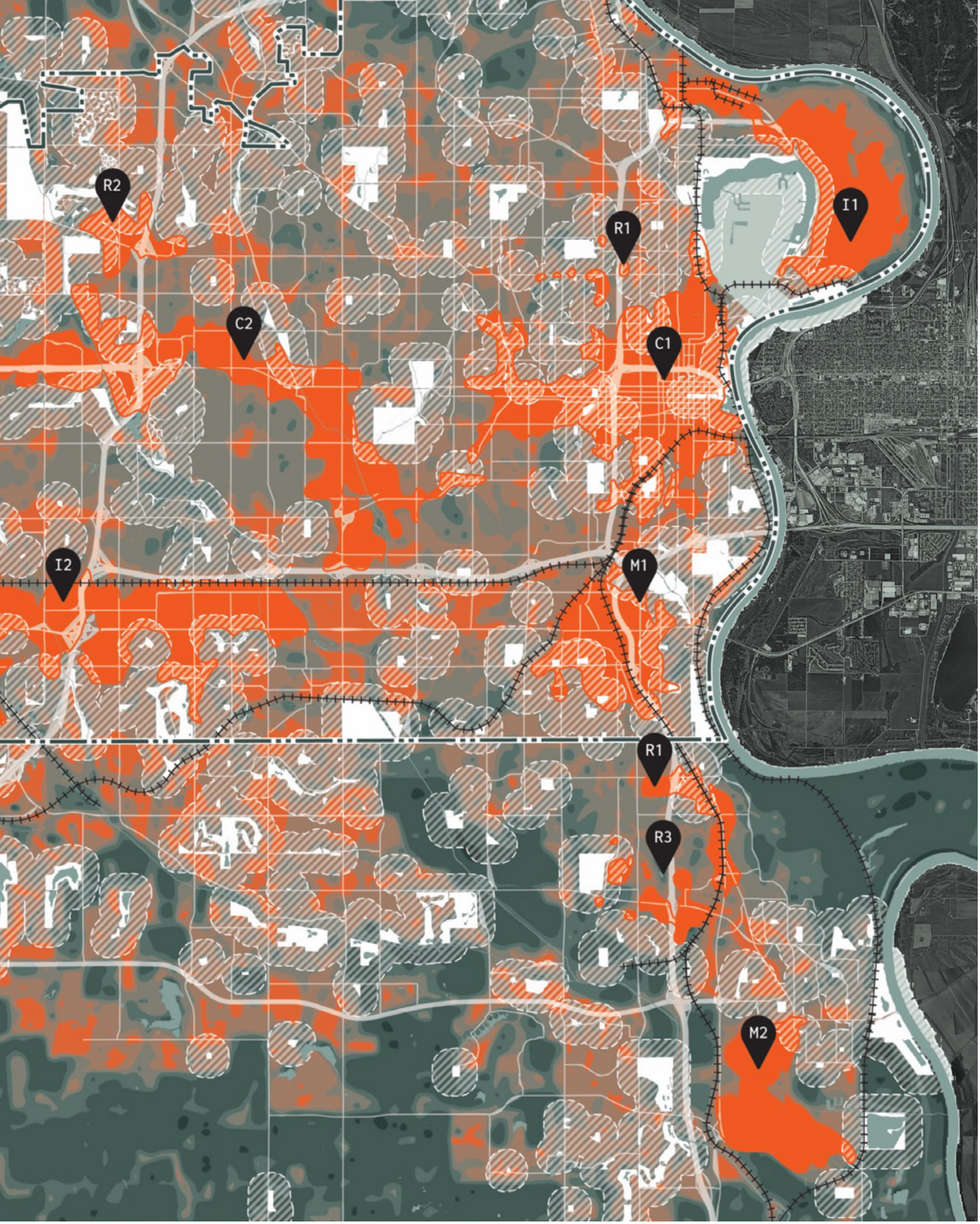
Heat visualization methodologies table.

TOOLS / TECHNIQUES

The tools and techniques for visualizing heat collected as part of this section are not all-inclusive of every method available. We selected these methods due to their commercial accessibility and availability of research documentation. Future research may include a formal methodology, (e.g. systematic literature review) to understand and quantify the prevalence of these visualization methods in contemporary literature.

In this section, we provide an overview of various approaches to mapping and visualizing heat, from satellite-based tools like LANDSAT imagery and GIS data, which provide broad, high-resolution thermal snapshots, to more localized approaches such as UAV infrared thermography and handheld thermography, each method offers unique advantages for understanding heat dynamics. Mobile biometeorological platforms and vehicle-mounted thermocouple sensors allow for dynamic and real-time heat mapping, capturing the complexity of thermal environments in motion. Environmental simulations, such as those performed with ENVI-met software, enable the modeling of future scenarios and the impact of potential interventions. Moreover, community engagement methods like heat walks, and tools like the Sky View Factor (SVF) and shade analysis add a vital human dimension to the scientific data, ensuring that the experiences and needs of those most affected by urban heat are considered in the planning process.

With each method, you will find a description, case study, and an indication of the appropriate phase/scale in which the method is most applicable. The LAF and CELA funded research allowed us the opportunity to explore Landsat and handheld/UAV thermography in greater detail, which is reflected in the case studies presented. Our hope was that by presenting these methods in an organized manner, we could encourage planners and designers to incorporate heat visualization methods into the design process, thereby acknowledging thermal disparities, and catalyzing the design of cooler and more comfortable places to live.



Heat Islands and proximity to green space in Omaha, NE. Landsat 8 and GIS data. Map by Salvador Lindquist.

LIMITATIONS:

Its low resolution limits the ability to capture fine-grained, localized temperature variations lacking the detail needed for targeted, site-specific heat mitigation strategies. The data is also updated infrequently, making it less effective for real-time monitoring. Landsat measures surface temperatures rather than thermal comfort, and cloud cover can obscure data accuracy.

SCALE/RESOLUTION

▰	▰	▱
regional	neighborhood	site

PROJECT PHASE

▰	▱	▱
pre-design	design	post-design

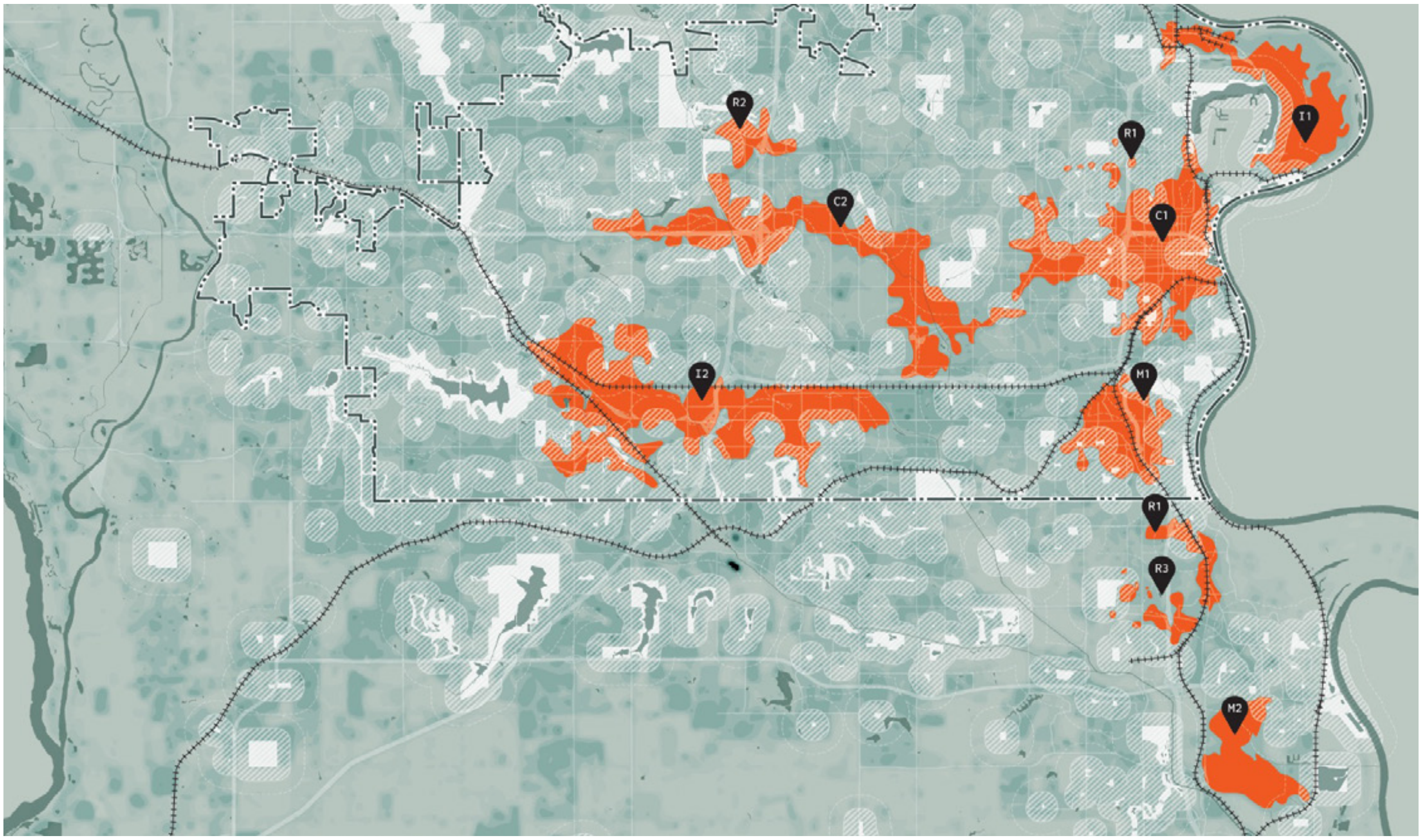
LANDSAT / GIS

BRIEF DESCRIPTION:

Landsat is a series of Earth-observing satellite missions jointly managed by NASA and the U.S. Geological Survey (USGS). Launched initially in 1972, the Landsat program has provided a continuous record of Earth's surface, making it one of the longest-running satellite imagery programs in existence. The satellites are equipped with various sensors which capture data across multiple spectral bands, from visible light to thermal infrared. This diverse range of data allows for detailed analysis of land cover, vegetation health, and, crucially, surface temperature, making Landsat an invaluable tool for studying urban heat islands and other climate-related phenomena.

Geographic Information Systems (GIS) coordinate with Landsat data to provide a powerful platform for analyzing and visualizing the spatial distribution of heat. By integrating the spectral data from Landsat with other geographical data layers, GIS enables researchers and urban planners to map temperature variations across different regions, identify hotspots, and correlate these findings with factors such as land use, population density, and socioeconomic variables. For example, by overlaying temperature data with land cover maps, GIS can reveal how different surfaces (like concrete, vegetation, and water bodies) contribute to urban heat islands, offering insights into where mitigation efforts are most needed.

The applications of Landsat and GIS in understanding heat distribution are extensive. On a regional scale, these tools can be used to monitor changes in surface temperatures over time, helping to track the effectiveness of interventions like tree planting or reflective roofing. They also play a critical role in assessing the impact of urbanization on local climates, guiding policy decisions aimed at improving urban resilience to extreme heat. Additionally, by combining Landsat data with demographic information in GIS, planners can identify vulnerable communities disproportionately affected by heat, ensuring that adaptation and mitigation strategies are equitably distributed.



Isolated Heat Islands in Omaha, NE delineated by the top 20% (Landsat-8) hottest areas in the city. Map by Salvador Lindquist.

CASE STUDY BACKGROUND

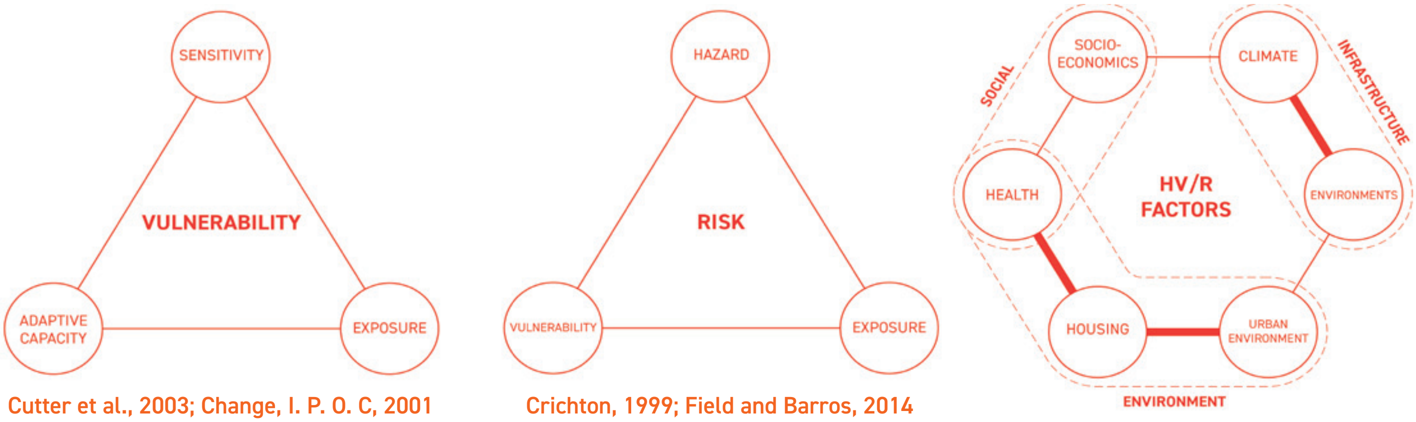
In this case study, Professor Salvador Lindquist collaborated with the City of Omaha to develop maps that reveal and analyze thermal disparities across the city. The project used Landsat 8 satellite imagery and Geographic Information Systems (GIS) data, beginning in two undergraduate design studios before being further developed independently by Lindquist.

The research was part of a larger effort with the City of Omaha Planning Department to create a Heat Resilience Plan, which complemented their ongoing Climate Action Plan. The study focused on Sarpy and Douglas Counties, covering the City of Omaha. These counties were chosen for their readily available GIS data. The City of Omaha experiences average high temperatures ranging from 33°F in January to 87°F in July (US Climate Data, 2023). The Heat Resilience Plan included identifying the "heat archipelago," a concept used to assess vulnerability within the city.

MAPPING THE HEAT ARCHIPELAGO

This research aims to find new ways to evaluate heat vulnerability by mapping the archipelago of urban heat islands in Omaha, Nebraska. By exploring how mapping and visualization techniques can show thermal disparities in cities, the study seeks to improve our understanding of heat vulnerability and guide interventions to boost urban heat resilience.

In recent heat research, urban heat islands are seen as an archipelago, with hot spots spread unevenly across a city, often in areas with lots of concrete and asphalt. Cooler areas are typically found near green spaces, trees, and shaded open areas (Borunda, 2021). To map these hot and cool spots, the study used Landsat 8 satellite imagery from August 3rd, 2022, focusing on thermal bands 4, 5, and 10. The data, downloaded from the USGS Earth Explorer website, was processed using ArcGIS Pro software to calculate key parameters like top of



Cutter et al., 2003; Change, I. P. O. C, 2001

Crichton, 1999; Field and Barros, 2014

Figure 2. Heat vulnerability/risk framework adapted from two population vulnerability/risk conceptual frames, population vulnerability to environmental hazards (Cutter et al., 2003; Change, I. P. O. C, 2001) and risk triangle (Crichton, 1999; Field and Barros, 2014)

atmosphere (TOA) radiance, brightness temperature (BT), normalized difference vegetation index (NDVI), vegetation cover, emissivity, and land surface temperature (LST) (Avdan & Jovanovska, 2016). The land surface temperature data was categorized and vectorized to create analysis-ready maps.

The Landsat 8 imagery was chosen for its moderate spatial resolution, global coverage, and suitable thermal bands for estimating land surface temperature. The imagery was preprocessed, including atmospheric correction and radiometric calibration, to ensure accurate LST values. The study carefully considered the spatial extent and resolution of the data, aiming for a detailed urban-scale analysis at a 30m x 30m resolution.

HEAT VULNERABILITY ASSESSMENT

For the heat vulnerability mapping, the study adapted a framework from Cheng et al. (2021), categorizing variables into environmental, social, and physical infrastructure factors (Figure 2). This framework was adjusted to fit the study area's characteristics and the specific factors affecting heat vulnerability. Environmental variables like land cover, vegetation density, and impervious surface area were analyzed using national census databases and satellite imagery. Social variables, including demographics and social vulnerability indices, were sourced from the 2020 Census and other data sets. Physical infrastructure factors, like building density and access to green spaces, were mapped using local GIS data.

The study identified nine distinct heat islands, representing areas with higher temperatures compared to their surroundings. The LST data was analyzed using spatial techniques like thresholding and clustering to define and group these heat islands. The heat islands were categorized into commercial, industrial, mixed-use, and residential land uses. The study ensured temporal and spatial consistency across all data sources, including the 2020 Census, Tree Equity Score data, and LST data, to maintain the accuracy of the analysis.

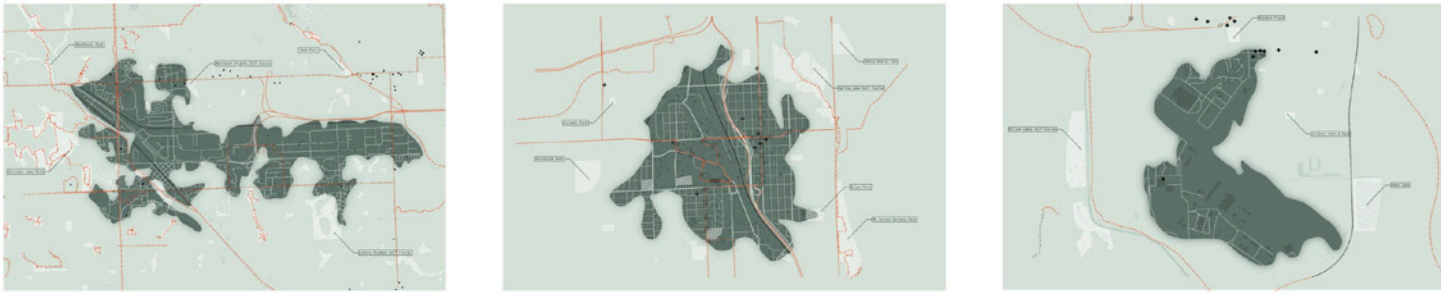
ISOLATING THE HEAT "ISLANDS"

The heat islands were analyzed in detail by comparing their heat vulnerability to city-wide data, isolating them to understand the contributing factors at a smaller scale (Figure 3). Data from the vulnerability mapping was used to extract socio-economic and environmental indicators relevant to heat vulnerability. These indicators, including population density, median income, and minority population percentage, were sourced from the United States Census Bureau and local agencies.

C1: DOWNTOWN

C2: DODGE CORRIDOR

I1: OMA AIRPORT



I2: I-80 CORRIDOR

M1: SOUTHSIDE TERRACE

M2: OFFUTT AIRBASE

R1: 75 NORTH

R2: LAKE FOREST

R3: BELLEVUE WEST

Figure 3. Delineated heat islands (Landsat Data) coded by land use type

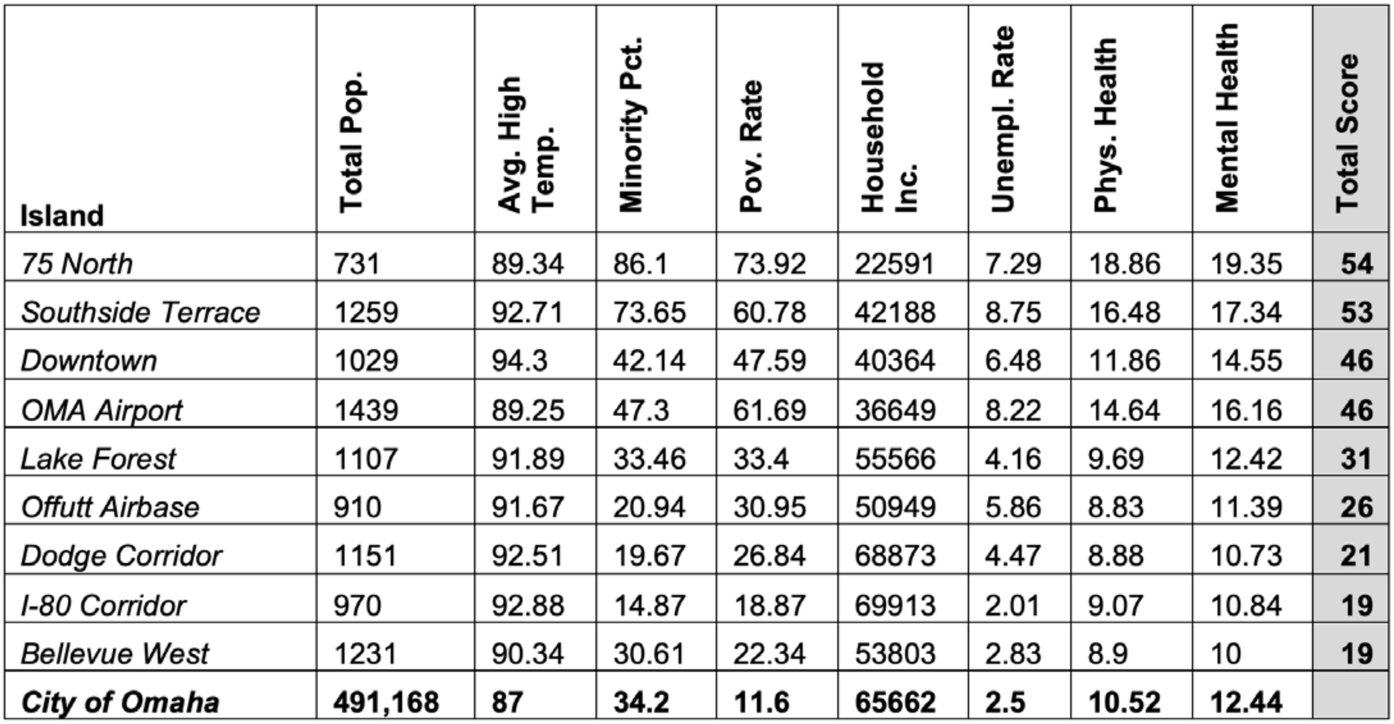
The extracted data was then analyzed within the boundaries of the heat islands, comparing it against Omaha's city-wide averages. Each indicator was weighted equally, and scores were assigned based on how each heat island compared to the city average. For instance, a higher poverty rate in a heat island would result in a higher vulnerability score for that area.

The heat islands were ranked based on their total vulnerability scores, identifying priority areas for intervention and resource allocation (Table 1). While this study used equal weighting for all criteria, future research could explore different weighting schemes to better reflect the importance of various vulnerability indicators.

RESULTS

The study compared metrics like average surface temperature, population density, minority population percentage, poverty rate, household income, and health indicators to city-wide averages, revealing significant spatial disparities in heat vulnerability within Omaha, Nebraska (Table 1). Across all heat islands, average surface temperatures and poverty rates were notably higher than the city-wide averages, indicating greater heat exposure and socio-economic vulnerability in these areas.

Neighborhoods like 75 North, Southside Terrace, and Downtown Omaha were identified as particularly vulnerable, with elevated surface temperatures and poverty rates compared to city-wide data. The study also found higher minority populations and unemployment rates in these heat islands,



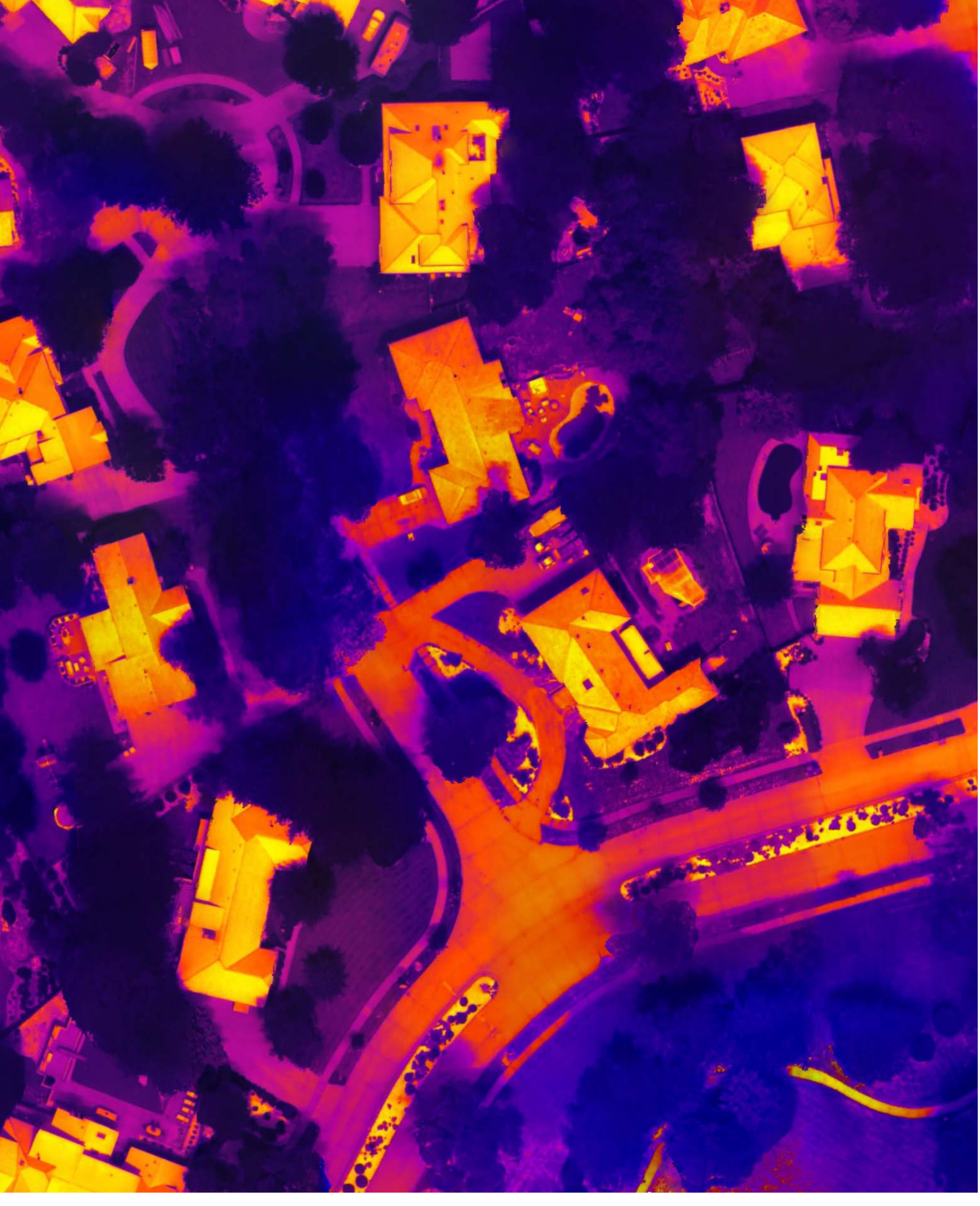
Island	Total Pop.	Avg. High Temp.	Minority Pct.	Pov. Rate	Household Inc.	Unempl. Rate	Phys. Health	Mental Health	Total Score
75 North	731	89.34	86.1	73.92	22591	7.29	18.86	19.35	**54**
Southside Terrace	1259	92.71	73.65	60.78	42188	8.75	16.48	17.34	**53**
Downtown	1029	94.3	42.14	47.59	40364	6.48	11.86	14.55	**46**
OMA Airport	1439	89.25	47.3	61.69	36649	8.22	14.64	16.16	**46**
Lake Forest	1107	91.89	33.46	33.4	55566	4.16	9.69	12.42	**31**
Offutt Airbase	910	91.67	20.94	30.95	50949	5.86	8.83	11.39	**26**
Dodge Corridor	1151	92.51	19.67	26.84	68873	4.47	8.88	10.73	**21**
I-80 Corridor	970	92.88	14.87	18.87	69913	2.01	9.07	10.84	**19**
Bellevue West	1231	90.34	30.61	22.34	53803	2.83	8.9	10	**19**
City of Omaha	**491,168**	**87**	**34.2**	**11.6**	**65662**	**2.5**	**10.52**	**12.44**	

Table 1. Isolated island data compared and ranked against the City of Omaha dataset.

highlighting the intersection of heat vulnerability with social and economic factors.

Lower household incomes and poorer physical and mental health outcomes were also observed in these areas, suggesting that residents face additional challenges in coping with heat stress. Addressing these disparities is crucial for building heat resilience and promoting equitable health outcomes in vulnerable communities.

The City of Omaha could use this data to strategically improve heat resilience and address heat disparity by implementing targeted interventions in the identified heat islands. For instance, the city could prioritize the planting of trees and the expansion of green spaces in neighborhoods like 75 North, Southside Terrace, and Downtown Omaha, where higher surface temperatures and socio-economic vulnerabilities are prevalent. This could help reduce the urban heat island effect by increasing shade and lowering ambient temperatures. Enhancing access to cooling centers and public health outreach in vulnerable communities would also be crucial, especially during heat waves. The city could further integrate these strategies into its Climate Action Plan, ensuring that heat resilience efforts are aligned with broader sustainability and equity goals. By focusing resources on the most affected areas and involving community stakeholders in the planning process, Omaha could build a more resilient urban environment that protects its most vulnerable residents from extreme heat. In the near term, the City of Omaha has identified the Southside Terrace heat island for targeted heat mitigation strategies. A nearly $1 million investment has been committed to integrating these strategies into a new mixed-housing development in the neighborhood.



Streetscape thermal enlargement of the Regency corridor scan. Thermal scan by Keenan Gibbons.

LIMITATIONS:

Offers aerial thermal data over larger areas but has limitations in capturing ground-level details and variations. Its effectiveness is highly weather-dependent. UAVs also require skilled operators and regulatory clearance for use in urban areas. Additionally, while UAVs can map temperature distributions, they still primarily measure surface temperatures rather than thermal comfort.

SCALE/RESOLUTION

☐	▨	▨
regional	neighborhood	site

PROJECT PHASE

▨	☐	▨
pre-design	design	post-design

UAV THERMOGRAPHY

BRIEF DESCRIPTION

UAV Thermography refers to the use of Unmanned Aerial Vehicles (UAVs), commonly known as drones, equipped with thermal imaging cameras to capture and analyze heat patterns from an aerial perspective. These specialized cameras detect infrared radiation emitted by objects and surfaces, converting this data into visual images that represent temperature variations. By analyzing the thermal data, UAV thermography can reveal how heat is distributed across different areas, highlighting hot and cool zones with high precision.

The process of UAV thermography involves flying the drone over a specified area, where it captures thermal images that are processed into detailed maps. These maps use color gradients to indicate temperature differences, with warmer areas typically represented by reds and oranges, and cooler areas by blues and greens. This visual representation of heat distribution helps in identifying hotspots or areas of interest that may require further investigation or intervention. In the field of landscape architecture, UAV thermography is a powerful tool for understanding microclimates within urban environments. Professionals can use this technology to identify areas where heat is disproportionately concentrated, such as on concrete surfaces, rooftops, or sparsely vegetated zones. This information is crucial when designing or retrofitting urban spaces to improve thermal comfort and reduce the urban heat island effect.

For instance, landscape architects can use UAV thermography to assess the effectiveness of green infrastructure, such as green roofs, tree canopies, and parks, in cooling urban environments. By comparing thermal maps taken before and after the implementation of such features, they can quantitatively evaluate their impact on reducing surface temperatures. Additionally, this tool can be used to monitor the performance of existing landscapes over time, ensuring that they continue to provide the intended cooling benefits.

CASE STUDY BACKGROUND

Landscape architects have long considered the potential of nature-based solutions (NbS) for addressing extreme heat (Kabisch 2016; Guardaro 2020), but there is a gap in how their distribution is mapped and understood. In the past, planners and design professionals have relied on Geographic Information Systems (GIS) to map surface temperatures. For example, the U.S. Geological Survey (USGS) provides georeferenced Landsat surface temperature maps available at a 30m x 30m spatial resolution. These data work well at a large scale (county or state), but lack the fidelity and resolution required to make targeted site-based landscape interventions. Broadly, how can emerging thermal-visualization technologies influence landscape planning in cities with significant environmental heat disparities? And more specifically, how can thermal visualization technologies provide a more granular level of understanding of localized heat impacts?

In this study, funded by the Landscape Architecture Foundation Deb Mitchell Research Grant, we test commercially available thermal visualization tools, from Unmanned Aerial Vehicles (UAV) to Forward-Looking Infrared (FLIR) cameras, to develop a toolkit for landscape planners and policymakers to make better-informed decisions in designing more just and equitable landscapes.[1] We are at a unique moment in time in which the democratization of UAVs has enabled access to a suite of imaging tools that were previously out of reach. This shift has wide-ranging implications for the way that designers perceive our cities. From high-fidelity orthographic photogrammetry to spectral point-cloud imaging, we are now able to technically situate and contextualize our work more accurately than ever before. But aside from the surveying potentials of mapping, low-aerial vantage points also lend themselves to new methods of representation.

VISUALIZING THERMAL DISPARITIES

Three corridors were selected in the application of high-resolution thermographic technology: 75 North, Regency, and the Gene Leahy Mall (Figure 1). The selected corridors emerged through a heat vulnerability assessment of the City of Omaha, Nebraska, to prioritize high degrees of difference between the prevailing land uses within the study areas. The 75 North corridor is characterized by low household income with higher rates of Black populations. The land use is predominantly low-density residential, adjacent to a major interstate (I-75) with discontinuous tree canopy and large areas of land vacancy. Regency is a high-income, predominantly white residential community, with a curvilinear suburban street grid. The street network includes a boulevard with a planted central median and regularly spaced street trees. Lastly, Gene Leahy Mall is a recently completed urban green space in Downtown Omaha with a variety of landscape typologies, including plazas, gathering lawns, playgrounds, and splash pads.

At 1/2 mile by 1/8 mile, the extent and dimensions of the corridors were determined by optimizing data capture limitations of the drone with the time constraints of concluding the scan within an acceptable range of solar noon. We used UAV thermography and a handheld FLIR thermal camera, with images captured simultaneously from roughly 1 pm – 2:30 pm during the scheduled fieldwork (August 3rd – 5th, 2023). Solar noon is when the sun reaches its apparent highest point in the sky, which was at roughly 1:29 pm.

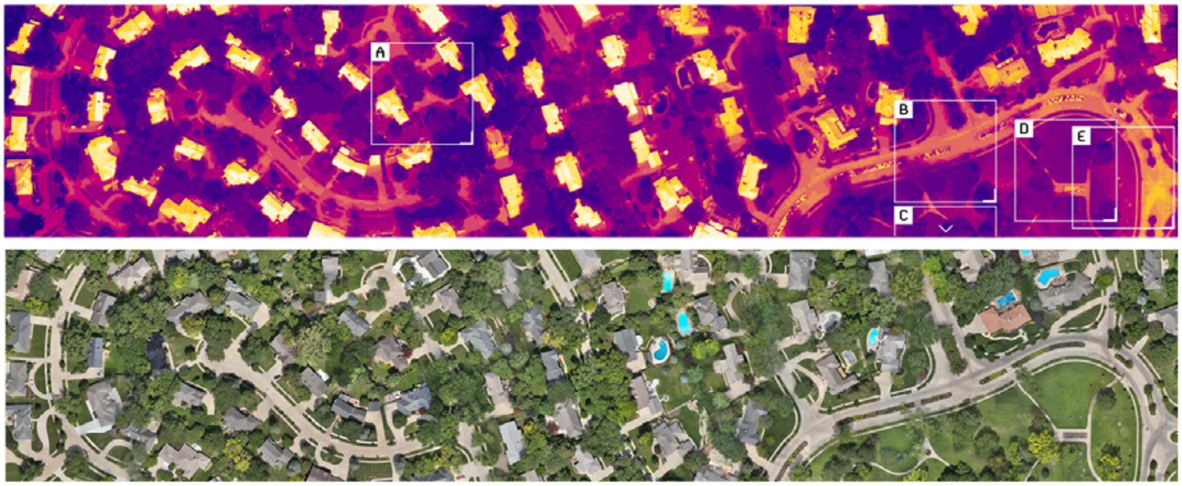
METHODS

Using the DJI Mavic 3 Enterprise Thermal, we scanned three target corridors (+/-42 acres): 75 North, Regency, and Gene Leahy Mall. Drone settings were normalized across all scans for a velocity of around 5 mph at no more than 200 feet above ground level (AGL) and 90% image overlap. We completed five scans during fieldwork, each with a duration of +/-80 minutes, repeating the Gene Leahy Mall and Regency corridors due to cloud cover.

UAV flight paths were preset and saved as georeferenced KMZ files. Flight paths included map area extents, altitude, velocity, and best practice settings for aerial UAV imaging, thermography, and post-processing. Each flight path was executed within its target corridor(s), capturing high-

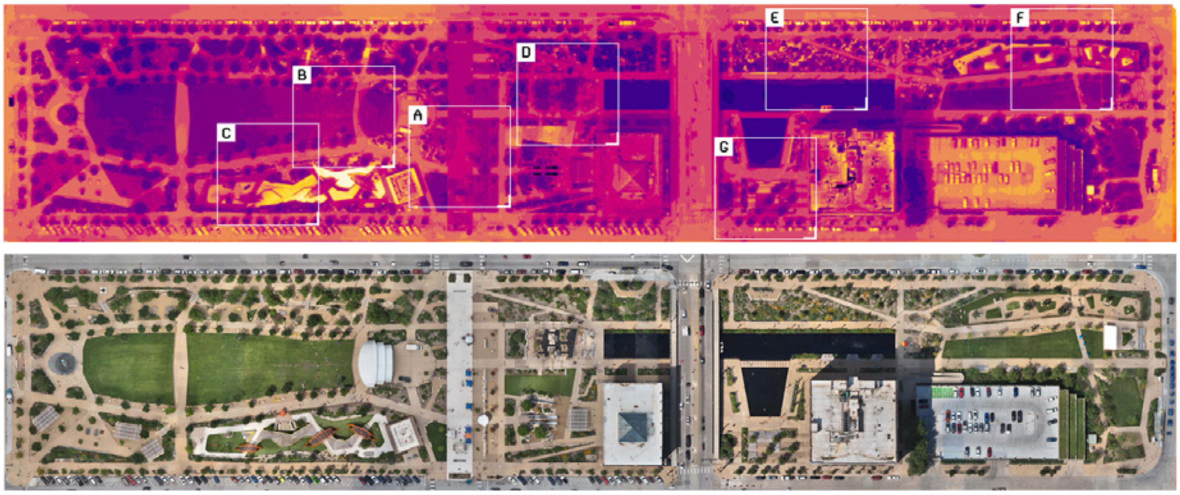
A STREET INTERSECTION
B INTERSTATE OVERPASS
C PARKING LOT
D COMMUNITY GARDEN
E STREETSCAPE

75 NORTH



A STREETSCAPE
B BOULEVARD
C PLAYGROUND
D PARK/GREEN SPACE
E NEIGHBORHOOD GATEWAY

REGENCY



A PLAZA
B CENTRAL LAWN
C PLAYGROUND
D SPLASH PAD
E STREETSCAPE
F DOG PARK
G AMPHITHEATER

GENE LEAHY MALL

Figure 1. Normalized UAV scans of high-resolution RGB images and corresponding infra-red thermography.

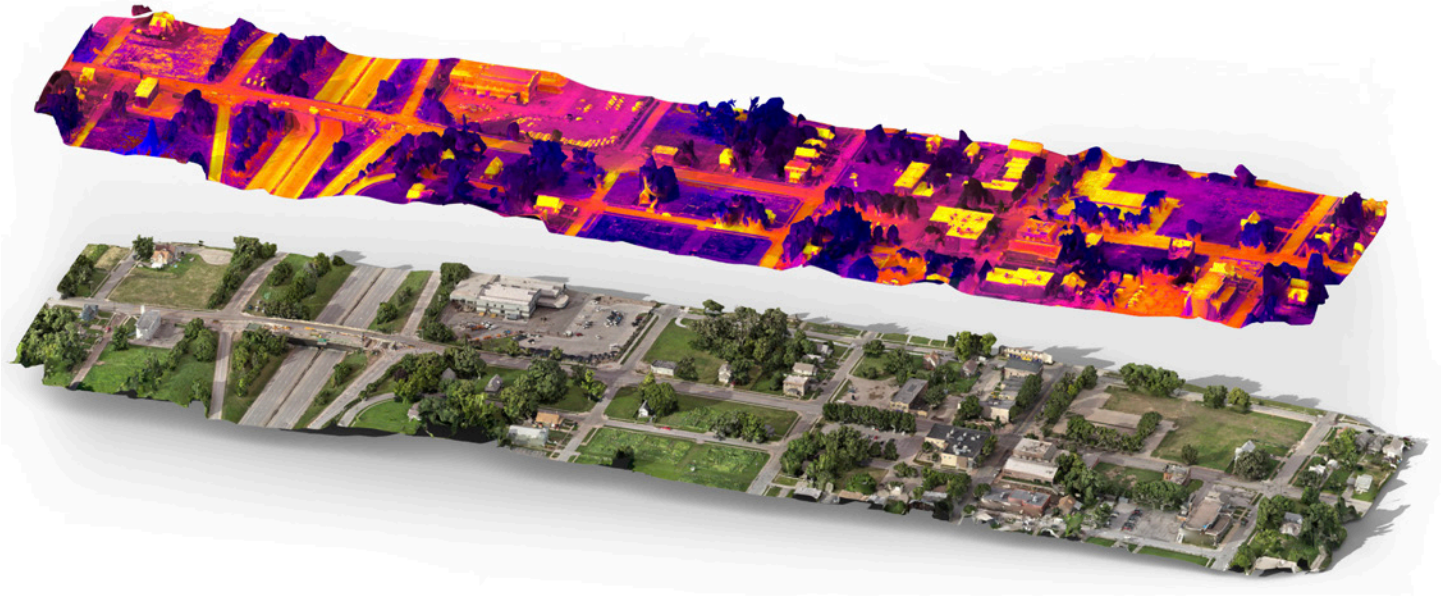


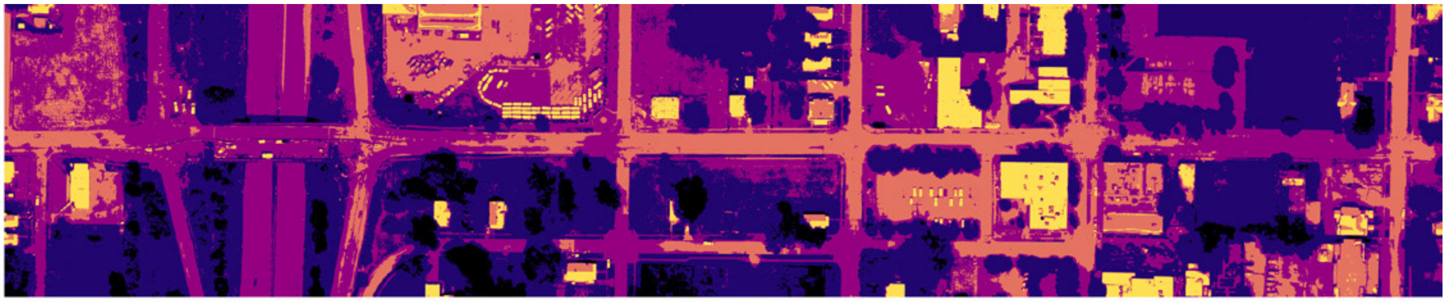
Figure 2. Digital surface model of the 75 North corridor generated through photogrammetry. Rendered with Rhino3D.

resolution RGB images and corresponding infrared thermography simultaneously to a microSD card. The ground sample distance (GSD), which varies based on altitude, camera, and flight velocity, was found to be just under 1.5 cm per pixel—a much higher resolution compared to the 30m per pixel produced by Landsat 9 imagery. Each image group was post-processed in various software, initially with DJI Terra, to generate companion standard and thermal models. For in-depth analysis at the macro scale, another photogrammetry software called Pix4D was utilized to generate georeferenced photogrammetry and orthomosaics of the overall target corridor(s). Pix4D can generate thermal indexes that can isolate and quantify temperature by surface area of the model.

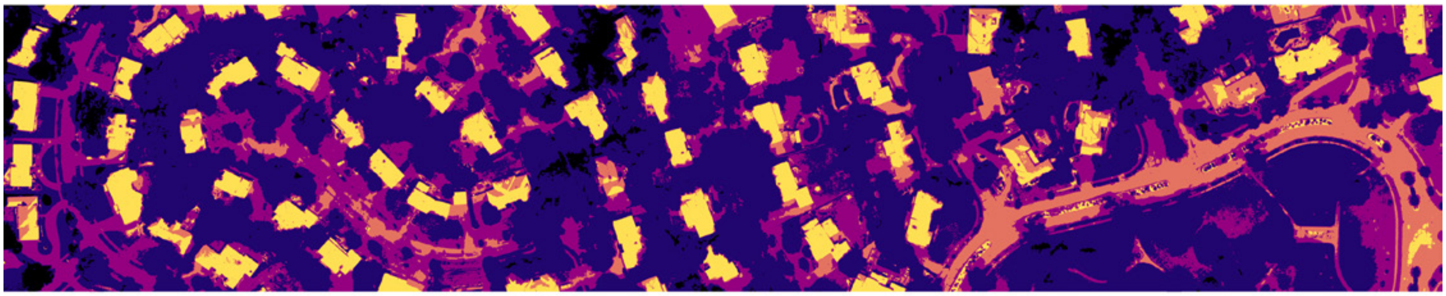
We used Pix4D to generate two separate data sets for each target corridor. The first data set, visualized above, indexed 22 equal thermal classes spanning a temperature range of 10°C to 65°C. The second data set indexed five thermal classes using the NOAA heat index classifications for each scan (NOAA, 2023). These datasets allowed for a more direct comparison in area (acre and percent of total area) between the three scans. Pix4D subsequently produces vector maps, as seen in Figure 3. The NOAA heat index classifications are calculated using air temperature and humidity, whereas the UAV thermography captures material surface temperatures. This distinction is important to note, as we simply used the color data index maps as a way to reduce the classes to produce a legible comparison rather than imply that these areas represent certain heat indices.

Additionally, UAV thermography can produce both RGB and infrared digital surface models generated from post-processing photogrammetry and point clouds. The digital surface model above was visualized in Rhino3D. Because drones rely on photogrammetry to produce 3D models and, unlike RGB images, the radiometric data format and projection of infrared images is reflected in the resulting models. As such, the detail of surfaces in the infrared model appear comparatively more coarse (Fig. 2).

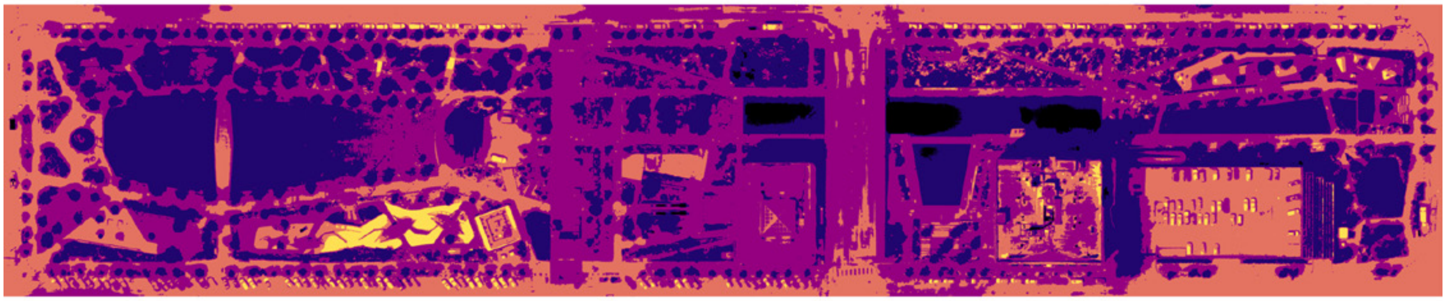
At the micro scale, individual thermal images were analyzed in DJI Thermal Analysis Tool 3 to apply spot temperatures, adjust visual spectrum, and toggle for emissivity. The georeferenced thermal models, orthomosaics, and indices at the macro scale with the spot temperatures and analyses from the granular micro scale were stacked to draw comparisons between various material temperature



75 NORTH



REGENCY



GENE LEAHY MALL

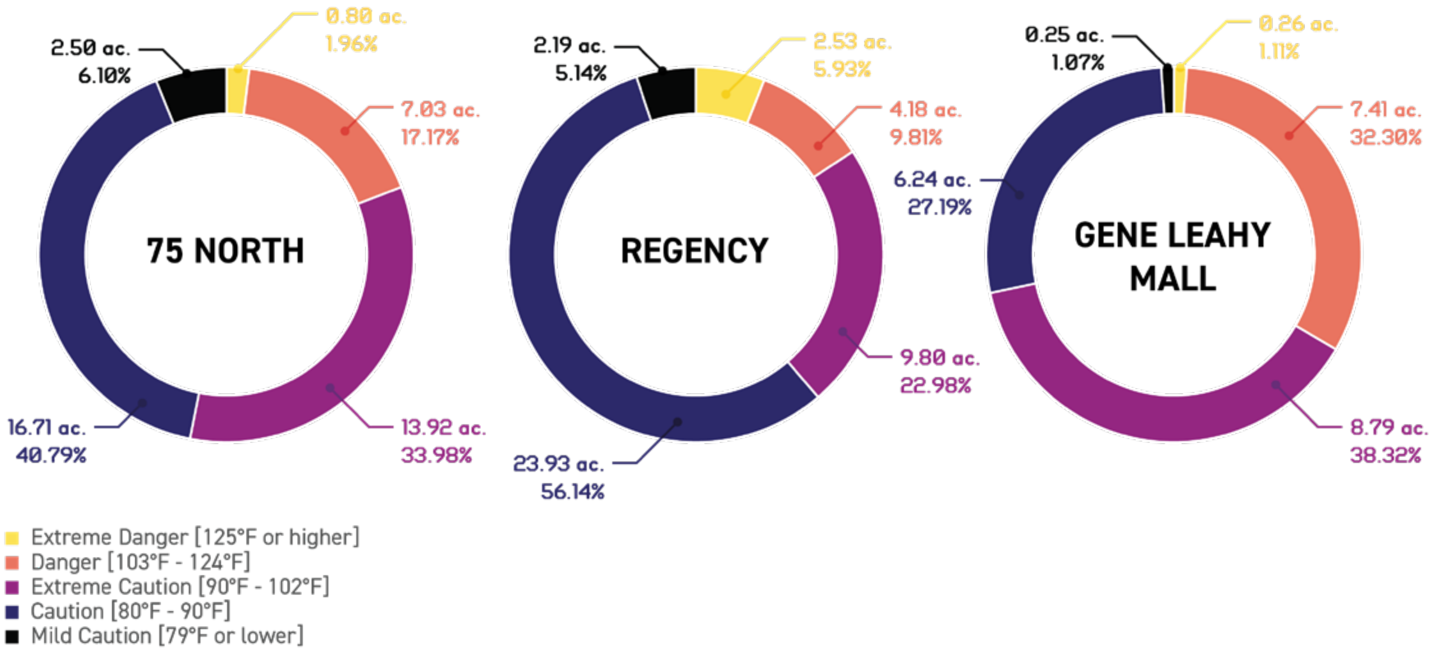


Figure 3. UAV Thermography organized into five heat classifications (NOAA) quantified by surface area.

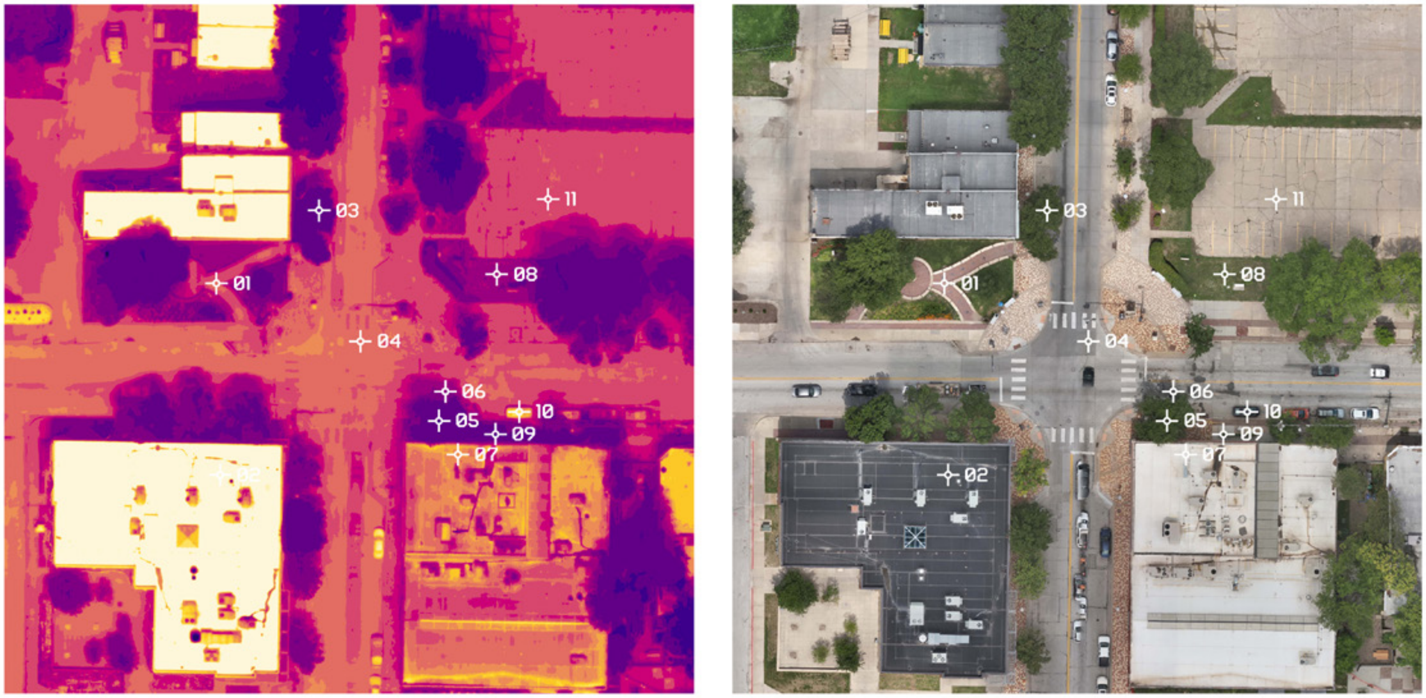


Figure 4. Micro-scale UAV scan (75 North) of high-resolution RGB images and corre-sponding infrared thermography.

readings (Fig. 4)(Table 2).

RESULTS AND DISCUSSION

The original goal of the research was to identify ways to holistically test the implications of available thermal visualization technologies to better understand and design for more equitable urban heat resilience. We wanted to better understand the capacities of these available tools to assist with better diagnosing the localized impacts of heat. Thermal conditions in urban environments exhibit significant spatial variability, necessitating a microscale evaluation. Relying solely on air temperature is insufficient to comprehensively represent the diverse range of thermal conditions encountered in such settings (Middel, 2019).

UAV and handheld thermography in tandem are just pieces of a broader toolkit for assessing thermal comfort but provide compelling ways of visualizing heat at a relatively high resolution. The images produced from these methods can aid in improving the transdisciplinary processes that contribute to consensus building and decision making by making urban heat conditions and disparities more accessible. While the tools were effective, we faced several challenges and limitations in conducting the fieldwork for this study:

To scan several corridors comparatively, we needed to operate the UAV on separate days. This presented several challenges by way of weather limitations and variability. The days on which the

Location	Material	Temperature
1	Concrete (Sidewalk; Sun)	108.0° F
2	Bituminous Roof (Black; Sun)	150.4° F
3	Tree Canopy	82.9° F
4	Concrete (Road; Sun)	113.0° F
5	Tree Canopy	82.2° F
6	Concrete (Road; Shade)	90.5° F
7	Bituminous Roof (White; Sun)	119.3° F
8	Lawn (Sun)	97.5° F
9	Concrete (Sidewalk; Shade)	85.6° F
10	Automobile (Black; Sun)	138.4° F
11	Asphalt (Sun)	107.2° F

Table 2. Associated spot temperature readings (Fig. 2) measured using FLIR Tools with infrared data captured by the DJI Mavic 3 Enterprise Thermal UAV.

flights occurred were fairly similar in temperature and UV index, although not exact, which may have impacted the final material surface temperature measurements. Due to the time limitations, we could only scan a 1/2 mile by 1/8 mile corridor. We selected for maximum variability of land use conditions, but due to the small sample, macro-scale data (Fig. 3) should not be used to generalize for a broader area unless the land use is similarly configured. The area measurements simplified by thermal classes can be used to draw some compelling conclusions which largely seem to be influenced by the surrounding urban condition.

In the 75 North corridor, over 53% of surfaces are above 90°F, which is considerably higher than in Regency, which shows 39% of surfaces over 90°F. This can be attributed to the significantly higher amounts of canopy coverage in Regency. Additionally, UAV thermography can produce both RGB and infrared digital surface models. The drone flight can be optimized to produce 3D thermography on oblique surfaces, which could be beneficial. In future studies, the efficacy and applicability of these models should be studied further.

CONCLUSION

In the era of climate change and increasing urbanization, understanding how heat is distributed across the urban environment is of paramount importance. The selected corridors in Omaha serve as microcosms of the broader urban challenges posed by rising temperatures and their impacts on human comfort, energy consumption, and infrastructure resilience. The combination of UAV thermography and handheld thermal imaging allowed us to better understand urban heat dynamics, rendering legible the various landscapes and material selections that contribute to the urban heat island effect.

Commercially available tools and technologies play a key role in understanding the impacts of urban heat in the built environment. By flying drones equipped with thermal sensors over cities, researchers and urban planners can gather critical data on surface temperatures, heat distribution, and thermal anomalies. This data can be used to identify heat islands, assess the effectiveness of urban heat mitigation strategies, and make informed decisions regarding urban planning and design. UAV thermography offers an efficient way to monitor and manage the effects of urban heat, ultimately contributing to more sustainable and comfortable urban environments.

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1. Lindquist, S, & Gibbons, K. (2024). Infrared Chorographies: Visualizing Thermal Disparities. Journal of Digital Landscape Architecture (JoDLA) 9.

Handheld thermal image of an ADA ramp at the Gene Leahy Mall.

LIMITATIONS:

Provides only localized, point-specific data, limiting its ability to assess broader areas comprehensively. Data collection is time-consuming and weather-dependent, as conditions like wind or cloud cover can affect accuracy. The tool measures surface temperature rather than human thermal comfort making broader heat assessments resource-intensive and less precise.

SCALE/RESOLUTION

☐	■	■
regional	neighborhood	site

PROJECT PHASE

■	☐	■
pre-design	design	post-design

HANDHELD THERMOGRAPHY

BRIEF DESCRIPTION

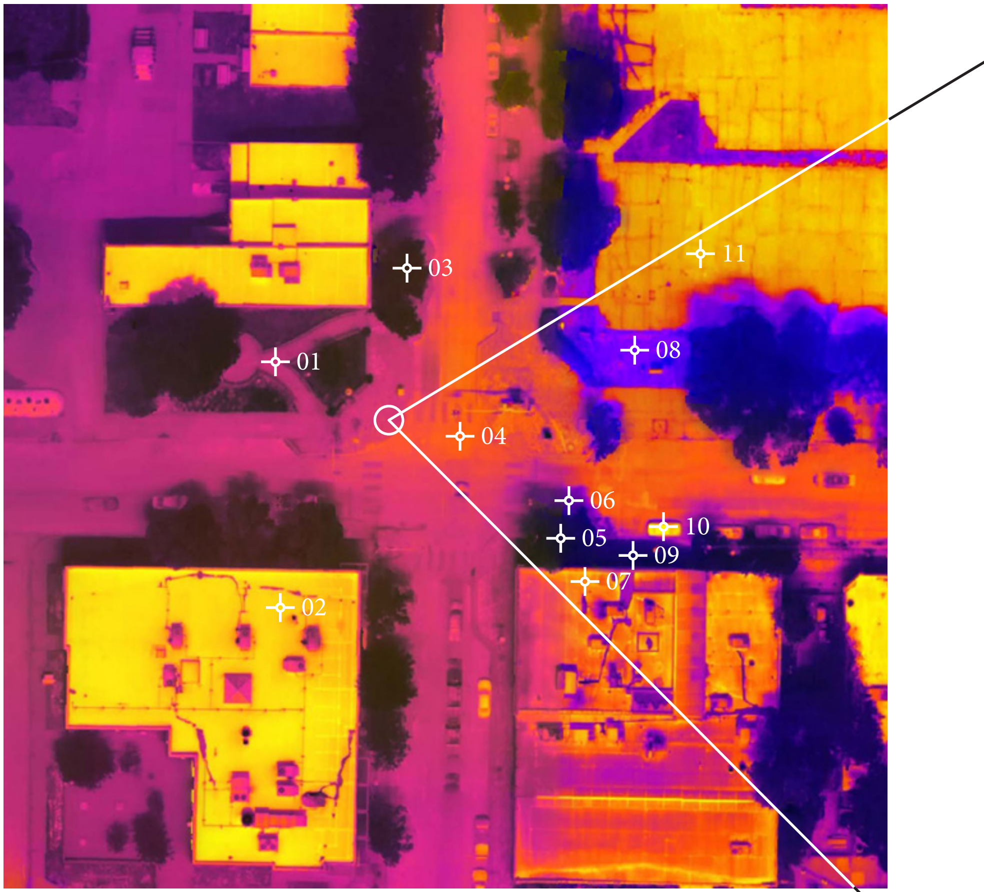
Handheld Thermography involves using portable thermal imaging cameras to capture infrared radiation emitted by surfaces, converting this data into visual heat maps. Unlike UAV thermography, which provides broader aerial views, handheld thermography allows for a more detailed and granular examination of specific surfaces and materials at close range. This close-up capability enables landscape architects to assess thermal variations on surfaces like pavements, building facades, or vegetation, which are often missed in broader UAV scans.

One of the key advantages of handheld thermography is its ability to pinpoint specific thermal anomalies or variations in real time. While UAVs provide an expansive overview, handheld devices allow practitioners to dive deeper into particular areas of interest, such as identifying heat retention in different materials or the cooling effects of specific vegetation. This level of detail is crucial for understanding the nuances of thermal comfort in outdoor spaces and the performance of different landscape elements under heat stress.

In landscape architecture practice, handheld thermography enhances the way heat is visualized by allowing for an on-the-ground perspective. It enables designers to gather data from hard-to-reach areas or locations that require more detailed analysis, such as shaded versus unshaded areas or the thermal performance of specific plant species. This tool helps in creating more precise heat maps, which can inform the placement of shade structures, vegetation, and other cooling strategies.

Furthermore, handheld thermography's portability makes it an ideal tool for iterative design processes, where designers can test and visualize the thermal impacts of various interventions on-site, making adjustments in real-time. This approach fosters a more responsive and adaptive design process, leading to more effective and targeted heat mitigation strategies in urban landscapes.

SPOT	MATERIAL	TEMP.
01	Concrete (Sidewalk; Sun)	108.0° F
02	Bituminous Roof (Black; Sun)	150.4° F
03	Tree Canopy	82.9° F
04	Concrete (Road; Sun)	113.0° F
05	Tree Canopy	82.2° F
06	Concrete (Road; Shade)	90.5° F
07	Bituminous Roof (White; Sun)	119.3° F
08	Lawn (Sun)	97.5° F
09	Concrete (Sidewalk; Shade)	85.6° F
10	Automobile (Black; Sun)	138.4° F
11	Asphalt (Sun)	107.2° F



CASE STUDY BACKGROUND

In the Landscape Architecture Foundation study, we utilized handheld thermography to complement the data collected through UAV thermography.[1] While UAV thermography allowed us to capture high-resolution thermal data from an aerial perspective, handheld thermography provided a crucial on-the-ground perspective, enabling a more detailed and localized understanding of heat distribution. This dual approach allowed us to cross-validate data and gain insights into how thermal variations manifest at different scales and within specific landscape typologies. By integrating these methods, we aimed to create a comprehensive toolkit that could be used by landscape architects to design more thermally resilient urban spaces.

METHODS

A handheld FLIR (Forward-Looking Infrared) thermal camera is a portable device designed to capture thermal images of objects and surfaces by detecting variations in their temperature. We used the handheld FLIR thermal camera (FLIR One Pro) for on-the-ground validation and supplemental visualization of the UAV thermography. Connected via cell phone Wi-Fi, the images are saved to FLIR's cloud-based servers as well as local storage. FLIR Tools can process these images to sample individual temperature readings, similar to the UAV thermography. The images captured with the FLIR handheld camera were selected qualitatively, prioritizing the capture of distinct landscape typologies (e.g. streetscape, plaza, playground) (Fig. 5).

Additionally, we used a temperature gun and Kestrel Heat Stress tracker to provide additional data at the locations where the FLIR handheld thermal camera was used. With the temperature gun, we measured surface temperature readings of various materials in the landscape both in direct sun and shade (where applicable). The Kestrel Heat Stress tracker provided additional data, including heat index, air temperature, and wet bulb globe temperature. We found the temperature gun measurements to accurately represent the spot measurements generated by Pix4D and DJI Terra.

DISCUSSION

While the tools were effective, we faced several challenges and limitations in conducting the fieldwork for this study:

Any temperature fluctuations in the ground measurements are largely dependent on rapidly changing weather conditions like cloud cover, but they remain within a reasonable standard deviation from the infrared imagery. Given the time and weather constraints of the fieldwork, a heat map generated using regularly spaced ground temperature measurements could produce helpful visualizations to further validate the data gathered from UAV thermography. Our ground measurements were helpful in spot-checking aerial measurements, but future studies could benefit from more robust "ground-truthing."

In landscape architecture practice, handheld thermography plays a crucial role by allowing professionals to capture detailed thermal data at a finer scale, which is especially valuable in urban environments where microclimates can vary significantly within short distances. Unlike UAV thermography, which provides a broader overview, handheld thermography enables the precise identification of specific heat sources or sinks in the landscape. This information is essential for designing targeted interventions, such as strategic placement of shade structures, vegetation, or reflective materials, to mitigate heat stress.

Moreover, handheld thermography helps landscape architects to better understand the thermal performance of different materials and surfaces in real-time, which can inform decisions during the design process. It also provides a tangible way to engage stakeholders, by visually demonstrating the thermal impacts of different design elements, thereby facilitating more informed discussions about urban heat resilience. This tool, when used in conjunction with aerial thermography, offers a comprehensive approach to addressing the complex challenges of urban heat in a nuanced and site-specific manner.

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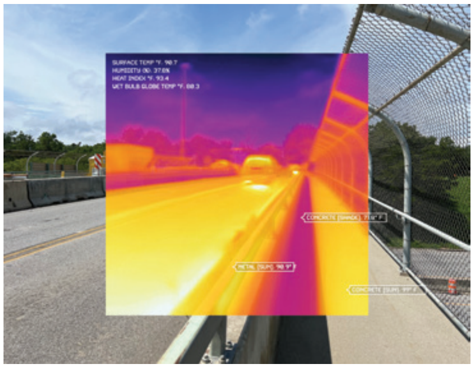
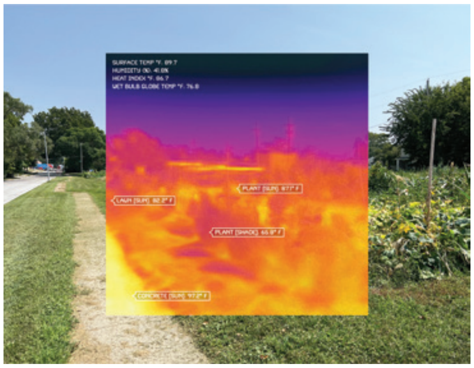
1. Lindquist, S, & Gibbons, K. (2024). Infrared Chorographies: Visualizing Thermal Disparities. Journal of Digital Landscape Architecture (JoDLA) 9.

75 NORTH


Interstate Overpass


Street Intersection


Community Garden

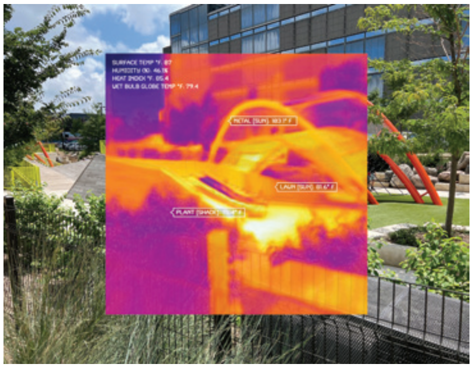
REGENCY


Street Intersection


Boulevard


Playground

GENE LEAHY MALL


Playground


Plaza


Streetscape

MaRTy is a "mobile biometeorological instrument platform that measures air temperature, humidity, wind speed and direction, GPS coordinates, and MRT (Mean Radiant Temperature) using the 6-directional method." Photo courtesy of SHaDE Lab, Arizona State University.

LIMITATIONS:

Its spatial coverage is limited, as it can only measure small areas at a time, making broader urban assessments resource-intensive and time-consuming. The machine itself is costly, although ASU has recently developed MaRTiny, which is a smaller and more accessible version of MaRTy. Data collection is typically short-term, providing snapshots rather than continuous monitoring.

SCALE/RESOLUTION

☐	▨	▨
regional	neighborhood	site

PROJECT PHASE

▨	☐	▨
pre-design	design	post-design

MOBILE BIOMETEOROLOGICAL INSTRUMENT PLATFORM

BRIEF DESCRIPTION

The Mobile Biometeorological Instrument Platform, known as MaRTy, is a mobile research station developed by Arizona State University (ASU). It is designed to measure and analyze various aspects of thermal comfort and heat exposure in urban environments, making it a valuable tool in the study of urban microclimates. MaRTy has the capacity to assess mean radiant temperature (MRT), which is crucial for understanding how humans experience heat in real-world conditions.

MRT is distinct from air temperature in that it accounts for all radiant heat sources a person is exposed to, including direct sunlight, reflected radiation from surrounding surfaces, and thermal radiation emitted by objects and structures in the environment. Unlike air temperature, which only measures the temperature of the air, MRT provides a more comprehensive assessment of the thermal environment as it is perceived by humans. This makes it the closest measure we have to a true understanding of thermal comfort, as it reflects the combined effects of air temperature, solar radiation, and infrared radiation on the human body. As a result, MRT is a critical variable in evaluating the potential health risks posed by extreme heat, particularly in densely built urban areas where radiant heat can be intensified by materials like concrete and asphalt.

In the context of landscape architecture, MaRTy's ability to measure MRT allows professionals to gain deeper insights into the thermal comfort of outdoor spaces. Instead of merely identifying hotspots, MaRTy can pinpoint areas where the overall thermal experience might be uncomfortable or hazardous for people. This data enables landscape architects to design interventions that enhance thermal comfort, such as optimizing shade coverage, selecting appropriate materials, and strategically placing vegetation to reduce radiant heat exposure.

CASE STUDY BACKGROUND

The Mobile Biometeorological Instrument Platform (MaRTy), developed by Arizona State University, is a cutting-edge tool designed to measure Mean Radiant Temperature (MRT)[1], offering a more nuanced understanding of thermal comfort in urban environments. Unlike traditional methods that focus solely on air temperature, MaRTy captures the radiant heat from all sources that affect the human body, making it crucial for landscape architects and urban planners who aim to design spaces that enhance thermal comfort. MaRTy's ability to provide a comprehensive picture of heat exposure is particularly valuable in cities facing extreme heat challenges.

METHODS

MaRTy employs a variety of sensors to measure key meteorological variables, such as MRT, air temperature, relative humidity, and wind speed. Its focus on MRT distinguishes it from other tools, as MRT is the most direct measure of the thermal environment a person experiences, taking into account the cumulative effect of all surrounding heat sources. This makes it a critical factor in assessing thermal comfort in outdoor spaces.

A notable application of MaRTy is in the "50 Grades of Shade" study conducted in Tempe, Arizona, where the platform was used to evaluate the effectiveness of different shade types in reducing MRT and, by extension, improving thermal comfort.[2] The study measured the change in MRT (ΔTMRT) across various shaded environments, revealing that shade could reduce MRT by as much as 20 to 40°C (36 to 72°F). This significant reduction in MRT highlights the essential role of shade in mitigating heat stress, with urban forms such as buildings providing the most effective cooling, followed by trees and lightweight structures.

Moreover, the study developed shade performance curves that illustrate the diurnal changes in MRT for each shade type under clear, hot conditions. These curves are invaluable for urban planners and municipalities in making evidence-based decisions on shade deployment, ensuring that the right type of shade is used in the right place to maximize thermal comfort.

DISCUSSION/CONCLUSION

MaRTy has significantly advanced our understanding of thermal comfort in urban landscapes by focusing on MRT, which is the most accurate measure of how heat is experienced by individuals. The "50 Grades of Shade" study demonstrated that effective shade deployment can reduce MRT by 20 to 40°C, substantially enhancing thermal comfort. This underscores the importance of understanding shade performance in the context of urban design, as different environments require tailored shading strategies to achieve the best thermal outcomes.

The study also introduced the concept of microclimate zones (MCZs), which are human-scale zones characterized by distinct thermal profiles influenced by the surrounding urban form and materials. This concept is a step towards formalizing the assessment of thermal performance from a human-centric perspective, pushing urban designers to consider the thermal implications of their designs more carefully.

Additionally, MaRTy's lower-cost, smaller-footprint alternative, MaRTiny, offers similar insights, making it a practical tool for more widespread use. Both tools are poised to become indispensable in the design and planning of urban environments, enabling the creation of spaces that are not only functional but also comfortable and sustainable in the face of rising temperatures

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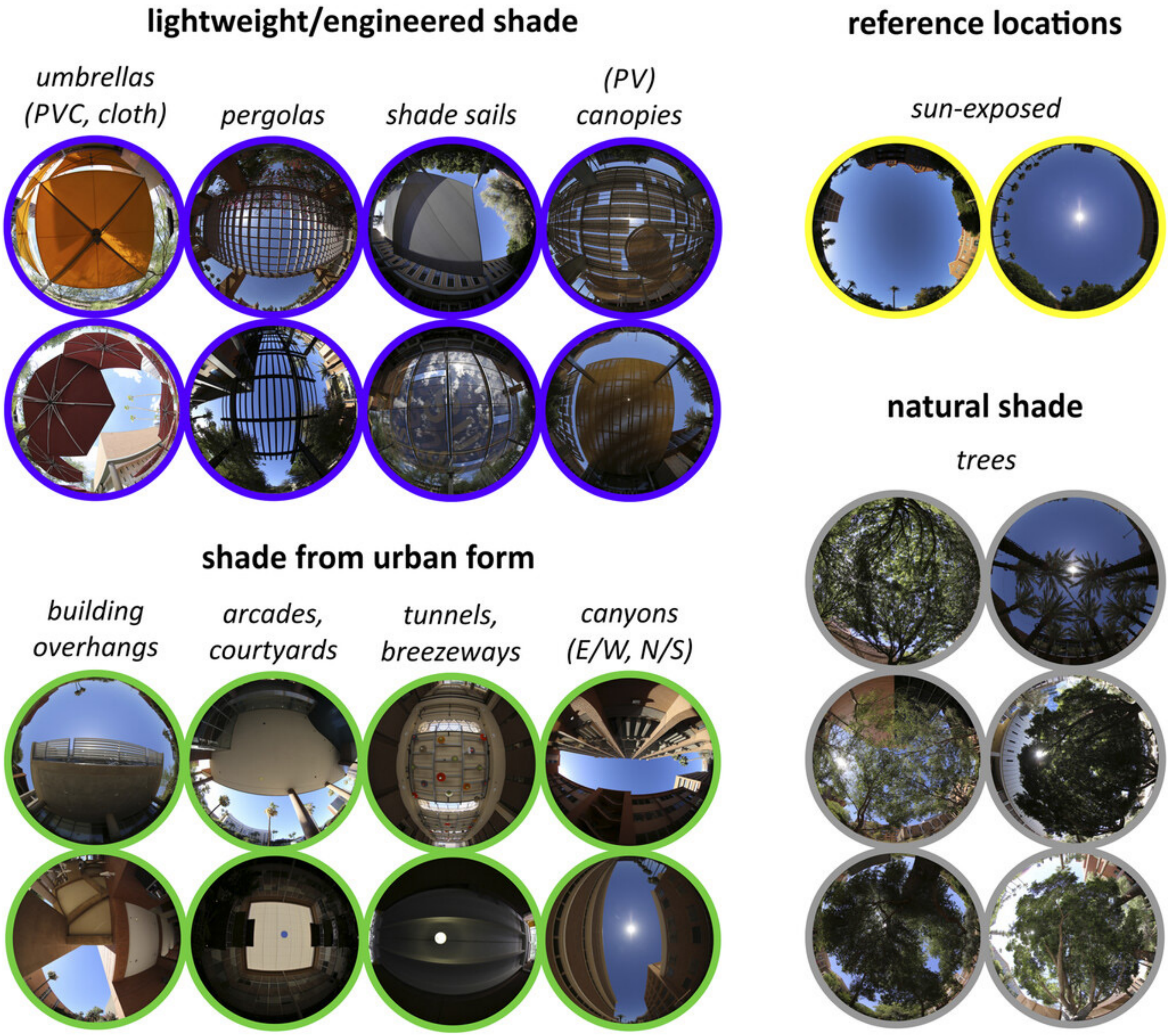
1. Middel, A., & Krayenhoff, E. S. (2019). Micrometeorological determinants of pedestrian thermal exposure during record-breaking heat in Tempe, Arizona: Introducing the Marty Observational Platform. Science of The Total Environment, 687, 137–151. https://doi.org/10.1016/j.scitotenv.2019.06.085

2. Middel, A., AlKhaled, S., Schneider, F. A., Hagen, B., & Coseo, P. (2021). 50 Grades of Shade. Bulletin of the American Meteorological Society, 102(9). https://doi.org/10.1175/bams-d-20-0193.1



"Sample of hemispherical fisheye photos for three shade groups with various shade types and sun-exposed reference locations; photos were taken at 1.1-m height with a Canon EOS 6D and Canon EF 8-15-mm f/4 fisheye USM ultra-wide zoom lens pointing upward." Middel et. al. 2019.

Abdoulaziz Abdoulaye of UNMC demonstrates a sensor used in the heat study (Photo by Fred Knapp, Nebraska Public Media News)

LIMITATIONS:

It is limited by the routes and areas the vehicle can access, potentially missing key locations. Data collection is time-consuming and offers only snapshots of heat conditions rather than continuous monitoring. Additionally, the method primarily captures surface temperatures rather than thermal comfort, and results can be affected by traffic, weather conditions, and road accessibility.

SCALE/RESOLUTION

regional neighborhood site

PROJECT PHASE

pre-design design post-design

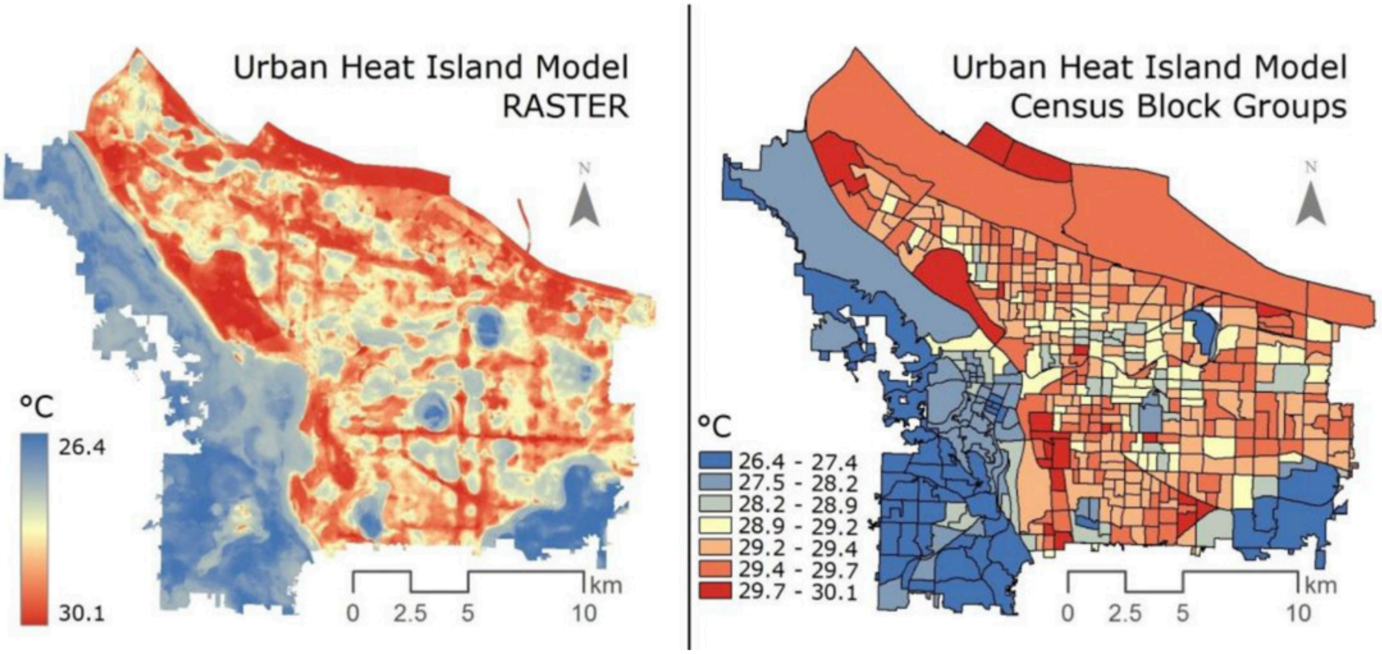
VEHICLE-TRAVERSE COLLECTION

BRIEF DESCRIPTION

Vehicle-traverse collection is a dynamic method used to assess the urban heat island (UHI) effect by equipping vehicles with thermal imaging technology to capture surface temperature data across different urban areas. This approach involves driving a vehicle fitted with thermal sensors, such as infrared cameras or temperature probes, which continuously record temperatures as the vehicle traverses various streets and neighborhoods.

This method provides a comprehensive, real-time view of temperature variations across a city, capturing data across a wide range of locations in a single trip. This continuous data collection enables detailed analysis of temperature gradients and hotspots over large areas, offering insights into how urban design, land use, and infrastructure contribute to the UHI effect. Unlike stationary measurements, which are limited to fixed points, vehicle-traverse collection can reveal varying street-level conditions and identify areas with significant heat disparities.

Vehicle-traverse collection stands out from other heat visualization methods such as UAV, handheld thermography, and Landsat imagery. While UAVs capture data from fixed altitudes and may miss ground-level variations, and handheld thermography provides localized measurements, vehicle-traverse collection combines the mobility of vehicles with high-resolution thermal sensing to cover extensive urban areas. It produces detailed heat maps that reflect granular, dynamic temperature changes. Unlike Landsat imagery, which offers broad, satellite-based data at a lower resolution and less frequent updates, vehicle-traverse collection can capture more specific and timely temperature variations. This method offers unique insights into localized heat patterns that can directly inform targeted design and planning interventions in landscape architecture.



Ambient Temperature Distributionin the Portland, Oregon study comparing the 1m resolution raster map to the census block groups (CBG), which averages the temperatures withing the CBG boundaries.[2]

CASE STUDY BACKGROUND

In this section, we will provide a brief overview of two case studies, the "Omaha Heat Campaign Report"[1] and "Assessing Vulnerability to Urban Heat: A Study of Disproportionate Heat Exposure and Access to Refuge by Socio-Demographic Status in Portland, Oregon."[2] Both the Omaha Heat Campaign and the Portland, Oregon study focus on the socio-environmental aspects of urban heat, examining how heat exposure is influenced by various factors including urban form, land use, and socio-demographic characteristics.

In Omaha, Nebraska, the Omaha Heat Campaign was initiated in response to growing concerns about heat inequities across the city. The campaign's primary goal was to map and understand how heat is distributed across different neighborhoods, with a focus on identifying areas where residents are most vulnerable to extreme heat. Similarly, the Portland study, aimed to investigate the relationship between urban heat exposure and socio-demographic factors, shedding light on which populations are most at risk.

METHODS

Both the Omaha Heat Campaign and the Portland study utilized vehicle-traverse data collection as a key method for capturing urban heat patterns. This method involves mounting temperature sensors on vehicles that are driven through various neighborhoods at different times of the day, allowing researchers to collect granular data on temperature variations across the urban landscape.

In Omaha, the vehicle-traverse data collection was heavily reliant on community volunteers. These volunteers were equipped with temperature sensors in their vehicles and drove predetermined routes across the city during peak heat periods. This approach provided a detailed map of temperature variations, highlighting areas where heat is most intense and where residents are most vulnerable.

The Portland study also employed vehicle-traverse data collection, but with a slightly different focus. In addition to mapping temperature variations, the Portland study integrated socio-demographic data to explore how heat exposure correlates with factors such as income, race, and access

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IT'S GETTING HOT IN HERE!

Omaha Urban Heat Watch Project*

Conclusions

The distribution of heat across a region often varies by the way land is used. Below are some examples of how changes in land use are impacting urban temperatures.

1. Residential areas with a high tree cover retain less heat throughout the day and have cooler temperatures.

2. Areas with a high density of industrial land use can retain more heat.

3. Large swaths of asphalt in commercial areas can retain more heat and result in higher temperatures.

Next Steps

The Urban Heat Watch Project is the first step to better understanding temperature distribution in Omaha. As extreme heat exposure poses a risk to human health, we can use this information to make informed decisions to reduce risks in our community. Opportunities to mitigate heat exposure include:

- Prioritize health equity
- Community engagement and empowerment
- Invest in urban parks and interactive water features
- Transform small areas into green spaces
- Convert recreational areas into greener spaces
- Invest in tree canopies along contiguous streets and in parks
- Leverage existing cool spaces through joint-use agreements

Learn More

Please visit the UNMC Water, Climate and Health Program website to learn more about this project.

*We acknowledge Umo'ho Nation People.

Contact: Abdoulaziz Abdoulaye at Abdoulaye.abdoulaziz@unmc.edu

Omaha Heat Campaign Report, UNMC 2022.

to cooling resources. By comparing heat maps with demographic data, the study was able to identify neighborhoods where residents are disproportionately exposed to extreme heat and have limited access to cooling resources.

RESULTS

In the Omaha Heat Campaign, the data revealed significant temperature disparities across the city, with some neighborhoods experiencing temperatures up to 10 degrees Fahrenheit higher than others. These hotter areas often coincided with neighborhoods that had higher rates of poverty, older housing stock, and fewer green spaces, highlighting the link between social vulnerability and heat exposure. The findings underscored the need for targeted interventions, such as increased tree planting and the development of cooling centers, in these vulnerable areas.

The Portland study also found pronounced thermal disparities, with some neighborhoods experiencing temperatures up to 13 degrees Fahrenheit higher than others. The study's results showed that lower-income neighborhoods and communities of color were more likely to be exposed to extreme heat and had less access to cooling resources. This inequitable distribution of heat exposure and access to cooling further emphasized the need for policies and interventions that address both environmental and social factors to reduce heat vulnerability in these communities.

DISCUSSION

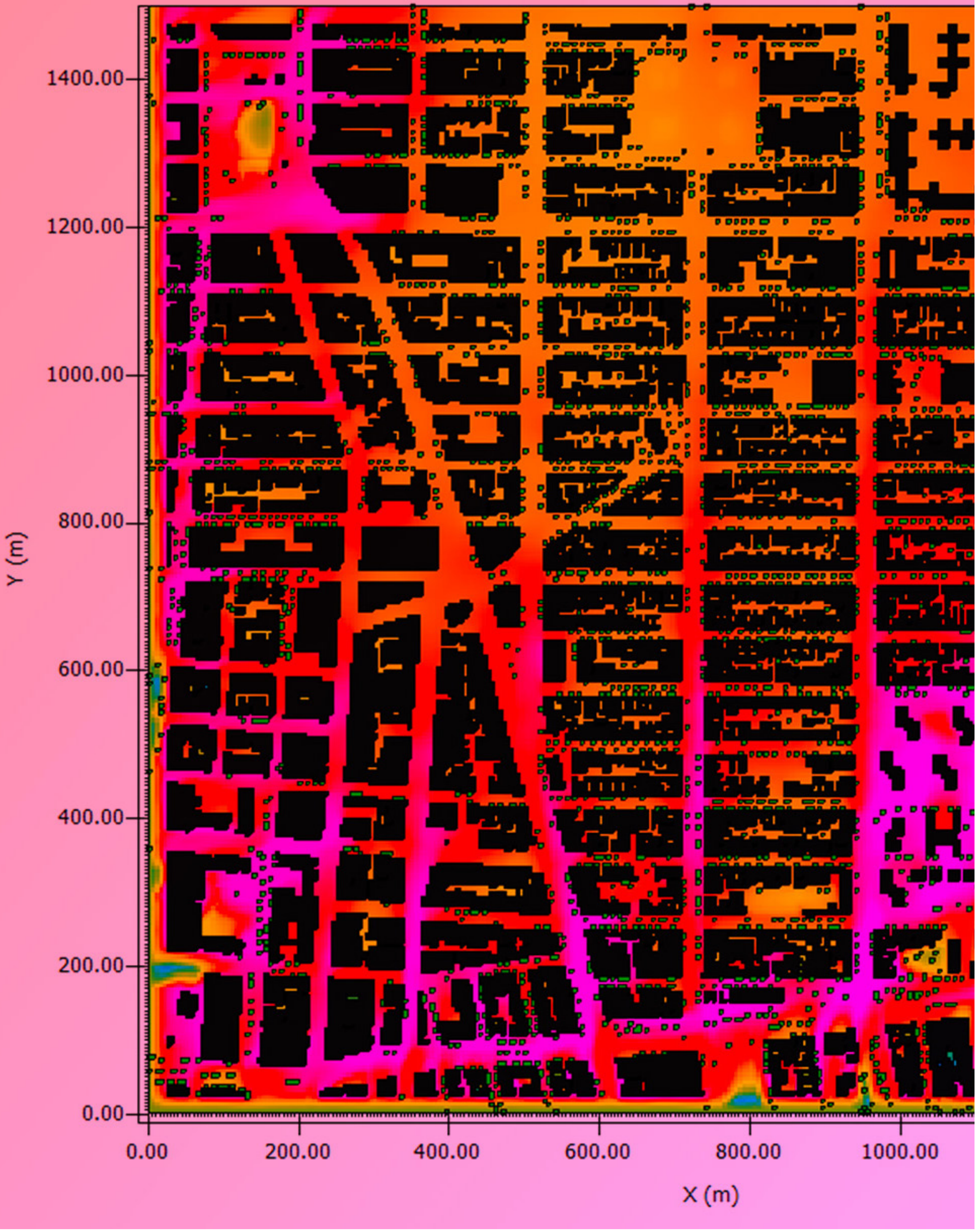
The use of vehicle-traverse data collection in both the Omaha Heat Campaign and the Portland study demonstrates a valuable tool for landscape architecture, design, and planning professionals for visualizing heat at a relatively high resolution. This method allows for a more detailed understanding of how heat is distributed across different urban environments and how various factors contribute to heat vulnerability.

For professionals in landscape architecture, design, and planning, this method provides a powerful way to visualize the impacts of extreme heat and to develop targeted interventions. By combining temperature data with socio-demographic information, as seen in the Portland study, professionals can better identify and prioritize areas where heat mitigation efforts are most needed. This approach also highlights the importance of community involvement, as demonstrated by the Omaha Heat Campaign, where local volunteers played a crucial role in collecting the data that informed the study.

---

1. Abdoulaye, A. (2022). (rep.). Omaha Heat Campaign Report. Omaha, NE: UNMC.

2. Voelkel, J., Hellman, D., Sakuma, R., & Shandas, V. (2018). Assessing Vulnerability to Urban Heat: A study of disproportionate heat exposure and access to refuge by socio-demographic status in Portland, Oregon. International Journal of Environmental Research and Public Health, 15(4), 640. https://doi.org/10.3390/ijerph15040640



Sample of urban heat island mapping using ENVI-met, an environmental simulation software.[1]

LIMITATIONS:

Has limitations in accuracy due to reliance on input data quality and assumptions. It often oversimplifies complex urban environments and weather patterns, leading to results that may not fully capture real-world conditions. Simulations are also computationally intensive, requiring significant resources and expertise to run. Additionally, they provide theoretical data rather than real-time information.

SCALE/RESOLUTION

☐	■	■
regional	neighborhood	site

PROJECT PHASE

■	■	☐
pre-design	design	post-design

ENVIRONMENTAL SIMULATION

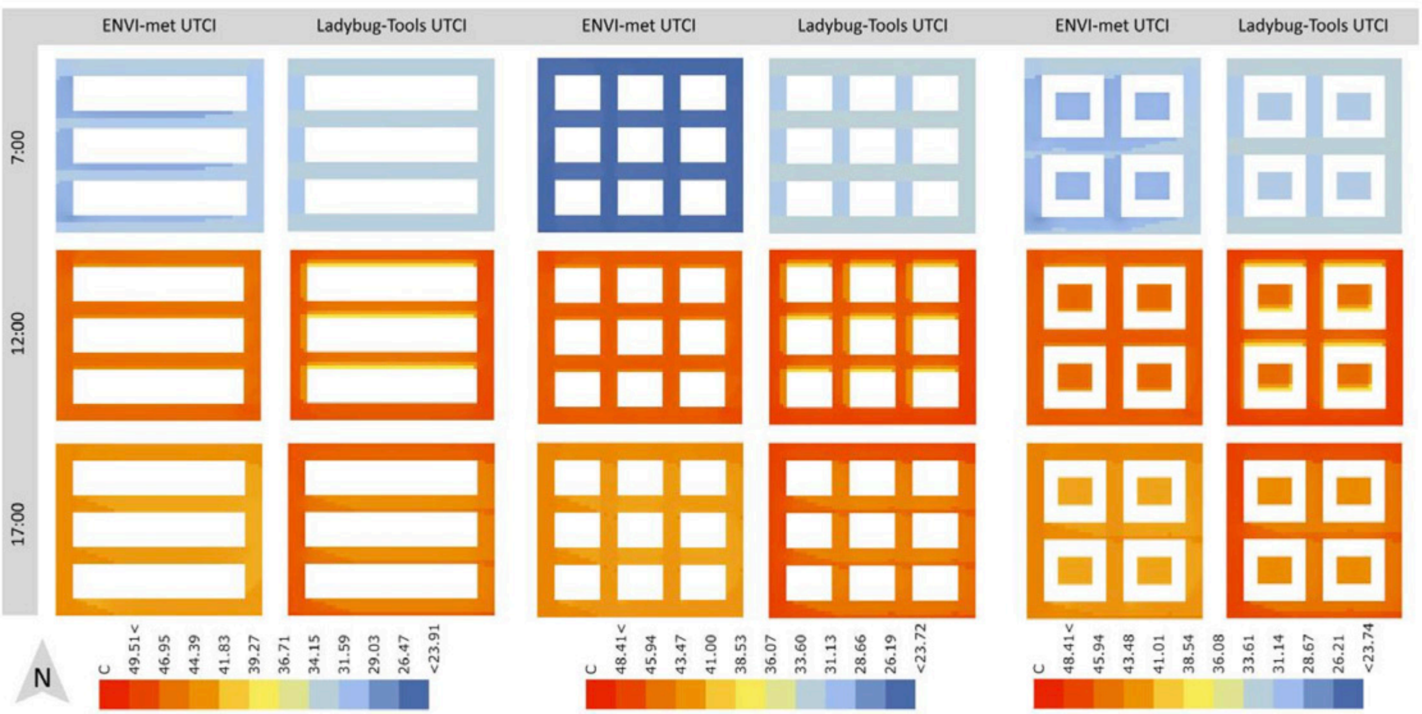
BRIEF DESCRIPTION

Environmental simulation is a critical process in understanding and predicting the behavior of environmental factors within built and natural environments. This practice involves using advanced computational tools to model various conditions such as temperature, humidity, wind flow, solar radiation, and their effects on buildings, landscapes, and urban spaces. By simulating these environmental conditions, designers and planners can make informed decisions that enhance sustainability, energy efficiency, and thermal comfort in their projects. Several software tools exist for environmental simulation, each offering capabilities tailored to specific aspects of environmental analysis:

ENVI-met is a popular tool, specifically designed for simulating microclimates in urban areas. It can model the interactions between buildings, vegetation, and atmospheric conditions, allowing designers to assess the impact of green spaces, materials, and urban layouts on local temperatures and comfort levels. There are many other softwares that assist in conducting environmental assessments, but ENVI-met is one of the more commonly utilized tools, although not without its limitations, which we will describe later in this section.[3]

Ladybug Tools, which integrates with Rhino and Grasshopper, offers a suite of environmental analysis tools that allow for detailed simulations of sunlight, wind, and thermal comfort. These tools are particularly valuable in early design stages, enabling iterative testing of design strategies.

These software tools are instrumental in simulating thermal comfort by allowing users to predict how different design elements—such as shading, orientation, and material choices—affect the temperature and humidity experienced by occupants early in the design stage.



Comparison of Universal Thermal Climate Index (UTCI) modeling between ENVI-met and Ladybug. Ibrahim, 2020.[4]

BACKGROUND

Environmental simulation plays a critical role in landscape architecture, enabling designers to model and predict the interactions between urban environments and climatic factors. Two prominent tools in this domain are ENVI-met and Ladybug, which provide advanced capabilities for simulating microclimates and informing sustainable design practices.

ENVI-MET: MICROCLIMATE MODELING

ENVI-met is a comprehensive environmental simulation software designed specifically for modeling urban microclimates. Developed by Professor Michael Bruse in 1998, it is used to simulate the behavior of various environmental factors such as air temperature, humidity, wind flow, and radiation at a high resolution.

Key Features:
Three-Dimensional Modeling: ENVI-met allows for the analysis of detailed 3D models that represent buildings, vegetation, water bodies, and other urban elements. This enables landscape architects to simulate how these elements interact with the atmosphere over time.

Microclimate Analysis: The software excels at simulating microclimates on a small scale, making it ideal for urban planning and landscape design. It helps in assessing how different design interventions—like the addition of green spaces or reflective materials—impact local climate conditions.

Heat Stress Analysis: ENVI-met is widely used to evaluate heat stress in urban areas, providing insights into how design changes can reduce the urban heat island effect and improve thermal comfort for inhabitants.

Applications in Landscape Architecture:
ENVI-met is often employed in the early stages of design to evaluate the potential impacts of different landscape interventions. For instance, a landscape architect might use ENVI-met to test the cooling effects of a proposed park in an urban heat island or

to assess how different tree species might influence wind patterns and shading.

LADYBUG: ENVIRONMENTAL ANALYSIS FOR GRASSHOPPER

Ladybug is a versatile environmental analysis tool that operates within the Grasshopper platform for Rhino, a popular 3D modeling software. Unlike ENVI-met, which focuses on detailed microclimate simulations, Ladybug offers a broader range of environmental analyses, making it a powerful tool for integrating climate considerations into the design process.

Key Features:
Parametric Design: Ladybug leverages Grasshopper's parametric design capabilities, allowing landscape architects to quickly iterate on different design scenarios and understand their environmental impacts.

Climate Data Integration: The tool can import and analyze climate data from around the world, providing insights into solar radiation, wind patterns, and thermal comfort. This makes it highly adaptable to different geographic contexts.

Daylighting and Solar Radiation: Ladybug is particularly well-known for its ability to simulate daylighting and solar radiation, helping designers optimize building orientations and shading devices to enhance energy efficiency and occupant comfort.

Applications in Landscape Architecture:
Ladybug is often used in urban design projects to optimize the layout of buildings and open spaces for energy efficiency and comfort. For example, a designer might use Ladybug to evaluate how different building configurations affect sunlight exposure in a public square, or to determine the most effective placement of trees to provide shade.

LIMITATIONS

Both ENVI-met and Ladybug Tools are valuable for environmental analysis and urban design but have several limitations that users should be aware of:

Complexity and Learning Curve: ENVI-met and Ladybug Tools both present steep learning curves. ENVI-met requires significant expertise in setting up simulations and interpreting outputs, while Ladybug Tools demands proficiency in both Grasshopper's visual programming and the plugin's specific functionalities.

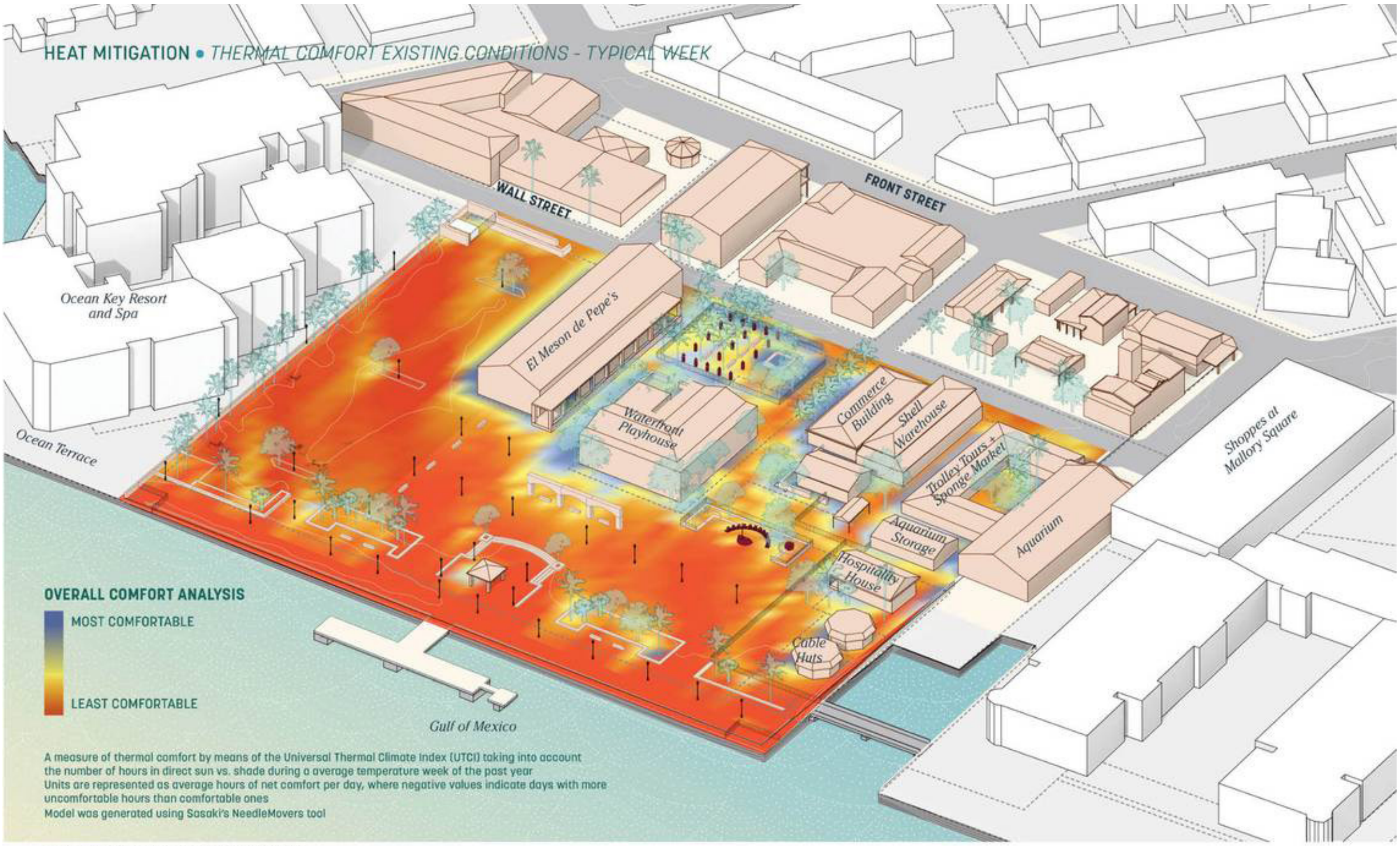
Data Input and Integration: Both tools rely on high-quality, accurate input data. ENVI-met requires detailed meteorological and urban input, while Ladybug Tools depends on precise weather files and accurate geometry in Rhino3D. Integrating and preparing this data can be challenging and may affect the quality of results.

Model Resolution: ENVI-met is suited for detailed microclimate simulations but may struggle with broader urban scales. Ladybug Tools excels in site-specific analyses and may not effectively capture larger-scale climatic patterns or broader urban contexts.

Computational Demands: Both tools can be computationally intensive. ENVI-met simulations, especially at high resolutions, can demand significant processing power and time. Ladybug Tools, while less demanding, can also require substantial computational resources for complex simulations.

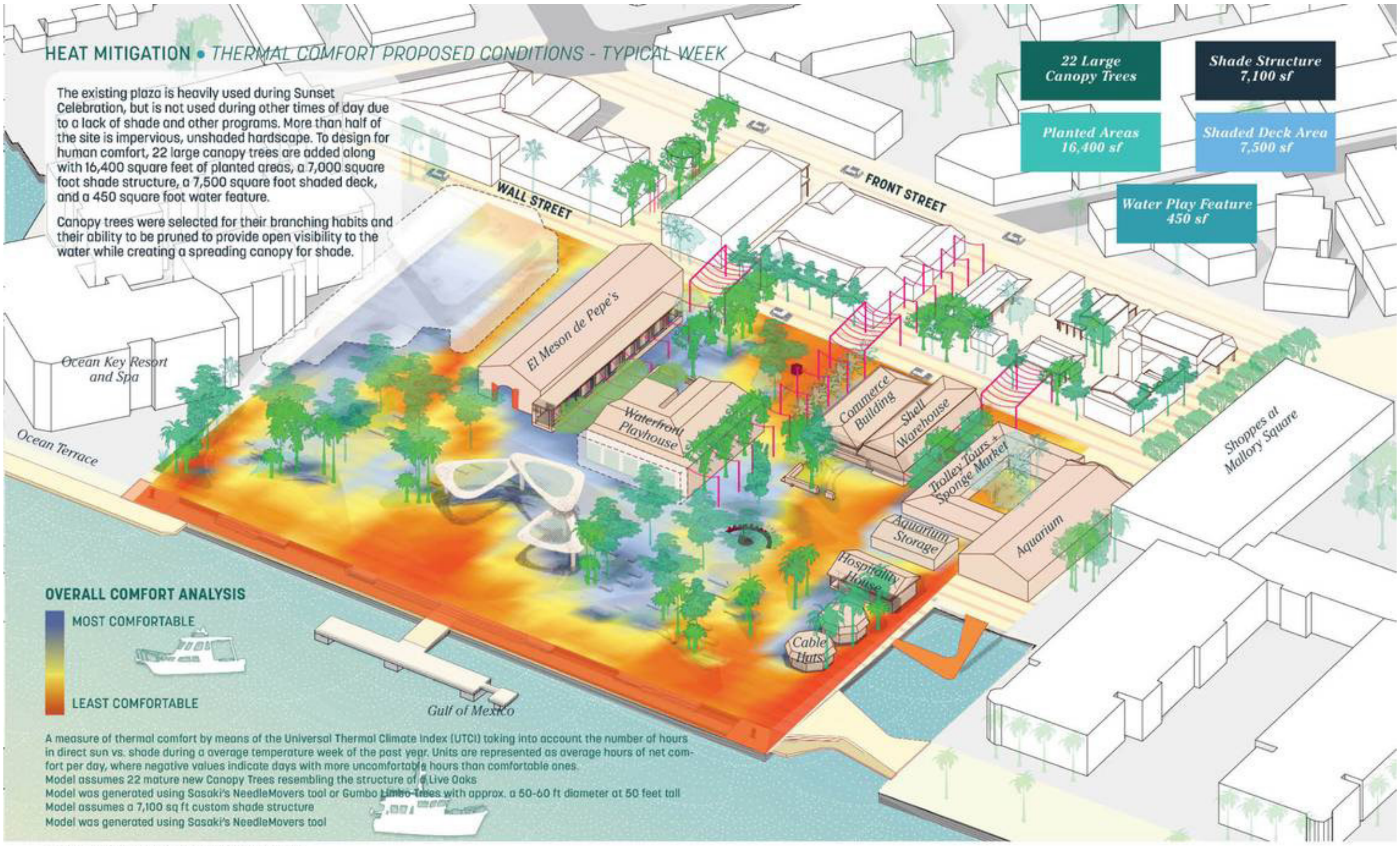
Boundary Conditions and Calibration: Accurate setup of boundary conditions and calibration is crucial for both tools. Inaccuracies or incorrect assumptions can compromise the reliability of the results.

Limited Multiscale Integration: ENVI-met and Ladybug Tools are often used for specific scales—ENVI-met for detailed microclimate analysis and Ladybug Tools for building-scale environmental studies. Integrating results from these tools into larger-scale urban or regional models can be complex and may require additional tools or adjustments.



A measure of thermal comfort by means of the Universal Thermal Climate Index (UTCI) taking into account the number of hours in direct sun vs. shade during a average temperature week of the past year
Units are represented as average hours of net comfort per day, where negative values indicate days with more uncomfortable hours than comfortable ones
Model was generated using Sasaki's NeedleMovers tool

MALLORY SQUARE SUNSET CELEBRATION



The existing plaza is heavily used during Sunset Celebration, but is not used during other times of day due to a lack of shade and other programs. More than half of the site is impervious, unshaded hardscape. To design for human comfort, 22 large canopy trees are added along with 16,400 square feet of planted areas, a 7,000 square foot shade structure, a 7,500 square foot shaded deck, and a 450 square foot water feature.

Canopy trees were selected for their branching habits and their ability to be pruned to provide open visibility to the water while creating a spreading canopy for shade.

A measure of thermal comfort by means of the Universal Thermal Climate Index (UTCI) taking into account the number of hours in direct sun vs. shade during a average temperature week of the past year. Units are represented as average hours of net comfort per day, where negative values indicate days with more uncomfortable hours than comfortable ones.
Model assumes 22 mature new Canopy Trees resembling the structure of a Live Oaks
Model was generated using Sasaki's NeedleMovers tool or Gumbo Limbo Trees with approx. a 50-60 ft diameter at 50 feet tall
Model assumes a 7,100 sq ft custom shade structure
Model was generated using Sasaki's NeedleMovers tool

MALLORY SQUARE SUNSET CELEBRATION

Thermal comfort level simulation at Mallory Square in Key West, Florida before (top) and after (bottom) design interventions. Images by Sasaki.[5]

Software Dependency: Ladybug Tools depends on Rhino3D and Grasshopper, adding complexity and potential cost. ENVI-met, while standalone, may require additional software or data for comprehensive analysis.

COMBINED APPLICATIONS

While ENVI-met and Ladybug are powerful on their own, they are often used in tandem to provide a comprehensive understanding of environmental conditions. For instance, a landscape architect might use ENVI-met to model detailed microclimate conditions at a specific site, then use Ladybug to analyze broader climatic trends and integrate those findings into a parametric design process.

Trends and Future Directions:

The use of environmental simulation tools like ENVI-met and Ladybug is expected to grow as urban areas continue to grapple with the challenges of climate change. These tools not only help in designing more resilient and sustainable urban environments but also facilitate the communication of complex environmental data to stakeholders, making them indispensable in modern landscape architecture.

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1. https://envi-met.com/urban-heat-island-and-climate-change/

2. https://www.miamiherald.com/news/local/environment/climate-change/article278517619.html

3. Other tools that do various types of environmental simulation include Rheologic, CityComfort+, MeteoDyn, CitySim Pro, Autodesk CFD, City Engine, and Airflow Analyst.

4. Ibrahim, Y. I., Kershaw, T., & Shepherd, P. (2020, September 1-3). A methodology for modelling microclimate: A Ladybug-tools and ENVI-met verification study. Paper presented at the 35th PLEA Conference on Sustainable Architecture and Urban Design, A Coruña, Spain.

5. https://www.miamiherald.com/news/local/environment/climate-change/article278517619.html

"Engaging Heat" community engagement exercise with residents of the South Omaha neighborhood. Photo by Salvador Lindquist.

LIMITATIONS:

Potential for inconsistent data collection due to varying participant knowledge and engagement. It is often subjective, relying on personal experiences rather than scientific measurements, which may lead to biased or incomplete data. Additionally, scaling these assessments to cover larger areas can be challenging, and the process can be time-consuming.

SCALE/RESOLUTION

regional	neighborhood	site

PROJECT PHASE

pre-design	design	post-design

COMMUNITY-LED HEAT ASSESSMENT

BRIEF DESCRIPTION

Community-led heat assessments are a participatory approach to evaluating the impacts of extreme heat within urban environments. Unlike traditional heat measurement tools, such as Landsat imagery, UAV thermography, and handheld thermal sensors, these assessments involve local residents in the data collection and analysis process. This grassroots methodology offers unique insights into heat exposure that may be missed by more conventional methods.

Community-led assessments typically involve training residents to use simple tools, like temperature loggers or mobile apps, to record heat conditions in their neighborhoods. Participants might also conduct surveys to gather qualitative data on their experiences with heat, including health impacts and access to cooling resources. This approach allows for the collection of data from a variety of micro-environments that might not be captured by broader, less granular methods.

One of the primary advantages of community-led assessments is their ability to capture localized heat experiences that are often overlooked by traditional tools. While Landsat imagery provides broad, satellite-based data, and UAV and handheld thermography offer high-resolution temperature readings, these methods often miss nuanced variations at the street level. Community-led assessments can identify specific hotspots and vulnerable areas based on direct, lived experiences of residents, revealing how different demographics are affected by extreme heat.

Furthermore, community involvement fosters greater engagement and empowerment, ensuring that the solutions and recommendations are directly informed by those most impacted. This participatory approach can lead to more effective and equitable heat adaptation strategies, as it considers the unique needs and challenges of various communities.

CASE STUDY BACKGROUND

In 2024, a third-year landscape architecture design studio engaged in a participatory project focused on extreme heat and odor mitigation in South Omaha. This initiative, titled “Engaging Heat,” aimed to involve local community stakeholders in the design process to address pressing environmental challenges.

The design studio’s approach was structured into three key areas: Impacts, Mitigation, and Sites. In the Impacts group, students explored how extreme heat and intense odors affect residents, seeking to capture the personal experiences and challenges faced by the community. The Mitigation group focused on identifying potential landscape architecture and nature-based solutions to address these issues. Students investigated how design interventions could effectively reduce heat and odor in the built environment. Finally, the Sites group involved determining priority areas for implementing heat mitigation strategies based on community input.

To facilitate meaningful engagement, students developed diverse methods for interaction, such as trading cards, models, and board games. These tools were designed to encourage conversation, gather feedback, and inform the design of project prototypes. By incorporating local perspectives and addressing real-world issues, the project aimed to create more effective and contextually relevant solutions, fostering a sense of ownership and stewardship among community members.

IMPACTS

Goal:
The Impacts group’s goal was to engage community stakeholders in the Beat the Heat Initiative to understand the effects of extreme heat on residents of South Omaha. Using a modified version of the game Operation, the team aimed to facilitate conversations and gather information about how heat impacts the human body, where these impacts occur, and which symptoms are most prevalent. Participants identified and placed model ailments into a representation of a human body and shared their personal experiences on corresponding playing cards.

Findings:
The engagement activity yielded detailed insights into the local impacts of extreme heat. Participants reported various heat-related issues, with specific observations depending on their locations:

Group A: Found significant heat impacts within residential areas, such as homes and nearby blocks. One resident highlighted a combination of heat exhaustion and other symptoms like headaches and nausea linked to local gas smells and drain issues at a specific address.

Group B: Identified concerns about heat and odor in public spaces, including streets near the Kroc Center and residential neighborhoods. Issues included strong odors from meatpacking plants and inadequate shade in high-traffic areas, resulting in intense heat and discomfort.

Group C: Documented significant heat impacts at local parks and community events. Residents expressed problems with sun exposure during events at Upland Park and other locations, where lack of shade led to sunburn and heat exhaustion.

Overall, the data collected highlighted critical areas and specific issues affecting residents, providing valuable insights to inform future design interventions aimed at mitigating extreme heat and enhancing community comfort.

MITIGATION

Goal:
The Mitigation group’s objective was to gather community feedback on various heat mitigation strategies for South Omaha. By utilizing a card/board game, the team aimed to engage residents in prioritizing and discussing potential interventions. This interactive approach not only provided insight into the community’s preferences but also facilitated

The Setup of Impaction

Students Assisting a Stakeholder Begin Gameplay

Student Assisting a Stakeholder in Sharing Their Thoughts

Stakeholder Playing Impaction

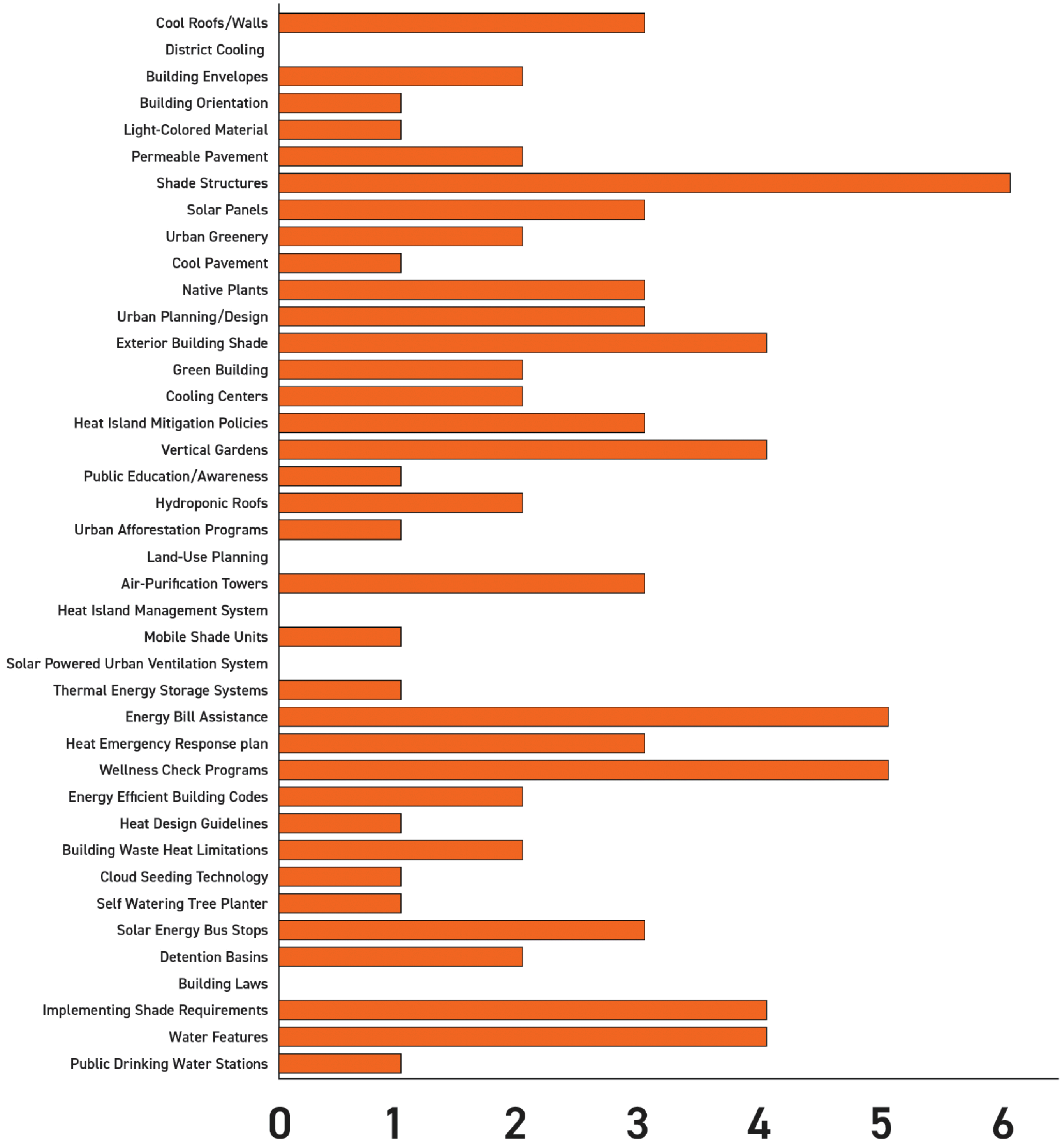
important conversations about how extreme heat impacts residents. The feedback was intended to guide the design of effective and community-centered heat mitigation solutions.

Findings:
The engagement activity produced two key data sets:

Pre-Game Voting Data: Participants initially voted on their preferred heat mitigation strategies from a selection of 40 cards. This voting process helped identify the community's top choices and highlighted the strategies they most wanted to see implemented in their area. Some of the top mitigation strategies selected as part of the Pre-game Voting Data include incorporating shade structures, energy bill assistance, and wellness check programs.

Challenge Response Data: During the game, participants responded to specific heat-related challenges using the mitigation cards. This provided insights into how residents perceive various strategies in the context of real-world issues such as heat, transportation, odors, and building stress. The data revealed which strategies were favored for addressing specific challenges and offered practical solutions for community problems.

The activity successfully engaged residents, who



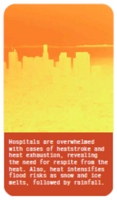
Cool Roofs/Walls	3
District Cooling	0
Building Envelopes	2
Building Orientation	1
Light-Colored Material	1
Permeable Pavement	2
Shade Structures	6
Solar Panels	3
Urban Greenery	2
Cool Pavement	1
Native Plants	3
Urban Planning/Design	3
Exterior Building Shade	4
Green Building	2
Cooling Centers	2
Heat Island Mitigation Policies	3
Vertical Gardens	4
Public Education/Awareness	1
Hydroponic Roofs	2
Urban Afforestation Programs	1
Land-Use Planning	0
Air-Purification Towers	3
Heat Island Management System	0
Mobile Shade Units	1
Solar Powered Urban Ventilation System	0
Thermal Energy Storage Systems	1
Energy Bill Assistance	5
Heat Emergency Response plan	3
Wellness Check Programs	5
Energy Efficient Building Codes	2
Heat Design Guidelines	1
Building Waste Heat Limitations	2
Cloud Seeding Technology	1
Self Watering Tree Planter	1
Solar Energy Bus Stops	3
Detention Basins	2
Building Laws	0
Implementing Shade Requirements	4
Water Features	4
Public Drinking Water Stations	1

were enthusiastic about providing feedback and participating in the game. The collected data will be instrumental in prioritizing and refining heat mitigation strategies, ensuring that future interventions align with community needs and preferences. The combination of general preferences and challenge-specific responses will help in designing targeted and effective solutions for mitigating extreme heat in South Omaha.

SITES

Goal:
The Sites group's objective was to identify and

HEAT



Hospitals are overwhelmed with cases of heatstroke and heat exhaustion, revealing the need for respite from the heat. Also, heat intensifies flood risks as snow and ice melts, followed by rainfall.

①

ROUND 1

SHADE STRUCTURES

A designed architectural element or feature implemented to provide protection from sunlight and glare. These could be awnings, umbrellas, pergolas, trellises, and canopies.

ROUND 9

WELLNESS CHECK PROGRAMS

Programs to check in on vulnerable populations can reduce heat-related illness and emergencies.

HEAT

- Implementing Shade Requirements
- Solar-Energy Bus Stops
- Energy-Efficient Building Codes
- Urban Greenery
- Shade Structures

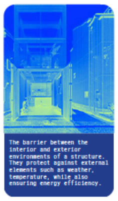
SMELL

Heat increases molecular movement, causing odors to spread more quickly. Urban temperature inversions trap these odorous compounds closer to the ground, intensifying bad smells.

②

ROUND 2

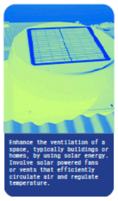
BUILDING ENVELOPES



The barrier between the interior and exterior environments of a structure. They protect against external elements such as weather, temperature, while also ensuring energy efficiency.

ROUND 10

SOLAR-POWERED VENTILATION SYSTEM



Enhance the ventilation of a space, typically buildings or homes, by using solar energy. Involve solar powered fans or vents that efficiently circulate air and regulate temperature.

SMELL

- Cooling Roofs/Walls
- Heat Island Mitigation Policies
- Land-Use Planning
- "Get yourself together, it's the Industry here!"
- Hydroponic Roofs
- Air-Purification Towers

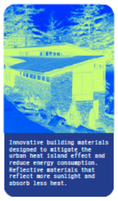
HOUSING

In regions with extreme heat, poorly designed or constructed housing can exacerbate heat retention, leading to discomfort, health risks, and increased energy consumption for cooling.

③

ROUND 3

COOLING ROOFS/WALLS



Innovative building materials designed to mitigate the urban heat island effect and reduce energy consumption. Reflective materials that reflect more sunlight and absorb less heat.

ROUND 11

COOLING ROOFS/WALLS

Innovative building materials designed to mitigate the urban heat island effect and reduce energy consumption. Reflective materials that reflect more sunlight and absorb less heat.

HOUSING

- Cooling Centers
- Land-Use Planning
- Building Envelopes
- Heat Island Mitigation Policies
- Vertical Gardens

ENERGY

Inefficient use of energy in heating processes wastes energy, money, and strains the energy grid. The heat can result in power outages, leaving communities without access to cooling systems.

④

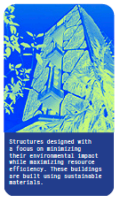
ROUND 4

BUILDING WASTE HEAT LIMITATIONS

Setting limits on the amount of waste heat a building can produce (such as heat from window air conditioners) can reduce outdoor temperatures.

ROUND 12

GREEN BUILDING



Structures designed with a focus on minimizing their environmental impact while maximizing resource efficiency. These buildings are built using sustainable materials.

ENERGY

- Building Envelopes
- Heat Emergency Response Plan
- Public Education/Awareness
- Cooling Pavement
- Exterior Building Shade

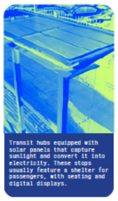
TRANSPORTATION

Inadequate shade at bus stops intensifies discomfort for commuters during hot days. Road infrastructure damage from heat poses as hazards and disruptions to commuters and the Food Supply Chain.

⑤

ROUND 5

SOLAR-ENERGY BUS STOP



Transit hubs equipped with solar panels that capture sunlight and convert it into electricity. These stops usually feature a shelter for passengers, with seating and digital displays.

TRANSPORTATION

- Public Drinking Water Stations
- Urban Planning and Design
- Land-Use Planning

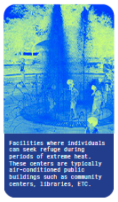
EDUCATION

Schools are forced to close due to extreme temperatures, impacting student education. Also, the heat poses risk to outdoor play, limiting opportunities for children's growth and development.

⑥

ROUND 6

COOLING CENTERS



Facilities where individuals can seek refuge during periods of extreme heat. These centers are typically air-conditioned public buildings such as community centers, libraries, ETC.

EDUCATION

- Wellness Check Programs
- Mobile Shade Units
- Shade Structures

BUILDING STRESS

Heat damages buildings and infrastructure by causing expansion and contraction, intensified by darker materials on walls and roofs that absorb heat, leading to rapid urbanization.

⑦

ROUND 7

HEAT DESIGN GUIDELINES

Heat design guidelines support infrastructure's ability to withstand projected heat conditions throughout its useful life.

BUILDING STRESS

- Implementing Shade Requirements
- Heat Design Guidelines
- Urban Afforestation Programs

MENTAL HEALTH CRISIS

Prolonged exposure to extreme heat takes a toll on residents' mental health, leading to stress, anxiety, and depression. Losing the ability to enjoy the outdoors has an affect on this.

⑧

ROUND 8

WELLNESS CHECK PROGRAMS

Programs to check in on vulnerable populations can reduce heat-related illness and emergencies.

MENTAL HEALTH CRISIS

- Energy Bill Assistance
- Urban Greenery
- "Cooling center with a buddy"

Challenge cards with winning card(s) from all rounds of game play

Other mitigation cards chosen by players to combat challenge card


cross walk
Food Pantries
moved
Trees
Trees
Kids Crossing (only red button)

map key areas within South Omaha where heat mitigation and other improvements are most needed. The activity aimed to engage residents and technical stakeholders in pinpointing specific locations associated with various conditions, such as extreme heat, odor, safety concerns, and community gathering spots. By using flags and a detailed map, the group sought to gather comprehensive feedback on these elements to guide future project focus.

Findings:
The activity successfully pinpointed critical locations and issues within the community. Participants used pins and notes to mark areas of concern, including:

Heat and Odor Hotspots: Residents highlighted areas suffering from extreme heat and unpleasant odors, particularly around South 27th Street, which is plagued by roadkill and decomposing animals exacerbated by summer heat. They also identified issues with sewer gas and manure from livestock trucks.

Safety and Aesthetics: Specific locations were flagged for being unsafe or unattractive. Residents noted the negative impacts of abandoned lots and industrial activities on their neighborhoods.

Community Spaces: The desire for improved public spaces was evident, with suggestions for enhanced parks, shaded bus stops, and better street design. The idea of a community innovation space similar to Do Space was also discussed.

Miscellaneous Issues: Additional concerns included the need for improved park cleanliness, street enhancements (wider sidewalks, slower speed limits), and stormwater management concerns.

Overall, the On-Site group's activity revealed a range of issues affecting the community and provided valuable insights into where and how mitigation efforts should be prioritized. The feedback collected will inform targeted interventions aimed at improving the quality of life and addressing specific challenges faced by South Omaha residents.

04

GLOSSARY + RESOURCES

GLOSSARY

A

Adaptation Planning: Developing strategies and actions to prepare for and reduce the impacts of extreme heat and climate change.
Adaptive Capacity: The ability of a system, community, or environment to adjust to extreme heat, minimizing potential damage or harm.
Air Conditioning: A system used to cool indoor spaces, which can be crucial during extreme heat events but also contributes to energy demand.
Albedo: The measure of reflectivity of a surface, with higher albedo surfaces reflecting more solar energy and helping to reduce heat absorption.
Ambient Temperature: The temperature of the surrounding air, which influences thermal comfort and heat stress.
Anisotropic: Anisotropic refers to a property of a material or object that varies depending on the direction in which it is measured. In other words, an anisotropic material has different physical properties (such as strength, conductivity, or light refraction) when measured along different axes or directions.
Anthropogenic Heat: Heat generated by human activities, including transportation, industrial processes, and energy use, contributing to the UHI effect.
ArcGIS: A geographic information system (GIS) used to analyze spatial data, including mapping heat islands and planning heat mitigation strategies.

B

Bioclimatic Design: An approach to building and landscape design that considers the climate and environmental conditions to improve thermal comfort.
Blue Infrastructure: The strategic use of water bodies and elements in urban areas to provide cooling and other ecosystem services.
Building Orientation: The positioning of a building in relation to the sun and wind, which can impact its exposure to heat and cooling efficiency.

C

Carbon Sequestration: The process of capturing and storing carbon dioxide from the atmosphere, which can be aided by urban green spaces and vegetation.
Catastrophe (CAT) Bond: A financial instrument designed to raise money in case of a catastrophe, used for funding responses to extreme heat and other disasters.
Climate Resilience: The ability of communities and ecosystems to withstand, recover from, and adapt to climate-related stresses like extreme heat.
Cool Corridors: Shaded urban pathways designed to provide relief from heat for pedestrians and cyclists.
Cool Roofs: Roofing materials that reflect more sunlight and absorb less heat, helping to reduce the UHI effect.
Cooling Centers: Public facilities designated as safe places for people to go during extreme heat events to avoid heat-related illnesses.
Community Resilience: The ability of a community to prepare for, respond to, and recover from heat events and other environmental challenges.

D

District Cooling: A system that distributes chilled water to multiple buildings for cooling purposes, reducing the need for individual air conditioning units.

E

Ecosystem Services: The benefits provided by natural ecosystems, including cooling through shading and evapotranspiration in urban environments.
Energy Benchmarking: The process of comparing a building's energy use to similar buildings to identify opportunities for improvement, including heat resilience.
Energy Efficiency: The goal of using less energy to perform the same task, which can help reduce the demand for cooling during extreme heat events.
Evaporative Cooling: A cooling method that uses water evaporation to lower air temperature, often employed in green spaces or urban parks.

Environmental Simulation: Environmental simulation refers to the use of computer models, software, or other digital tools to replicate and analyze various environmental processes and conditions. These simulations can model a wide range of natural and human-influenced systems, such as weather patterns, climate change, air and water quality, ecosystem dynamics, and urban environments.
Extreme Heat Event: A period of excessively high temperatures that pose risks to health and safety.

G

Global Temperature Rise: The increase in Earth's average temperature due to human activities, leading to more frequent and severe heat events.
Greenhouse Gas Emissions: Gases released into the atmosphere, primarily from burning fossil fuels, that trap heat and contribute to global warming and extreme heat events.
Global Warming: The long-term rise in Earth's average temperature due to human activities, leading to more frequent and severe heat events.
Green Building: A building designed to reduce environmental impact, often incorporating strategies to mitigate extreme heat.
Green Infrastructure: A network of natural and semi-natural areas designed to deliver a wide range of ecosystem services, including cooling urban areas.
Green Roofs: Roofs covered with vegetation to absorb rainwater, provide insulation, and reduce the UHI effect.
Ground Cover: Plants or materials that cover the ground surface, helping to reduce heat absorption and mitigate the UHI effect.

H

Handheld Thermography: The use of portable infrared cameras to measure surface temperatures, often used to identify heat islands.
Heat Action Plan: A strategic plan developed by communities or cities to prepare for and respond to extreme heat events.
Heat Capacity: The amount of heat energy required to change the temperature of a material, affecting how quickly urban areas heat up or cool down.
Heat Dome: A weather phenomenon where a high-pressure system traps warm air, leading to prolonged periods of extreme heat.
Heat Emergency Response Plan: A plan outlining the actions to be taken by individuals, communities, and governments during extreme heat events to protect public health.
Heat Index: A measure that combines air temperature and relative humidity to determine how hot it feels to the human body.
Heat Inversion (Temperature Inversion):
A heat inversion, or temperature inversion, occurs when a layer of warmer air traps cooler air beneath it, reversing the typical atmospheric temperature pattern where air cools with altitude. This phenomenon creates a stable layer that prevents the cooler air near the ground from rising and mixing with the warmer air above. Heat inversions can lead to air quality problems because they trap pollutants, such as smog and particulate matter, close to the surface.
Heat Island: Urban areas that experience higher temperatures than their rural surroundings due to human activities and built environments.
Heat-Related Illness: Health conditions caused by excessive heat exposure, including heat exhaustion, heat cramps, and heatstroke.
Heat Resilience: The ability of a community, system, or individual to withstand, respond to, and recover from the impacts of extreme heat.
Heat Stress: The physical strain on the body due to prolonged exposure to high temperatures, which can lead to heat-related illnesses.
Heat Vulnerability Index (HVI): A tool used to identify populations or regions most at risk of adverse health outcomes from extreme heat.

I

Indoor Thermal Comfort: The condition of mind that expresses satisfaction with the indoor thermal environment; influenced by temperature, humidity, and air movement.
Infrared Thermography: The use of infrared cameras to capture temperature variations on surfaces, useful in identifying heat islands and thermal inefficiencies.

Intergovernmental Panel on Climate Change (IPCC): The IPCC is a United Nations body established to provide scientific assessments on climate change, its impacts, and potential future risks, as well as adaptation and mitigation strategies.

L

Land Surface Temperature (LST): The temperature of the Earth's surface, as measured from satellite or ground-based sensors.

Landsat: Landsat is a long-running satellite program jointly managed by NASA and the U.S. Geological Survey (USGS) that provides high-resolution imagery of Earth's surface. Since its launch in 1972, the Landsat program has captured detailed data on land use, vegetation, water bodies, and urban development. The data collected by Landsat satellites is used for a wide range of applications, including environmental monitoring, agriculture, forestry, and urban planning.

Low Impact Development (LID): Sustainable land development practices that reduce environmental impact, including strategies for managing heat and stormwater.

M

Mean Radiant Temperature (MRT): Mean Radiant Temperature (MRT) is a measure of the average temperature of all surrounding surfaces that contribute to the radiant heat exchange experienced by a person or object. It reflects how the temperature of the environment (e.g., walls, ground, buildings) affects thermal comfort through radiation. MRT is a key factor in human thermal comfort models because it accounts for the heat radiated from surfaces, which can significantly impact how hot or cold a person feels, especially in outdoor urban environments where surfaces like pavement or buildings may absorb and emit heat.

Microclimate: The localized climate of a specific place, which can differ significantly from the broader regional climate.

Microgrid: A localized grid that can operate independently or in conjunction with the main electrical grid, providing energy resilience during extreme heat events.

Mitigation: Measures taken to reduce the severity of heat in urban areas, such as increasing green spaces or reflective surfaces.

Mobile Biometeorological Instrument Platform: A portable system for measuring various climatic parameters, including temperature and humidity, to assess heat exposure.

Multispectral Imaging: The use of sensors to capture data across different wavelengths, often used in remote sensing to study vegetation and surface temperatures.

N

National Oceanic and Atmospheric Administration (NOAA): NOAA is a U.S. federal agency focused on understanding and monitoring the Earth's oceans, atmosphere, and climate. It conducts research, provides weather forecasts, tracks severe weather events, monitors marine ecosystems, and plays a key role in studying climate change and its impacts on the environment.

O

Orthomosaic: An orthomosaic is a high-resolution, geometrically corrected image created by stitching together multiple aerial photographs. Unlike standard aerial images, orthomosaics are free from distortions caused by perspective, camera angle, or terrain variations, ensuring that the scale is uniform across the entire image. This allows for accurate measurements of distance, area, and angles directly on the image. Orthomosaics are commonly used in mapping, surveying, urban planning, and landscape architecture to provide detailed, accurate representations of large areas.

P

Passive Cooling: Design strategies that cool buildings and spaces without the use of mechanical systems, often through natural ventilation and shading.

Permeable Pavement: A type of pavement that allows water to pass through it, reducing surface temperatures and aiding in stormwater management.
Phenological Change: Phenological change refers to the timing of seasonal and biological events in plants and animals, such as flowering, leaf unfolding, fruiting, and migration, which are influenced by environmental factors like temperature and weather patterns. This term is often used to study the impacts of climate change on ecosystems.
Photogrammetry: Post-processing and generating 3D models and orthoimages from georeferenced 2D images.
Photovoltaic (PV) Panels: Solar panels that convert sunlight into electricity, which can also provide shading and reduce heat gain in urban areas.
Public Health Emergency: A state of emergency declared due to a public health threat, such as extreme heat, allowing for special measures to protect the population.

R

Radiant Heat: The transfer of heat through electromagnetic waves, which can contribute to outdoor thermal discomfort during heatwaves.
Reflective Surfaces: Materials designed to reflect sunlight rather than absorb it, helping to reduce heat buildup in urban areas.
Rhino3D: Rhino3D is a 3D computer graphics and computer-aided design (CAD) software developed by Robert McNeel & Associates, primarily used for creating, editing, and analyzing complex three-dimensional models across various industries including architecture, engineering, and product design.

S

Shade Analysis: The study of how shadows are cast by objects and structures, used to plan for cooling through strategic shading.
Shading: The use of trees, awnings, or other structures to block direct sunlight and reduce ambient temperatures.
Sky View Factor (SVF): The proportion of sky visible from a point on the ground, influencing how much heat an area retains or loses.
Solar Reflectance Index (SRI): A measure of a material's ability to reflect solar heat, with higher values indicating cooler surfaces.
Solar Noon: Solar noon is the moment when the sun reaches its highest position in the sky for a given location, directly aligning with the meridian of that location. It is the time of day when the sun is at its maximum elevation, resulting in the shortest shadow of the day for objects at that specific location.
Solar Radiation: The energy emitted by the sun, which affects surface temperatures and can be mitigated by reflective or shaded surfaces.
Surface Temperature: The temperature of the ground or any other surface, which can be significantly higher than air temperature during heat events.

T

Thermal Comfort: A condition of mind that expresses satisfaction with the thermal environment; influenced by temperature, humidity, and air movement.
Thermal Imaging: A technology that captures temperature differences on surfaces, often used to detect heat islands or areas of poor insulation.
Thermal Mass: The ability of a material to absorb and store heat energy, helping to moderate temperature fluctuations.
Thermal Resilience: The ability of buildings and communities to maintain thermal comfort during extreme heat events.
Thermography: The use of infrared imaging to measure temperature variations, useful in identifying heat islands and thermal inefficiencies.
Tree Canopy: The layer of leaves, branches, and stems of trees that provide shade and cooling in urban environments.
Tree Planting Programs: Initiatives to increase tree cover in urban areas, which can help to mitigate heat and improve environmental quality.

U

Urban Canyon: Narrow street corridors lined with tall buildings, where limited airflow can trap heat and exacerbate the UHI effect.
Urban Forestry: The management and care of trees in urban settings, contributing to cooling through shading and evapotranspiration.
Urban Heat Island (UHI): An urban area that experiences higher temperatures than its rural surroundings due to human activities and the concentration of buildings and infrastructure.

V

Vegetative Cooling: The cooling effect produced by plants through processes such as shading and evapotranspiration, reducing local temperatures.
Vegetative Roofs: Also known as green roofs, these are rooftops covered with vegetation to absorb rainwater, provide insulation, and reduce the UHI effect.
Ventilation: The process of moving air through a space, which can help reduce indoor temperatures during extreme heat events.
Vulnerability Assessment: The process of identifying and evaluating the susceptibility of populations, infrastructure, or ecosystems to the impacts of extreme heat.

W

Water Retention: The ability of a surface or material to retain water, which can help cool the environment through evaporation.
Wet Bulb Globe Temperature (WBGT): A composite temperature used to estimate the effect of temperature, humidity, wind speed, and solar radiation on humans.

Z

Zero Net Energy (ZNE): A building or community that produces as much energy as it consumes, often incorporating strategies for cooling and heat resilience.

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