  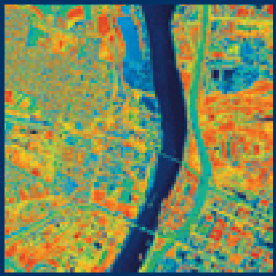 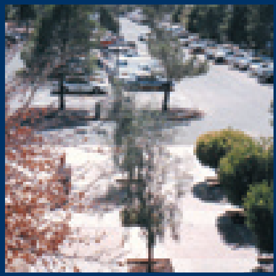 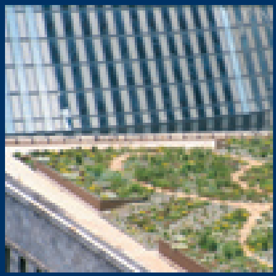

Reducing Urban Heat Islands: Compendium of Strategies

Urban Heat Island Basics

Acknowledgements

Reducing Urban Heat Islands: Compendium of Strategies describes the causes and impacts of summertime urban heat islands and promotes strategies for lowering temperatures in U.S. communities. This compendium was developed by the Climate Protection Partnership Division in the U.S. Environmental Protection Agency's Office of Atmospheric Programs. Eva Wong managed its overall development. Kathleen Hogan, Julie Rosenberg, and Andrea Denny provided editorial support. Numerous EPA staff in offices throughout the Agency contributed content and provided reviews. Subject area experts from other organizations around the United States and Canada also committed their time to provide technical feedback.

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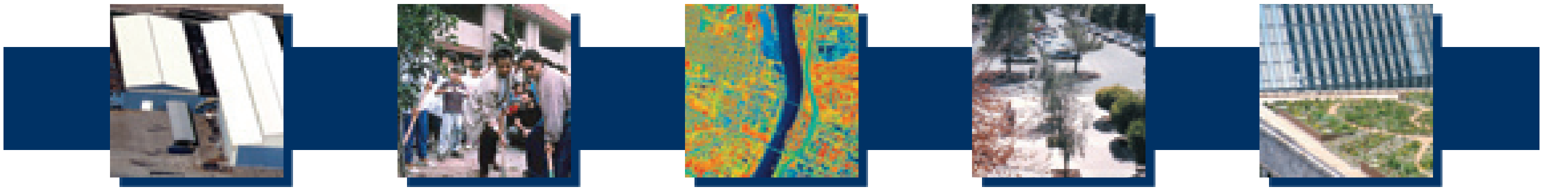
Contents



Urban Heat Island Basics

As urban areas develop, changes occur in the landscape. Buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist generally become impermeable and dry.* This development leads to the formation of urban heat islands—the phenomenon whereby urban regions experience warmer temperatures than their rural surroundings.

This chapter provides an overview of different types of urban heat islands, methods for identifying them, and factors that contribute to their development. It introduces key concepts that are important to understanding and mitigating this phenomenon, as well as additional sources of information. It discusses:

- General features of urban heat islands
- Surface versus atmospheric heat islands
- Causes of urban heat island formation
- Urban heat island impacts on energy consumption, environmental quality, and human health
- Resources for further information.

1. What Are Urban Heat Islands?

Many urban and suburban areas experience elevated temperatures compared to their outlying rural surroundings; this difference in temperature is what constitutes an urban heat island. The annual mean air temperature of a city with one million or more people can be 1.8 to 5.4°F (1 to 3°C) warmer than its surroundings,[1] and on a clear, calm night, this temperature difference can be as much as 22°F (12°C).[2] Even smaller cities and towns will produce heat islands, though the effect often decreases as city size decreases.[3]

This chapter focuses on *surface* and *atmospheric* urban heat islands. These two heat island types differ in the ways they are formed, the techniques used to identify and measure them, their impacts, and to some degree, the methods available to mitigate them. Table 1 summarizes the basic characteristics of each type of heat island. These features are described in more detail in the following sections of this chapter.

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* This change in landscape may differ in regions such as deserts, where moisture may increase in urban areas if development introduces grass lawns and other irrigated vegetation.

Table 1: Basic Characteristics of Surface and Atmospheric Urban Heat Islands (UHIs)[4]

Feature	Surface UHI	Atmospheric UHI
Temporal Development	• Present at all times of the day and night • Most intense during the day and in the summer	• May be small or non-existent during the day • Most intense at night or predawn and in the winter
Peak Intensity (Most intense UHI conditions)	• More spatial and temporal variation: ▪ Day: 18 to 27°F (10 to 15°C) ▪ Night: 9 to 18°F (5 to 10°C)	• Less variation: ▪ Day: -1.8 to 5.4°F (-1 to 3°C) ▪ Night: 12.6 to 21.6°F (7 to 12°C)
Typical Identification Method	• Indirect measurement: ▪ Remote sensing	• Direct measurement: ▪ Fixed weather stations ▪ Mobile traverses
Typical Depiction	• Thermal image	• Isotherm map • Temperature graph

1.1 Surface Urban Heat Islands

On a hot, sunny summer day, the sun can heat dry, exposed urban surfaces, like roofs and pavement, to temperatures 50 to 90°F (27 to 50°C) hotter than the air,[5] while shaded or moist surfaces—often in more rural surroundings—remain close to air temperatures. Surface urban heat islands are typically present day and night, but tend to be strongest during the day when the sun is shining.

On average, the difference in daytime surface temperatures between developed and rural areas is 18 to 27°F (10 to 15°C); the difference in nighttime surface temperatures is typically smaller, at 9 to 18°F (5 to 10°C).[6]

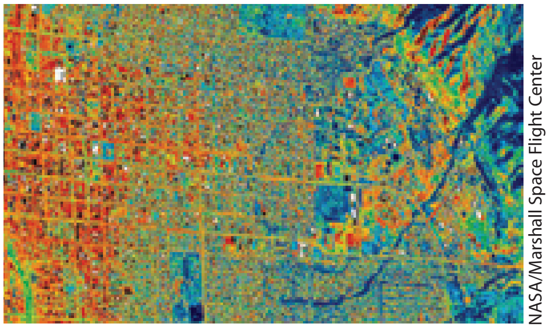
The magnitude of surface urban heat islands varies with seasons, due to changes in the sun's intensity as well as ground cover and weather. As a result of such variation, surface urban heat islands are typically largest in the summer.[7]

How Weather Influences Urban Heat Islands

Summertime urban heat islands are most intense when the sky is clear and winds are calm. Heavy cloud cover blocks solar radiation, reducing daytime warming in cities. Strong winds increase atmospheric mixing, lowering the urban-rural temperature difference. This document, *Reducing Urban Heat Islands: Compendium of Strategies,* focuses on mitigating summertime heat islands through strategies that have maximum impact under clear, calm conditions.

To identify urban heat islands, scientists use direct and indirect methods, numerical modeling, and estimates based on empirical models. Researchers often use remote sensing, an indirect measurement technique, to estimate surface temperatures. They use the data collected to produce thermal images, such as that shown in Figure 1.

Figure 1: Thermal Image Depicting a Surface Urban Heat Island



This image, taken from an aircraft, depicts a midday surface urban heat island in Salt Lake City, Utah, on July 13, 1998. White areas are around 160°F (70°C), while dark blue areas are near 85°F (30°C). Note the warmer urban surface temperatures (left side of image) and cooler surfaces in the neighboring foothills (on the right).

1.2 Atmospheric Urban Heat Islands

Warmer air in urban areas compared to cooler air in nearby rural surroundings defines atmospheric urban heat islands. Experts often divide these heat islands into two different types:

- **Canopy layer urban heat islands** exist in the layer of air where people live, from the ground to below the tops of trees and roofs.
- **Boundary layer urban heat islands** start from the rooftop and treetop level and extend up to the point where urban landscapes no longer influence the atmosphere. This region typically extends no more than one mile (1.5 km) from the surface.[8]

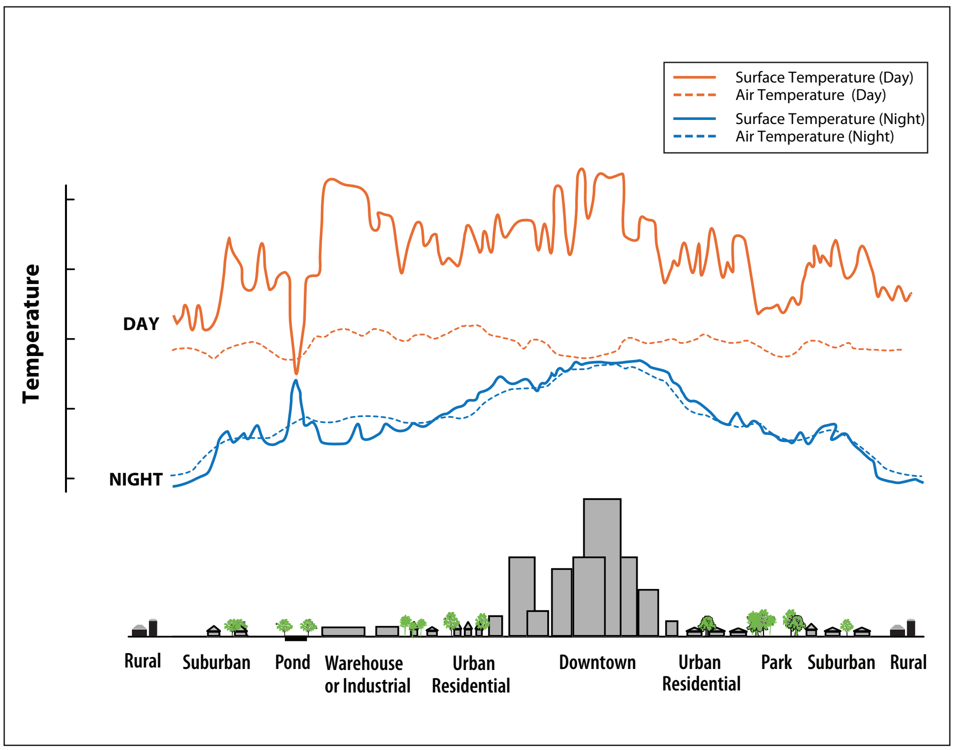
Canopy layer urban heat islands are the most commonly observed of the two types and are often the ones referred to in discussions of urban heat islands. For this reason, this chapter and compendium use the more general term *atmospheric urban heat islands* to refer to canopy layer urban heat islands.

Atmospheric urban heat islands are often weak during the late morning and throughout the day and become more pronounced after sunset due to the slow release of heat from urban infrastructure. The timing of this peak, however, depends on the properties of urban and rural surfaces, the season, and prevailing weather conditions.

Surface and Air Temperatures: How Are They Related?

Surface temperatures have an indirect, but significant, influence on air temperatures, especially in the canopy layer, which is closest to the surface. For example, parks and vegetated areas, which typically have cooler surface temperatures, contribute to cooler air temperatures. Dense, built-up areas, on the other hand, typically lead to warmer air temperatures. Because air mixes within the atmosphere, though, the relationship between surface and air temperatures is not constant, and air temperatures typically vary less than surface temperatures across an area (see Figure 2).

Figure 2: Variations of Surface and Atmospheric Temperatures



Modified from Voogt, 2000

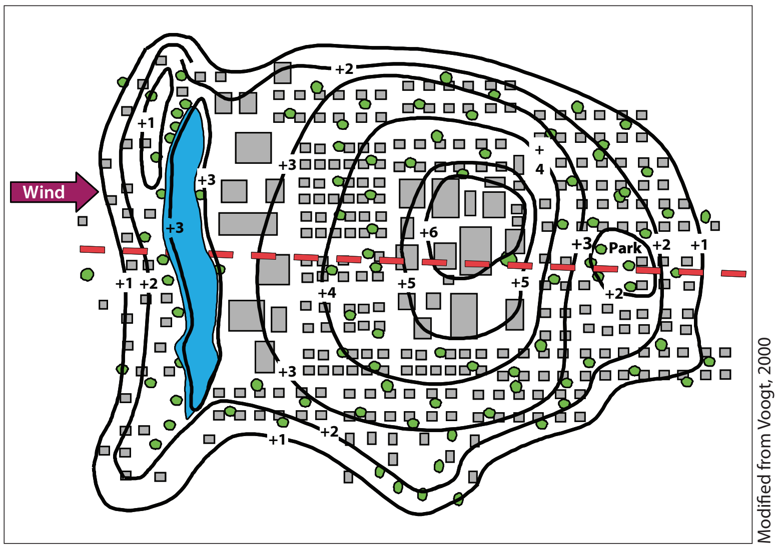
Surface and atmospheric temperatures vary over different land use areas. Surface temperatures vary more than air temperatures during the day, but they both are fairly similar at night. The dip and spike in surface temperatures over the pond show how water maintains a fairly constant temperature day and night, due to its high heat capacity.

* Note: The temperatures displayed above do not represent absolute temperature values or any one particular measured heat island. Temperatures will fluctuate based on factors such as seasons, weather conditions, sun intensity, and ground cover.

Atmospheric heat islands vary much less in intensity than surface heat islands. On an annual mean basis, air temperatures in large cities might be 1.8 to 5.4°F (1 to 3°C) warmer than those of their rural surroundings.[9]

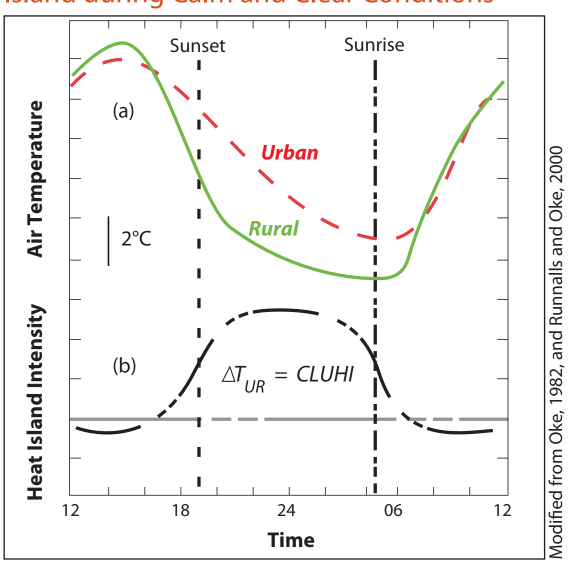
Researchers typically measure air temperatures through a dense network of sampling points from fixed stations or mobile traverses, which are both direct measurement methods. Figure 3 illustrates a conceptual isotherm map that depicts an atmospheric urban heat island. The center of the figure, which is the hottest area, is the urban core. A simple graph of temperature differences, as shown in Figure 4, is another way to show the results.

Figure 3: Isotherm Map Depicting an Atmospheric Nighttime Urban Heat Island



This conceptual map with overlaid isotherms (lines of equal air temperature) exhibits a fully developed nighttime atmospheric urban heat island. The dotted red line indicates a traverse along which measurements are taken.

Figure 4: Conceptual Drawing of the Diurnal Evolution of the Urban Heat Island during Calm and Clear Conditions



Atmospheric urban heat islands primarily result from different cooling rates between urban areas and their surrounding rural or non-urban surroundings (section (a) of Figure 5). The differential cooling rates are most pronounced on clear and calm nights and days when rural areas can cool more quickly than urban areas. The heat island intensity (section (b)) typically grows from mid- to late afternoon to a maximum a few hours after sunset. In some cases, a heat island might not reach peak intensity until after sunrise.

Urban Heat Islands, Climate Change, and Global Warming

Urban heat islands refer to the elevated temperatures in developed areas compared to more rural surroundings. Urban heat islands are caused by development and the changes in radiative and thermal properties of urban infrastructure as well as the impacts buildings can have on the local micro-climate—for example tall buildings can slow the rate at which cities cool off at night. Heat islands are influenced by a city's geographic location and by local weather patterns, and their intensity changes on a daily and seasonal basis.

The warming that results from urban heat islands over small areas such as cities is an example of local climate change. Local climate changes resulting from urban heat islands fundamentally differ from global climate changes in that their effects are limited to the local scale and decrease with distance from their source. Global climate changes, such as those caused by increases in the sun's intensity or greenhouse gas concentrations, are not locally or regionally confined.

Climate change, broadly speaking, refers to any significant change in measures of climate (such as temperature, precipitation, or wind) lasting for an extended period (decades or longer). Climate change may result from:

- Natural factors, such as changes in the sun's intensity or slow changes in the Earth's orbit around the sun
- Natural processes within the climate system (e.g. changes in ocean circulation)
- Human activities that change the atmosphere's composition (e.g. burning fossil fuels) and the land surface (e.g. deforestation, reforestation, or urbanization).

The term climate change is often used interchangeably with the term global warming, but according to the National Academy of Sciences, "the phrase 'climate change' is growing in preferred use to 'global warming' because it helps convey that there are [other] changes in addition to rising temperatures."

Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the lowest layer of the atmosphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human induced. In common usage, "global warming" often refers to the warming that can occur as a result of increased emissions of greenhouse gases from human activities. Global warming can be considered part of global climate change along with changes in precipitation, sea level, etc.

The impacts from urban heat islands and global climate change (or global warming) are often similar. For example, some communities may experience longer growing seasons due to either or both phenomena. Urban heat islands and global climate change can both also increase energy demand, particularly summertime air conditioning demand, and associated air pollution and greenhouse gas emissions, depending on the electric system power fuel mix.

Strategies to reduce urban heat islands—the focus of this document, *Reducing Urban Heat Islands: Compendium of Strategies*—produce multiple benefits including lowering surface and air temperatures, energy demand, air pollution and greenhouse gas emissions. Thus, advancing measures to mitigate urban heat islands also helps to address global climate change.

For more information on global warming see EPA's Climate Change website, <www.epa.gov/climatechange>.

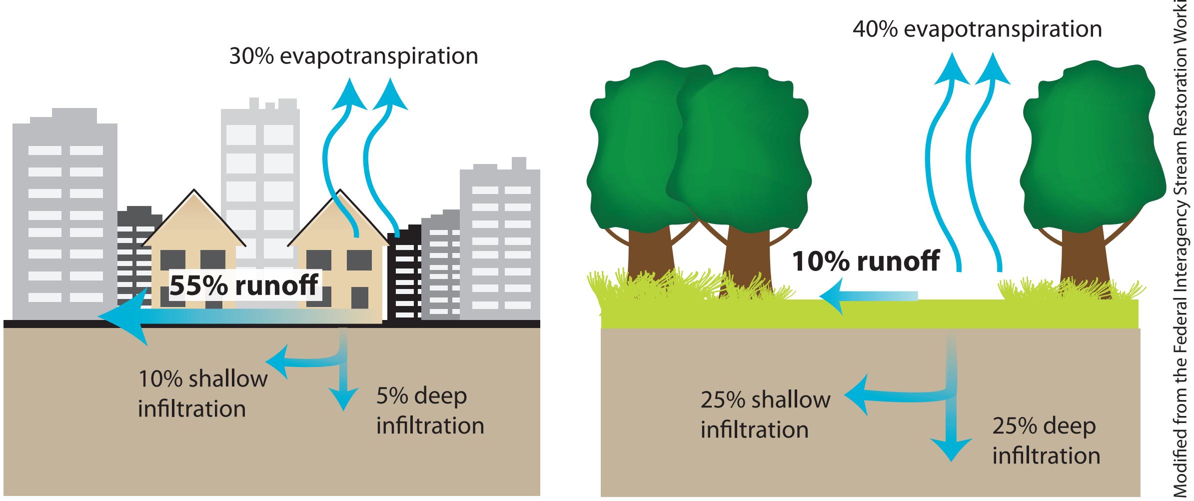
2. How Do Urban Heat Islands Form?

While many factors contribute to urban heat island formation (see Table 2), this chapter focuses on vegetative cover and surface properties because communities can directly address these factors with available technologies. See the “Trees and Vegetation,” “Green Roofs,” “Cool Roofs,” and “Cool Pavement” chapters for detailed information on these strategies.

2.1 Reduced Vegetation in Urban Areas

In rural areas, vegetation and open land typically dominate the landscape. Trees and vegetation provide shade, which helps lower surface temperatures. They also help reduce air temperatures through a process called evapotranspiration, in which plants release water to the surrounding air, dissipating ambient heat. In contrast, urban areas are characterized by dry, impervious surfaces, such as conventional roofs, sidewalks, roads, and parking lots. As cities develop, more vegetation is lost, and more surfaces are paved or covered with buildings. The change in ground cover results in less shade and moisture to keep urban areas cool. Built up areas evaporate less water (see Figure 5), which contributes to elevated surface and air temperatures.

Figure 5: Impervious Surfaces and Reduced Evapotranspiration



Highly developed urban areas (right), which are characterized by 75%-100% impervious surfaces, have less surface moisture available for evapotranspiration than natural ground cover, which has less than 10% impervious cover (left). This characteristic contributes to higher surface and air temperatures in urban areas.

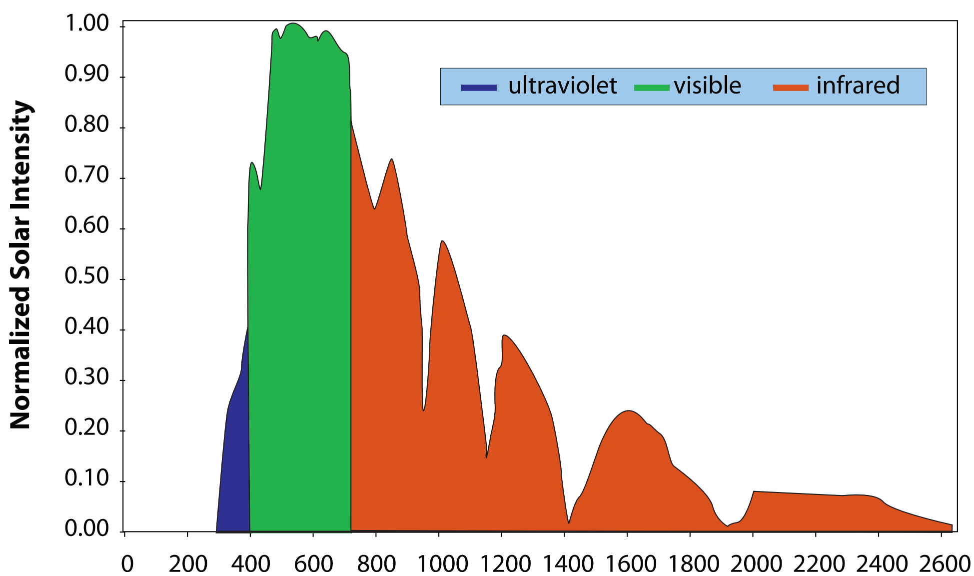
2.2 Properties of Urban Materials

Properties of urban materials, in particular solar reflectance, thermal emissivity, and heat capacity, also influence urban heat island development, as they determine how the sun's energy is reflected, emitted, and absorbed.

Figure 6 shows the typical solar energy that reaches the Earth's surface on a clear summer day. Solar energy is composed of ultraviolet (UV) rays, visible light, and infrared energy, each reaching the Earth in different percentages: five percent of solar energy is in the UV spectrum, including the type of rays responsible for sunburn; 43 percent of solar energy is visible light, in colors ranging from violet to red; and the remaining 52 percent of solar energy is infrared, felt as heat. Energy in all of these wavelengths contributes to urban heat island formation.

Solar reflectance, or albedo, is the percentage of solar energy reflected by a surface. Much of the sun's energy is found in the visible wavelengths (see Figure 6); thus, solar reflectance is correlated with a material's color. Darker surfaces tend to have lower solar reflectance values than lighter surfaces. Researchers are studying and developing cool colored materials, though, that use specially engineered pigments that reflect well in the infrared wavelengths. These products can be dark in color but have a solar reflectance close to that of a white or light-colored material. (See the "Cool Roofs" chapter for further discussion of cool colored roof products.)

Figure 6: Solar Energy versus Wavelength Reaching Earth's Surface



Solar energy intensity varies over wavelengths from about 250 to 2500 nanometers.

Urban areas typically have surface materials, such as roofing and paving, which have a lower albedo than those in rural settings. As a result, built up communities generally reflect less and absorb more of the sun's energy. This absorbed heat increases surface temperatures and contributes to the formation of surface and atmospheric urban heat islands.

Although solar reflectance is the main determinant of a material's surface temperature, thermal emittance, or emissivity, also plays a role. Thermal emittance is a measure of a surface's ability to shed heat, or emit long-wave (infrared) radiation. All things equal, surfaces with high emittance values will stay cooler, because they will release heat more readily. Most construction materials, with the exception of metal, have high thermal emittance values. Thus, this property is mainly of interest to those installing cool roofs, which can be metallic. See the "Cool Roofs" chapter of the compendium for more information.

Another important property that influences heat island development is a material's heat capacity, which refers to its ability to store heat. Many building materials, such as steel and stone, have higher heat capacities than rural materials, such as dry soil and sand. As a result, cities are typically more effective at storing the sun's energy as heat within their infrastructure. Downtown metropolitan areas can absorb and store twice the amount of heat compared to their rural surroundings during the daytime.[10]

Radiative and Thermal Properties—Cool Roofs and Cool Pavements

Albedo and emissivity are considered "radiative properties." Heat capacity, on the other hand, is one of several "thermal properties" a material can possess. For thin materials like roofing, which is typically placed over insulation, reflectance and emittance are the main properties to consider, as the heat capacity of a well insulated roof is low. For pavements, which are thicker than roofing products and are placed on top of the ground, which has its own set of thermal characteristics, designers and researchers need to consider a more complex set of factors that include radiative and thermal properties—such as heat capacity, thermal conductivity, and density.

2.3 Urban Geometry

An additional factor that influences urban heat island development, particularly at night, is urban geometry, which refers to the dimensions and spacing of buildings within a city. Urban geometry influences wind flow, energy absorption, and a given surface's ability to emit long-wave radiation back to space. In developed areas, surfaces and structures are often at least partially obstructed by objects, such as neighboring buildings, and become large thermal masses that cannot release their heat very readily because of these obstructions. Especially at night, the air above urban centers is typically warmer than air over rural areas. Nighttime atmospheric heat islands can have serious health implications for urban residents during heat waves (see textbox in Section 3.3, "Factors in Heat-Related Illnesses and Death.")

Researchers often focus on an aspect of urban geometry called urban canyons, which can be illustrated by a relatively narrow street lined by tall buildings. During the day, urban canyons can have competing effects. On the one hand, tall buildings can create shade, reducing surface and air temperatures. On the other, when sunlight reaches surfaces in the canyon, the sun's energy is reflected and absorbed by building walls, which further lowers the city's overall albedo—the net reflectance from surface albedo plus urban geometry—and can increase temperatures.[11] At night, urban canyons generally impede cooling, as buildings and structures can obstruct the heat that is being released from urban infrastructure.

Table 2: Factors that Create Urban Heat Islands

Factors Communities are Focusing On
• Reduced vegetation in urban regions: Reduces the natural cooling effect from shade and evapotranspiration. • Properties of urban materials: Contribute to absorption of solar energy, causing surfaces, and the air above them, to be warmer in urban areas than those in rural surroundings.
Future Factors to Consider
• Urban geometry: The height and spacing of buildings affects the amount of radiation received and emitted by urban infrastructure. • Anthropogenic heat emissions: Contribute additional warmth to the air.*
Additional Factors
• Weather: Certain conditions, such as clear skies and calm winds, can foster urban heat island formation. • Geographic location: Proximity to large water bodies and mountainous terrain can influence local wind patterns and urban heat island formation.

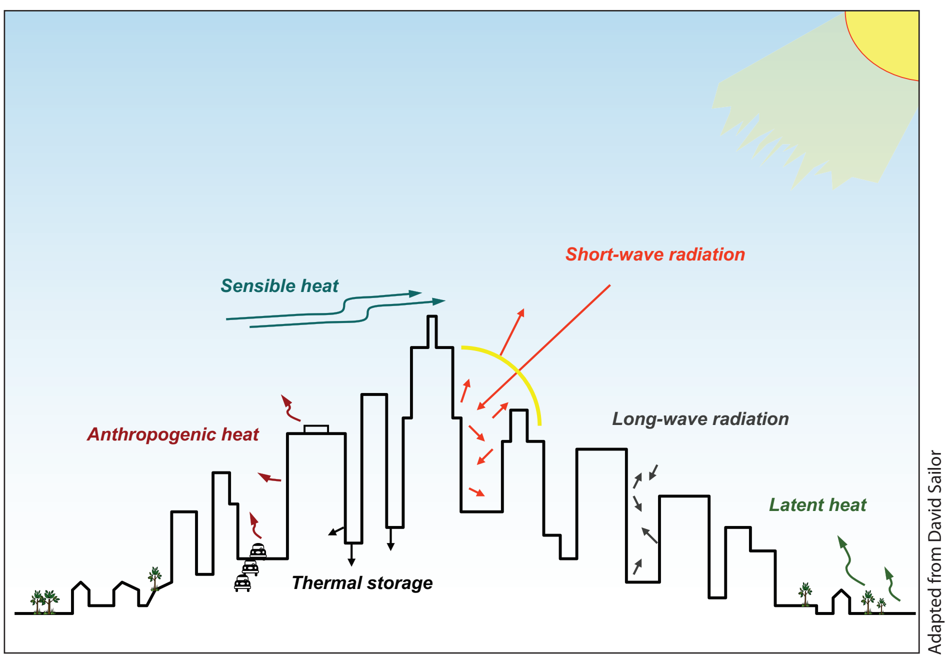
* Although communities currently can lower anthropogenic heat emissions through energy efficiency technologies in the building and vehicle sectors, this compendium focuses on modifying vegetative cover and surface properties of urban materials, as they have long been regarded as urban heat island reduction strategies. An emerging body of literature on the role waste heat plays in urban heat island formation, though, may lead communities to focus on anthropogenic heat in the near future.

The Urban Surface Energy Budget

An energy budget provides an equation that quantifies the balance of incoming and outgoing energy flows, or fluxes (see Figure 7). The surface energy budgets of urban areas and their more rural surroundings will differ because of differences in land cover, surface characteristics, and level of human activity. Such differences can affect the generation and transfer of heat, which can lead to different surface and air temperatures in urban versus rural areas. Various elements of the budget include:

- **Short-wave radiation** is ultraviolet, visible light, and near-infrared radiation from the sun that reaches the Earth (see Figure 6). This energy is a key driver of urban heat islands. Urban surfaces, compared to vegetation and other natural ground cover, reflect less radiation back to the atmosphere. They instead absorb and store more of it, which raises the area's temperature.
- **Thermal storage** increases in cities in part due to the lower solar reflectance of urban surfaces, but it is also influenced by the thermal properties of construction materials and urban geometry. Urban geometry can cause some short-wave radiation—particularly within an urban canyon—to be reflected on nearby surfaces, such as building walls, where it is absorbed rather than escaping into the atmosphere.

Figure 7: Urban Surface Energy Budget



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The Urban Surface Energy Budget (continued)

- Similarly, urban geometry can impede the release of **long-wave, or infrared, radiation** into the atmosphere. When buildings or other objects absorb incoming short-wave radiation, they can re-radiate that energy as long-wave energy, or heat. However, at night, due to the dense infrastructure in some developed areas that have low sky view factors (see section 2.3), urban areas cannot easily release long-wave radiation to the cooler, open sky, and this trapped heat contributes to the urban heat island.
- Evapotranspiration describes the transfer of **latent heat,** what we feel as humidity, from the Earth's surface to the air via evaporating water. Urban areas tend to have less evapotranspiration relative to natural landscapes, because cities retain little moisture. This reduced moisture in built up areas leads to dry, impervious urban infrastructure reaching very high surface temperatures, which contribute to higher air temperatures.*
- Convection describes the transfer of **sensible heat,** what we feel as temperature, between the surface and air when there is a difference in temperature between them. High urban surface temperatures warm the air above, which then circulates upwards via convection.
- **Anthropogenic heat** refers to the heat generated by cars, air conditioners, industrial facilities, and a variety of other manmade sources, which contributes to the urban energy budget, particularly in the winter.

* This change in landscape may differ in regions such as deserts, where moisture may increase in urban areas if development introduces grass lawns and other irrigated vegetation.

The effects of urban geometry on urban heat islands are often described through the "sky view factor" (SVF), which is the visible area of the sky from a given point on a surface. For example, an open parking lot or field that has few obstructions would have a large SVF value (closer to 1). Conversely, an urban canyon in a downtown area that is surrounded by closely spaced, tall buildings, would have a low SVF value (closer to zero), as there would only be a small visible area of the sky.

2.4 Anthropogenic Heat

Anthropogenic heat contributes to atmospheric heat islands and refers to heat produced by human activities. It can come from a variety of sources and is estimated by totaling all the energy used for heating and cooling, running appliances, transportation, and industrial processes. Anthropogenic heat varies by urban activity and infrastructure, with more energy-intensive buildings and transportation producing more heat.[12] Anthropogenic heat typically is not a concern in rural areas and during the summer. In the winter, though, and year round in dense, urban areas, anthropogenic heat can significantly contribute to heat island formation.

2.5 Additional Factors

Weather and location strongly influence urban heat island formation. While communities have little control over these factors, residents can benefit from understanding the role they play.

- **Weather.** Two primary weather characteristics affect urban heat island development: wind and cloud cover. In general, urban heat islands form during periods of calm winds and clear skies, because these conditions maximize the amount of solar energy reaching urban surfaces and minimize the amount of heat that can be convected away. Conversely, strong winds and cloud cover suppress urban heat islands.
- **Geographic location.** Climate and topography, which are in part determined by a city's geographic location, influence urban heat island formation. For example, large bodies of water moderate temperatures and can generate winds that convect heat away from cities. Nearby mountain ranges can either block wind from reaching a city, or create wind patterns that pass through a city. Local terrain has a greater significance for heat island formation when larger-scale effects, such as prevailing wind patterns, are relatively weak.

3. Why Do We Care about Urban Heat Islands?

Elevated temperatures from urban heat islands, particularly during the summer, can affect a community's environment and quality of life. While some heat island impacts seem positive, such as lengthening the plant-growing season, most impacts are negative and include:

- Increased energy consumption
- Elevated emissions of air pollutants and greenhouse gases
- Compromised human health and comfort
- Impaired water quality.

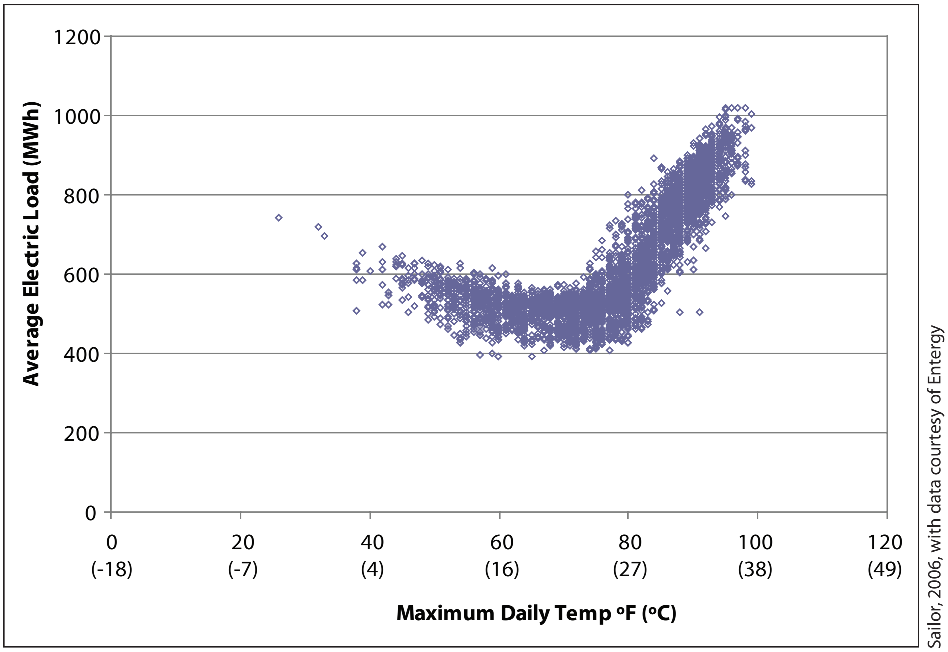
Wintertime Benefits of Urban Heat Islands

Communities may benefit from the wintertime warming effect of urban heat islands. Warmer temperatures can reduce heating energy needs and help to melt snow and ice on roads. Fortunately, urban heat island mitigation strategies—for example, trees and vegetation and green roofs—generally provide year-round benefits, or their winter penalty, such as that from cool roofs, is much smaller than their summertime benefits.

3.1 Energy Consumption

Elevated summertime temperatures in cities increase energy demand for cooling and add pressure to the electricity grid during peak periods of demand, which generally occur on hot, summer weekday afternoons, when offices and homes are running cooling systems, lights, and appliances (see Figure 8). This peak urban electric demand increases 1.5 to 2 percent for every 1°F (0.6°C) increase in summertime temperature. Steadily increasing downtown temperatures over the last several decades mean that 5 to 10 percent of community-wide demand for electricity is used to compensate for the heat island effect.[13] During extreme heat events, which are exacerbated by urban heat islands, the resulting demand for cooling can overload systems and require a utility to institute controlled, rolling brownouts or blackouts to avoid power outages.

Figure 8: Increasing Power Loads with Temperature Increases[14]



As shown in this example from New Orleans, electrical load can increase steadily once temperatures begin to exceed about 68 to 77°F (20 to 25°C). Other areas of the country show similar demand curves as temperature increases.

3.2 Air Quality and Greenhouse Gases

As discussed in Section 3.1, higher temperatures can increases energy demand, which generally causes higher levels of air pollution and greenhouse gas emissions. Currently, most electricity in the United States is produced from combusting fossil fuel. Thus, pollutants from most power plants include sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO), and mercury (Hg). These pollutants are harmful to human health and contribute to complex air quality problems such as acid rain. Further, fossil-fuel-powered plants emit greenhouse gases, particularly carbon dioxide (CO_2), which contribute to global climate change.

In addition to increases in air emissions, elevated air temperatures increase the rate of ground-level ozone formation, which is produced when NO_x and volatile organic compounds (VOCs) react in the presence of sunlight. If all other variables are equal—such as the level of precursor emissions or wind speed and direction—ground-level ozone emissions will be higher in sunnier and hotter weather.

3.3 Human Health and Comfort

Increased daytime surface temperatures, reduced nighttime cooling, and higher air pollution levels associated with urban heat islands can affect human health by contributing to general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality.

Urban heat islands can also exacerbate the impact of heat waves, which are periods of abnormally hot, and often humid, weather. Sensitive populations, such as children, older adults, and those with existing health conditions, are at particular risk from these events. For example, in 1995, a mid-July heat wave in the Midwest caused more than 1,000 deaths.[15] While it is rare for a

Factors in Heat-Related Illnesses and Death

Low income elderly people who live in row homes are at a particular risk for heat-related health incidents. Living on the upper floor of a typical row home, with a dark roof, brick construction, and windows on only two sides, could contribute to the risk of heat-related illness or death during heat waves, as temperatures in these homes can be extreme.[16] These homes often lack air conditioning, especially in areas unaccustomed to high temperatures. Further, even when air conditioning is available, residents may not use it for fear of high utility bills.

Social isolation and physical health also contribute to one's vulnerability. Elderly people, especially, may not have family or friends nearby, may not report to work regularly, and may lack neighbors who can check on them, leaving them stranded during extreme heat events. The elderly may also fail to hear news or other warnings of impending heat waves and recommendations on how to cope. Finally, their bodies may be less able to handle heat stress.

The lack of nighttime relief in air temperatures is strongly correlated with increased mortality during heat waves. Some studies suggest that these oppressive nighttime temperatures may be more significant than high maximum daytime temperatures.[17]

For more information on heat-related health incidents and ways to respond, see the EPA Excessive Heat Events Guidebook <www.epa.gov/hiri/about/pdf/EHEguide_final.pdf>

heat wave to be so destructive, heat-related mortality is not uncommon. The Centers for Disease Control estimates that from 1979 to 1999, excessive heat exposure contributed to more than 8,000 premature deaths in the United States.[18] This figure exceeds the number of mortalities resulting from hurricanes, lightning, tornadoes, floods, and earthquakes combined.

3.4 Water Quality

Surface urban heat islands degrade water quality, mainly by thermal pollution. Pavement and rooftop surfaces that reach temperatures 50 to 90°F (27 to 50°C) higher than air temperatures transfer this excess heat to stormwater. Field measurements from one study showed that runoff from urban areas was about 20-30°F (11-17°C) hotter than runoff from a nearby rural area on summer days when pavement temperatures at midday were 20-35°F (11-19°C) above air temperature. When the rain came before the pavement had a chance to heat up, runoff temperatures from the rural and urban areas differed by less than 4°F (2°C).[19] This heated stormwater generally drains into storm sewers (see Figure 5) and raises water temperatures as it is released into streams, rivers, ponds, and lakes. A study in Arlington, Virginia, recorded temperature increases in surface waters as high as 8°F (4°C) in 40 minutes after heavy summer rains.[20]

Water temperature affects all aspects of aquatic life, especially the metabolism and reproduction of many aquatic species. Rapid temperature changes in aquatic ecosystems resulting from warm storm-water runoff can be particularly stressful. Brook trout, for example, experience thermal stress and shock when the water temperature changes more than 2 to 4ºF (1-2°C) in 24 hours.[21]

4. Strategies to Reduce Urban Heat Islands

Although urban climatologists have been studying urban heat islands for decades, community interest and concern regarding them has been more recent. This increased attention to heat-related environment and health issues has helped to advance the development of heat island reduction strategies, mainly trees and vegetation, green roofs, and cool roofs. Interest in cool pavements has been growing, and an emerging body of research and pilot projects are helping scientists, engineers, and practitioners to better understand the interactions between pavements and the urban climate.

This compendium *Reducing Urban Heat Islands: Compendium of Strategies* provides details about how these strategies work, their benefits and costs, factors to consider when selecting them, and additional resources for communities to further explore. It presents the multiple benefits—beyond temperature reduction—that a community can accrue from advancing heat island reduction strategies. It also gives examples of how communities have implemented these strategies through voluntary and policy efforts in the "Heat Island Reduction Activities" chapter. Communities can use this compendium as a foundation and starting point for understanding the nuts and bolts of existing urban heat island reduction strategies that communities are currently advancing.

Future policy efforts may focus on encouraging strategies to modify urban geometry and anthropogenic heat in communities to reduce urban heat islands. Research in this area is on-going, and there is a growing awareness of the importance of these factors.

5. Additional Resources

The table on the next page provides additional resources on urban heat island formation, measurement, and impacts.

Table 3: Urban Heat Island Resources

Name	Description	Web Link
General Information		
EPA's Heat Island Website	Through this website, EPA provides background information, publications, reports, access to national webcasts, a database of urban heat island activities, and links to other resources to help communities reduce urban heat islands.	<www.epa.gov/heatislands>
International Association for Urban Climate (IAUC)	This international website is the main forum in which urban climatologists communicate. Urban climate resources, including a bimonthly newsletter, and information on upcoming meetings can be found here.	<www.urban-climate.org>
Lawrence Berkeley National Laboratory (LBNL) Heat Island Group	LBNL provides background information on urban heat islands and their impacts through this website. It also presents some of the impacts heat island reduction strategies can have on temperature, energy consumption, and air quality.	<http://eetd.lbl.gov/HeatIsland>
National Center of Excellence - SMART Innovations for Urban Climate and Energy	Arizona State University's National Center of Excellence collaborates with industry and government to research and develop technologies to reduce urban heat islands, especially in desert climates. Its website provides background information on urban heat islands.	<www.asusmart.com/urbanclimate.php>
Urban Heat Islands: Hotter Cities	This article explains urban heat islands and presents solutions to mitigate them.	<www.actionbioscience.org/environment/voogt.html>
Measuring Heat Islands and Their Impacts		
National Aeronautics and Space Administration (NASA) and the U.S. Geological Survey Landsat Program	The Landsat program is a series of Earth-observing satellites used to acquire images of the Earth's land surface and surrounding coastal regions. These images provide information from which researchers can derive surface temperatures and evaluate urban heat islands.	<http://landsat.gsfc.nasa.gov/>
National Weather Service	The National Weather Service is a source for air temperature measurements, climate and weather models, and past and future climate predictions. The site also has links to excessive heat outlooks, fatality statistics, historic data on major heat waves, drought information, and advice on how to minimize the health risks of heat waves.	<www.nws.noaa.gov/>
EPA's Excessive Heat Events Guidebook	This document is designed to help community officials, emergency managers, meteorologists, and others plan for and respond to excessive heat events by highlighting best practices that have been employed to save lives during excessive heat events in different urban areas. It provides a menu of options that officials can use to respond to these events in their communities.	<www.epa.gov/hiri/about/heatguidebook.html>

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