HOT ZONES: URBAN HEAT ISLANDS

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Research brief by
Climate Central

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Urban Heat Islands

INTRODUCTION

Urban heat islands are metropolitan places that are hotter than their outlying areas, with the impacts felt most during summer months. About 85% of the U.S. population lives in metropolitan areas. Paved roads, parking lots, and buildings absorb and retain heat during the day and radiate that heat back into the surrounding air. Neighborhoods in a highly-developed city can experience mid-afternoon temperatures that are 15°F to 20°F hotter than nearby tree-lined communities or rural areas with fewer people and buildings.

Climate change is making extreme heat events worse and more frequent, with summer temperatures stretching into the shoulder seasons of spring and fall. Heat events adversely affect health and quality of life—and this is especially acute in urban communities. Higher cooling demand strains the electric grid and raises electric bills. And heat-related impacts fall unequally, with historically underserved populations facing greater health threats.

This report will look at the factors that contribute to the heat island effect, and our analysis will show how they vary in places across the United States. We'll discuss some of the impacts of higher temperatures on human health and the built environment. We'll also take a look at how communities are adapting to these new normals and consider solutions for lessening some of the intensity of the urban heat island.

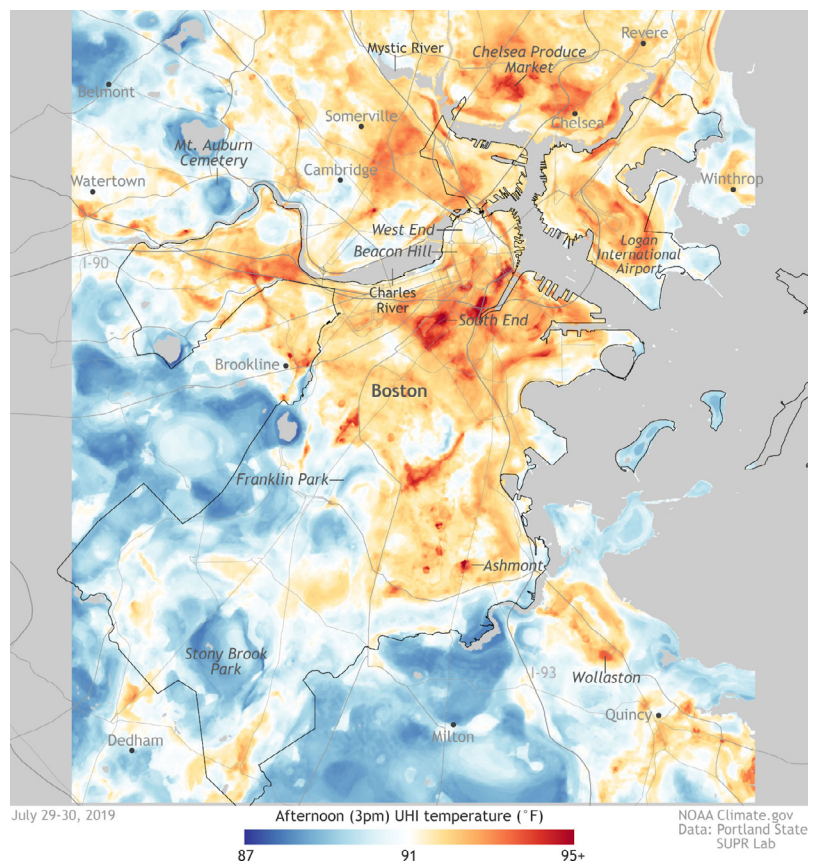## CLIMATE CENTRAL'S URBAN HEAT INTENSITY INDEX

Climate Central created an index to evaluate the intensity of urban heat islands (UHI) and applied it to 159 cities in the U.S. The index is based on research led by Valentino Sangiorgio that quantifies the factors that cause developed areas to heat up. By measuring the type of land cover in each city, from greenspace to paved areas, and factoring in building height and population density, our research team adapted the Sangiorgio model to estimate how urban heat island intensity varies across U.S. cities.

The primary contributions to the intensity score are (in order of contribution):

- Albedo
- Percentage of greenery
- Population density
- Building height
- Average width of streets and irregularity of the city

The index score for a city is a temperature showing the potential difference in average temperature for the city compared to its less

Boston-area urban heat island effect

July 29-30, 2019

Afternoon (3pm) UHI temperature (°F)

87   91   95+

NOAA Climate.gov
Data: Portland State
SUPR Lab

developed surroundings. The temperatures range from less than 5°F to nearly 9°F. It's important to remember that each score is an average for the entire city, and certain neighborhoods or areas of a city will likely be cooler or hotter, depending on vegetation and other factors. So for example, our index shows that Baltimore may be up to 7°F warmer on average, although within the city, residents living next to a park will be cooler than residents living next to a parking lot or highway.

The cities with the five highest scores are New Orleans, Newark, N.J., New York City, Houston and San Francisco. Yet each city has its own unique layout, showing that the overall heat island effect is composed of different elements in each city.

Cities in the Midwest and Northeast, such as New York, Newark, Boston, Chicago, Providence, Detroit and Cleveland have more compact, historically built-out environments, with taller buildings. These factors add to the intensity of their urban heat island footprint. Cities like Houston and Fresno, Calif., scored higher due to the large percentage of impermeable surfaces that make up their city's topography.

Do urban heat islands only occur in large cities?

Malls, parking lots, hospital campuses, playgrounds--anywhere with more impervious surfaces and fewer trees can create a heat island effect, even if they are located in what might be considered a rural or suburban area. The term "urban" has no standard definition. What is considered urban in one city or region may be very different from another city. And there are different scales of urban heat islands to show heat island effects in parts of a city: microscale (yard), local (neighborhood) mesoscale (city).

Table 1: Top 20 cities urban heat island intensity

CITY	INDEX SCORE (°F)	CRITICAL COMPONENT(S)
1. New Orleans	8.94	Albedo, impermeable surface
2. Newark, N.J.	7.71	Impermeable surface, building height, population density
3. New York City	7.62	Building height, impermeable surface, population density
4. Houston	7.46	Impermeable surface, albedo
5. San Francisco	7.37	Building height, impermeable surface, population density
6. Boston	7.24	Building height, population density
7. Chicago	7.24	Building height, Impermeable surface, population density
8. Miami	7.24	Building height, Impermeable surface
9. Baltimore, Md.	7.08	Building height, impermeable surface
10. Providence, R.I.	7.08	Building height, impermeable surface
11. Sacramento, Calif.	7.08	Building height, impermeable surface
12. Salinas, Calif.	7.08	Albedo, Impermeable surface
13. Burlington, Vt.	7.05	Albedo
14. Bend, Ore.	6.97	Albedo, impermeable surface

CITY	INDEX SCORE (°F)	CRITICAL COMPONENT(S)
15. Cleveland, Ohio	6.97	Building height, Impermeable surface
16. Detroit	6.97	Impermeable surface, building height
17. Erie, Pa.	6.97	Impermeable surface
18. Fresno, Calif.	6.97	Impermeable surface
19. Lafayette, La.	6.97	Impermeable surface, building height
20. McAllen, Texas	6.97	Impermeable surface

Perhaps surprisingly, many cities in the extremely hot Southwest scored lower on the index. Their relatively low scores are largely because their surrounding areas have temperatures similar to city temperatures. That doesn't mean these cities aren't experiencing heat impacts. Rather, it emphasizes that much of the outlying area consists of desert or rock, which have lower albedo and are thus naturally hotter.

WHY IT'S HOTTER IN THE CITY

By mid-summer of 2021, communities across the United States had already sweltered through record-shattering heat events. Urban heat islands can exacerbate the impact of these heat waves, compromising health and comfort, and often creating dangerous conditions for many vulnerable populations.

A number of the reasons why urban areas get hotter were included as components in our heat intensity index:

There are more human-created heat emissions. Population density matters. Heat emissions come from all the activities of city life: transportation, machinery and appliances, industrial facilities, and the heating and cooling of buildings. During a heat wave, air conditioning from urban buildings can add 20% more heat to the outside air, compared to regular summer weather.

Less vegetation means reduced evaporative cooling. Partially through a process called evapotranspiration, plants help cool the air. Leaves absorb some of the heat energy from the air, causing evaporation of water

Graphic 1: Impermeable surfaces and less vegetation add to the heat island effect.
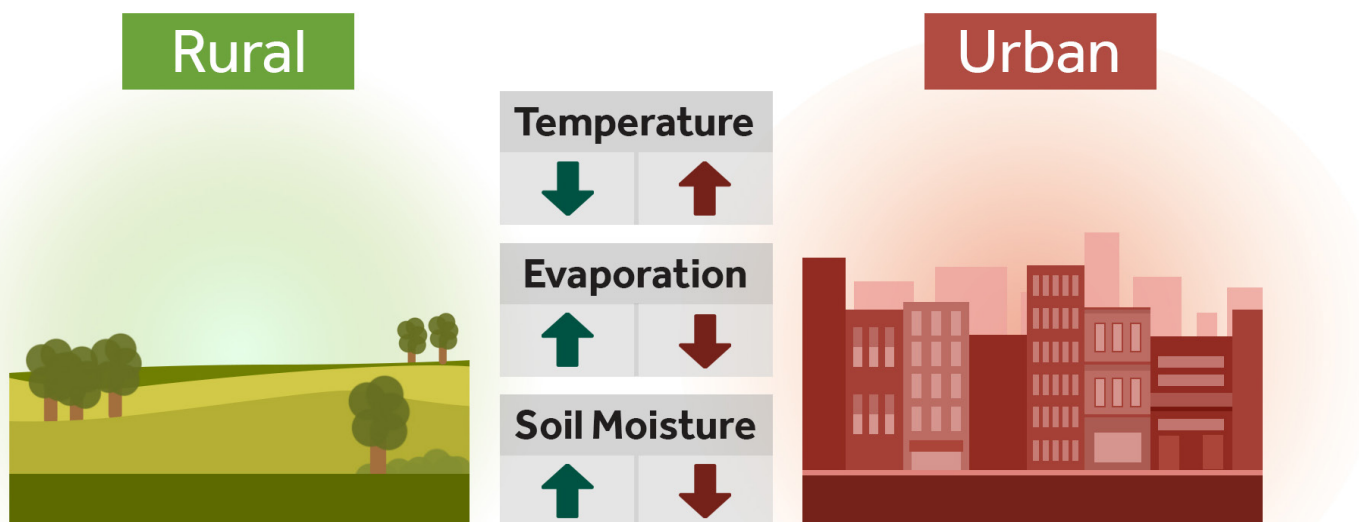
within the leaves. Because evaporation is a cooling process, the surrounding air slightly cools. Replacing trees with buildings or concrete reduces this natural cooling effect. The flip side is that trees and vegetation, alone or in combination with shading, can help reduce peak summer temperatures by 2–9°F (1–5°C) in an urban area.

The shape and height of buildings can impact airflow. Scientists call it "increased surface roughness." Simply, the size and dimensions of buildings influence how air moves through a city during the day, playing a large role in the trapping or dissipation of heat.

Narrow urban canyons cause warmer air to linger over cities, especially at night. Tall buildings provide multiple surfaces that reflect and absorb sunlight and also block wind. This can create large masses of trapped hot air that cannot release heat very readily because of the obstruction of neighboring buildings. Besides preventing cooling down, this type of urban geometry can prevent pollutants from dissipating, reducing air quality.

Miles of hard, dark surfaces in a city absorb and then radiate back heat. Albedo indicates the percentage of sunlight reflected by a surface. Lower albedo means that a surface is absorbing more sunlight and thus heating up. Cities' roads and sidewalks, buildings and parking lots—whether brick, asphalt, or concrete—all have low albedo.

HOW DO WE MEASURE THE HEAT AND INTENSITY OF URBAN HEAT ISLANDS?

Climate change and urban heat islands

Climate change is caused by increased greenhouse gas emissions, and is not confined to any particular location or region—it's global. Urban heat islands are local—caused by development and the increase of impermeable surfaces and loss of vegetation in cities, impacting the local microclimate. Heat islands are further affected by a city's location, seasonal weather patterns, and daily weather variability can affect their intensity. In addition, climate change is increasing the frequency, intensity, and/or duration of extreme weather events. These two effects compound to cause extra warming in many cities and should be factored into individual city's adaptation strategies.

While humans are creating new urban heat islands, this does not explain the warming trends that scientists have been recording. We see evidence of warming across the planet, including in the oceans where urbanization is not a factor and in weather stations in rural areas. We also see warming trends in places like New York City that have been urban heat islands for a very long time.

Urban heat islands are usually considered the temperature difference between a city and its surrounding areas, but temperatures can vary widely within a city. Some areas can get hotter than others due to the amount of heat-absorbing buildings and pavements, while other neighborhoods are cooler because of more trees and green space. These temperature differences create smaller, intra-urban heat islands. In graphic 2 on page 7, you can see that parks, ponds, and residential areas are cooler than downtown areas with tall buildings.

There are several ways to collect temperature data.

- To measure air temperature, monitors are generally situated on shaded level ground, away from concrete, about 4 to 6 feet above the ground.

- Measuring **surface temperatures** shows how solar radiation can heat up exposed surfaces, like roofs and pavement, to temperatures much hotter than the air. For example, during the heatwave in the Pacific Northwest in June, ground temperatures in urban areas of Washington state reached 131°F.

- Researchers can use instruments mounted on satellites and airplanes to look at temperature differences at very fine scales, such as the difference between a running track and an adjacent grassy field. A combination of satellite data for surface temperatures and air temperature data from monitoring stations can help create a more complete picture of a city's heat island.

The temperature at the ground level can vary from the air above the city. **Surface urban heat islands** differ from **atmospheric urban heat islands** in the ways they get formed, how they are measured, and in their impacts and mitigation solutions (see graphic 2).

Surface urban heat islands are strongest during the day. Clear skies with little or no wind produce the most intense summertime heat island conditions. Cloud cover helps to block solar radiation and strong winds increase atmospheric mixing.

Canopy layer urban heat islands exist in the layer of air where people live, from the surface to below the tops of trees and roofs. **Boundary layer urban heat islands** begin at the rooftop and treetop level and extend up to the point where urban landscapes no longer influence the atmosphere.

IMPACTS OF URBAN OVEARHEATING ON AIR QUALITY, HEALTH, AND ENERGY DEMAND

Extreme heat is the top weather killer. Urban heat islands worsen the impact of heat waves, particularly for vulnerable populations, such as children, older adults, and those with existing health conditions. Extreme heat is the leading cause of death among weather-related fatalities over the past 30 years, according to the National Weather Service. The 1995 Chicago heat wave was one of the deadliest climate disasters in U.S. history, killing 739 people, mostly elderly and poor. Its impacts were felt worst in older, industrialized neighborhoods with buildings with black roofs and poor ventilation, surrounded by pavement.

Documenting urban heat islands at the "hyperlocal" level

Since 2017, NOAA has supported community-led urban heat island mapping campaigns in a growing number of cities every year. In each city, NOAA partners with local universities and environmental and social justice groups to study how heat risk aligns with other important dimensions of local vulnerability to heat events, including race and ethnicity, income, access to air conditioning, and comorbidities for heat illness. Local volunteers traverse their city using specially-designed sensors to record temperature and humidity. Block by block, they find the most dangerous local hot spots, including where kids walk to school, ball fields, bus stops, and other heavily-used places. Dr. Kim Cobb, a climate scientist at Georgia Tech is part of the Atlanta team this year, and underlined the importance of involving the community. "You can't sit on the sidelines and hurl reports at them," she says. "We need to begin conversations about what cities can do and get through these acute heat periods. We can get ahead of the scramble and mobilize a community through its connective tissue." She said that engagement creates better opportunities to then talk about the longer-term infrastructure issues and need for resources.

Extreme heat makes air pollution worse. Hot weather patterns can trap pollutants in the lower atmosphere, in a phenomenon known as stagnation. These nearly stationary domes of hot air may hold particulates and ground-level ozone, causing health problems from respiratory distress to eye irritation. In addition, heat and sunlight directly contribute to creating ground-level ozone. Long-term exposure to ozone pollution can cause asthma, increased allergies, and other damage to respiratory health.

Heat and heat-amplified air pollution worsen existing health conditions. Ground-level ozone and particulates irritate the lungs, and are particularly harmful to people with conditions like asthma. Extreme heat and exertion can make you sweat profusely, leading people with diabetes to become dehydrated and experience a rise in glucose levels. Also, diabetes can affect your sweat glands so your body can't cool as effectively. And individuals with pre-existing cardiovascular diseases are at a greater risk for morbidity and mortality during extreme heat events.

Extreme heat makes it harder and even dangerous for people to work outside. Workers who are exposed to extreme heat or work in hot environments are at risk of heat stress. Those at high risk during a heat episode include outdoor workers such as farmers and construction workers, and those in hot environments such as bakery workers, miners, boiler room workers, factory workers, and others.

Low-income neighborhoods and communities of color face disproportionate impacts. Research has found that neighborhoods experiencing higher intensity urban heat islands were often the same ones subjected to discriminatory, race-based housing practices known as redlining. People living in households below the poverty line also tend to live in areas that have less green space compared to those at more than two times the poverty line. This interactive map created by the Science Museum of Virginia and Esri shows formerly redlined neighborhoods in 108 cities and their exposure to urban heat.

Increased energy demand for cooling strains the grid, drives up energy costs, and creates more greenhouse gas emissions. Areas around the country now brace for rolling blackouts or power outages, which have the potential to become life-threatening in a matter of hours for certain vulnerable populations. Lower-income households face energy burdens, typically living in less energy efficient homes and paying disproportionately more than the average household for energy. Air conditioners dump heat into the surrounding atmosphere, contributing directly to urban heat island effects. And with 60% of the nation's electricity still supplied by burning coal, oil, or natural gas, air conditioners contribute to carbon dioxide emissions, creating a bad climate feedback loop.

ADAPTATION AND MITIGATION SOLUTIONS

Extreme urban heat is a public health threat, especially for individuals and communities that are more vulnerable due to health, social, economic, or other reasons. But there are a number of short-term and long-term solutions to adapt to an increasingly warmer future, as well as to mitigate some of the urban heat stress.

Short term solutions are mostly about getting people out of the heat and ensuring their health and safety. A number of cities have created strategies to assist the most vulnerable communities, and Miami appointed its first ever Chief Heat Officer to coordinate efforts to protect people from the heat in May 2021. Other community efforts can include:

- Assistance with energy bills.
- Providing information and transportation to public places with air conditioning or cooling centers.
- Public alerts, telephone hotlines and neighborhood teams to look in on seniors and those with health conditions.

Graphic 2: Heat Island temperature profile. Temperature varies depending on land use

Longer-term solutions are often more difficult in terms of planning and finding adequate resources and funding, and not all mitigation strategies work for all places.

- Planting trees, particularly along paved streets. Shaded surfaces may be 20–45°F (11–25°C) cooler than the peak temperatures of unshaded surfaces. Trees also absorb carbon dioxide (a greenhouse gas), improve air quality, and can slow down stormwater runoff. American Forests have created an interactive tool to look at "tree equity" at the local level.

- A green roof, or rooftop garden, is a vegetative layer grown on a rooftop and can provide shade and lower temperatures of the roof surface and surrounding air. There are a number of examples around the country. Check out the gardens on the roofs of Chicago's and Atlanta's city halls, the meadow atop a building at Brooklyn Botanical Gardens, and the American Society of Landscape Architects in Washington, D.C., which is home to nearly 5 million square feet of green roofs.

- Cool roofs are made of highly reflective and emissive materials that remain cooler than traditional materials, and help to reduce energy use.

- Cool pavements, or whitewashing roads and sidewalks, is more complicated than roofs. In cities with urban canyons, the sunlight may not even reach the street level long enough to make a significant difference. In places like Los Angeles, a cool pavement study showed that heat was reflected off the white surface, but onto pedestrians and made people feel hotter.

- While research has shown that the width of streets, canyon orientation and building heights all have a role in urban heat island, varying the height of new buildings to increase air circulation and considering the layout of streets and buildings is a holistic but much more long-term approach for cities and planners.

- ACEEE maintains a database tracking mitigation efforts for urban heat islands across most major U.S. cities.

- In 2020, solar power was the cheapest source of electricity in many parts of the world. By displacing fossil fuel-based electricity, solar energy can reduce not only carbon dioxide emissions but also reduce air pollutants that are a threat to public health. Solar panels have also been shown to provide shade and reduce the heat island effect. There are a number of equitable strategies to deploy solar energy, allowing disadvantaged communities to see significant co-benefits such as reduced energy bills and good jobs.

GLOSSARY

Albedo - A measure of a material's ability to reflect sunlight (including the visible, infrared, and ultraviolet wavelengths) on a scale of 0 to 1. An albedo value of 0.0 indicates that the surface absorbs all solar radiation, and a 1.0 albedo value represents total reflectivity.

Anthropogenic heat - Heat generated by buildings, people, or machinery.

Canopy - Tree cover in an urban setting. Canopy size is an important determinant of a city's heat island reduction potential. The "urban fabric" can be characterized both above and below the canopy for a better understanding of the area's surface cover.

Cool Roofs - Roofing material that has high solar reflectance. This characteristic can reduce heat transfer to the indoors and enhance roof durability. Cool roofs may also be highly emissive, releasing a large percentage of the solar energy they absorb.

Evapotranspiration - Plants absorb water through their roots and emit it through their leaves, called "transpiration." Evaporation, the conversion of water from a liquid to a gas, also occurs from the soil around vegetation and from trees and vegetation as they intercept rainfall on leaves and other surfaces. Together, these processes are referred to as evapotranspiration, which lowers temperatures by using heat from the air to evaporate water.

Green Roofs - Rooftops planted with vegetation. Intensive green roofs have thick layers of soil (6 to 12 inches or more) that can support a broad variety of plant or even tree species.

Microclimate - A climate in a small area that varies significantly from the overall climate of a region. Microclimates are formed by natural or man-made geography and topography, such as hills, buildings, and the presence or absence of trees and vegetation.

Surface Roughness - In the context of heat islands, this refers to the presence of buildings, trees, and other irregular land topography in an urban area.

Urban Heat Island Effect - a measurable increase in ambient urban air temperatures resulting primarily from the replacement of vegetation with buildings, roads, and other heat-absorbing infrastructure. The heat island effect can result in significant temperature differences between rural and urban areas.

Source: EPA Heat Island Effect Glossary

APPENDIX: Climate Central's Urban Heat Island Intensity Analysis Methodology

1. Using the US Local Climate Zone (LCZ) database developed by Demuzere, et al. (2020) and the city boundary file, extract the LCZ type for each grid cell within a city's boundary.

2. Calculate the total number of grid cells in each of the 14 LCZ categories and the percentage of the total for each. Two of the LCZ categories were not used by the researchers because they are not generally found in the US (#7 & #9).

3. Merge the LCZ urban canopy parameters (UCP) from Stewart and Oke (2012) to each of the LCZs. These parameters give more detail as to the characteristics of the LCZ. For the purposes of this analysis the mid-point was selected as the value for each UCP.

4. Multiply the % LCZ value in each city by the UCP for those parameters that represent a percentage.

5. For those UCPs that represent a value, assign the appropriate value to the city and LCZ.

6. For the measures of % sum across all LCZs for the city. For measures with a representative value, average across the LCZs.

7. Apply parameters of the index developed by Sangiorgio, et al (2020) to the final "totals" for each city.

8. Because of the relative consistency of particular design features of American cities, like street width and irregularity of the city, all the locations will be assigned the same value.

9. The values across all categories are then added to determine the total Urban Heat Island Intensity Index (UHII).