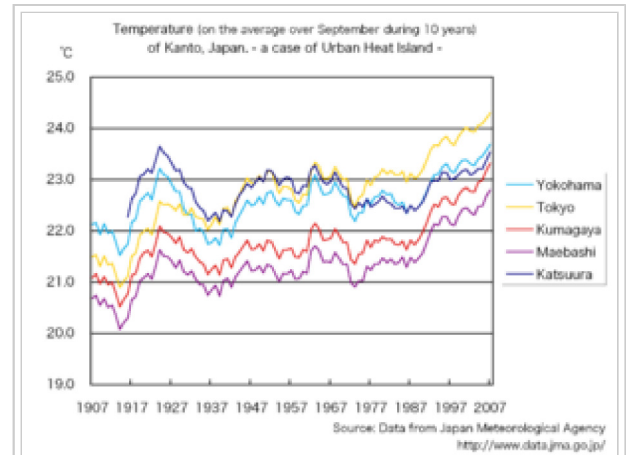


# Urban heat island

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An **urban heat island (UHI)** is a metropolitan area which is significantly warmer than its surroundings. The temperature difference usually is larger at night than during the day and larger in winter than in summer, and is most apparent when winds are weak. The main cause of the urban heat island is modification of the land surface by urban development; waste heat generated by energy usage is a secondary contributor. As population centres grow they tend to modify a greater and greater area of land and have a corresponding increase in average temperature. Partly as a result of the urban heat island effect, monthly rainfall is about 28% greater between 20-40 miles downwind of cities, compared with upwind.<sup>[1]</sup>



Tokyo, a case of Urban Heat Island. Normal temperatures of Tokyo goes up more than the surrounding area.

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## Causes

There are several causes of a UHI, as outlined in Oke (1982). The principal reason for the night-time warming is (comparatively warm) buildings blocking the view to the (relatively cold) night sky (see thermal radiation). Two other reasons are changes in the thermal properties of surface materials and lack of evapotranspiration in urban areas. Materials commonly used in urban areas, such as concrete and asphalt, have significantly different thermal bulk properties (including heat capacity and thermal conductivity) and surface radiative properties (albedo and emissivity) than the surrounding rural areas. This causes a change in the energy balance of the urban area, often leading to higher temperatures than surrounding rural areas. The energy balance is also affected by the lack of vegetation in urban areas, which inhibits cooling by evapotranspiration.

Other causes of a UHI are due to geometric effects. The tall buildings within many urban

areas provide multiple surfaces for the reflection and absorption of sunlight, increasing the efficiency with which urban areas are heated. This is called the "canyon effect". Another effect of buildings is the blocking of wind, which also inhibits cooling by convection. Waste heat from air conditioning, industry, and other sources also contributes to the UHI. High levels of pollution in urban areas can also increase the UHI, as many forms of pollution change the radiative properties of the atmosphere.

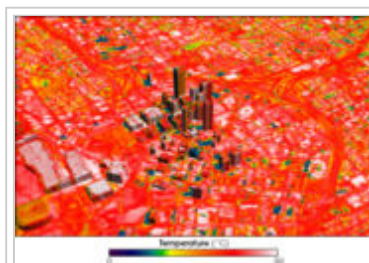
The EPA discusses one of the reasons when it says:

*Heat islands form as vegetation is replaced by asphalt and concrete for roads, buildings, and other structures necessary to accommodate growing populations. These surfaces absorb - rather than reflect - the sun's heat, causing surface temperatures and overall ambient temperatures to rise.*

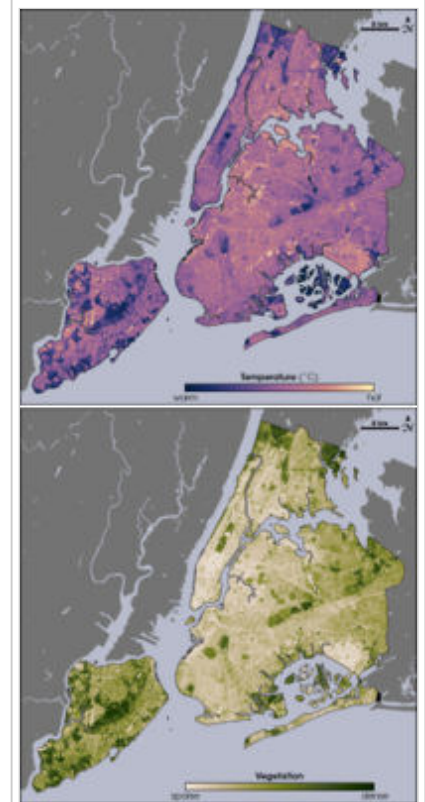
The lesser-used term *heat island* refers to any area, populated or not, which is consistently hotter than the surrounding area.

Some cities exhibit a heat island effect, largest at night (see below), and particularly in summer,<sup>[2]</sup> or perhaps in winter,<sup>[3]</sup> with several degrees between the center of the city and surrounding fields. The difference in temperature between an inner city and its surrounding suburbs is frequently mentioned in weather reports: e.g., "68 degrees downtown, 64 in the suburbs."

## Significance



Thermal image of Atlanta, Georgia, blue shows cool temperatures, red warm, and hot areas appear white. Daytime air temperatures were only about 26.7°C (80°F), but some surface temperatures reached 47.8°Celsius (118°F).



Thermal (top) and vegetation (bottom) infrared satellite data measured by NASA's Landsat 7 Enhanced Thematic Mapper Plus on August 14, 2002, one of the hottest days in New York City's summer. A comparison of the images shows that where vegetation is dense, temperatures are cooler.

UHIs have the potential to directly influence the health and welfare of urban residents. Within the United States alone, an average of 1000 people die each year due to extreme heat (Changnon et al., 1996). As UHIs are characterized by increased temperature, they can potentially increase the magnitude and duration of heat waves within cities. Research has found that the mortality rate during a heat wave increases exponentially with the maximum temperature (Buechley et al., 1972), an effect that is exacerbated by the UHI. The nighttime effect of UHIs (discussed below) can be particularly harmful during a heat wave, as it deprives urban residents of the cool relief found in rural areas during the night (Clarke, 1972).

Research in the United States suggests that the relationship between extreme temperature and mortality in the U.S. varies by location. According to the Program on Health Effects of Global Environmental Change at Johns Hopkins University (JHU), heat is most likely to increase the risk of mortality in cities at mid-latitudes and high latitudes with significant annual temperature variation. For example, when Chicago and New York experience unusually hot summertime temperatures, elevated levels of illness and death are predicted. In contrast, parts of the country that are mild to hot year-round have a lower public health risk from excessive heat. JHU research shows that residents of southern cities, such as Miami, tend to be acclimated to hot weather conditions and therefore less vulnerable.

Another consequence of urban heat islands is the increased energy required for air conditioning and refrigeration in cities that are in comparatively hot climates. The Heat Island Group estimates that the heat island effect costs Los Angeles about \$100 million per year in energy.<sup>[4]</sup> Conversely, those that are in cold climates such as Chicago would presumably need somewhat less in the way of heating.

Aside from the obvious effect on temperature, UHIs can produce secondary effects on local meteorology, including the altering of local wind patterns, the development of clouds and fog, the humidity, and the rates of precipitation<sup>[5]</sup>.

Using satellite images, researchers discovered that city climates have a noticeable influence on plant growing seasons up to 10 kilometers (6 miles) away from a city's edges. Growing seasons in 70 cities in eastern North America were about 15 days longer in urban areas compared to rural areas outside of a city's influence.<sup>[6][7]</sup>

## Mitigation

The heat island effect can be counteracted slightly by using white or reflective materials to build houses, pavements, and roads, thus increasing the overall albedo of the city. This is a long established practice in many countries. A second option is to increase the amount of well-watered vegetation. These two options can be combined with the implementation of green roofs.

The city of New York determined that largest cooling potential per area was highest for street trees, followed by living roofs, light covered surface, and open space planting. From the standpoint of cost effectiveness, light surfaces, light roofs, and curbside planting have lower costs per temperature reduction.<sup>[1]</sup>

## Diurnal behavior

The IPCC states that "it is well-known that compared to non-urban areas urban heat islands raise night-time temperatures more than daytime temperatures."<sup>[8]</sup> For example, Moreno-Garcia (Int. J. Climatology, 1994) found that Barcelona was 0.2°C cooler for daily maxima and 2.9°C warmer for minima than a nearby rural station. In fact, a description of the very first report of the UHI by Luke Howard in 1820 says:

*Howard was also to discover that the urban center was warmer at night than the surrounding countryside, a condition we now call the urban heat island. Under a table presented in The Climate of London (1820), of a nine-year comparison between temperature readings in London and in the country, he commented: "Night*

*is 3.70° warmer and day 0.34° cooler in the city than in the country." He attributed this difference to the extensive use of fuel in the city.<sup>[9]</sup>*

Though the air temperature UHI is generally most apparent at night, urban heat islands exhibit significant and somewhat paradoxical diurnal behavior. The air temperature UHI is large at night and small during the day, while the opposite is true for the surface temperature UHI. From Roth et al. (1990):

*Nocturnal urban–rural differences ... in surface temperatures are much smaller than in the day-time. This is the reverse of the case for near-surface air temperatures.*

Throughout the daytime, particularly when the skies are free of clouds, urban surfaces are warmed by the absorption of solar radiation. As described above, the surfaces in the urban areas tend to warm faster than those of the surrounding rural areas. By virtue of their high heat capacities, these urban surfaces act as a giant reservoir of heat energy. (For example, concrete can hold roughly 2000 times as much heat as an equivalent volume of air.) As a result, the large daytime surface temperature UHI is easily seen via thermal remote sensing (e.g. Lee, 1993).

However, as is often the case with daytime heating, this warming also has the effect of generating convective winds within the urban boundary layer. It is theorized that, due to the atmospheric mixing that results, the air temperature UHI is generally minimal or nonexistent during the day, though the surface temperatures can reach extremely high levels (Camilloni and Barros, 1997).

At night, however, the situation reverses. The absence of solar heating causes the atmospheric convection to decrease, and the urban boundary layer begins to stabilize. If enough stabilization occurs, an inversion layer is formed. This traps the urban air near the surface, and allows it to heat from the still-warm urban surfaces, forming the nighttime air temperature UHI.

The explanation for the night-time maximum is that the principal cause of UHI is blocking of "sky view" during cooling: surfaces lose heat at night principally by radiation to the (comparatively cold) sky, and this is blocked by the buildings in an urban area. Radiative cooling is more dominant when wind speed is low and the sky is cloudless, and indeed the UHI is found to be largest at night in these conditions.<sup>[10][11]</sup>

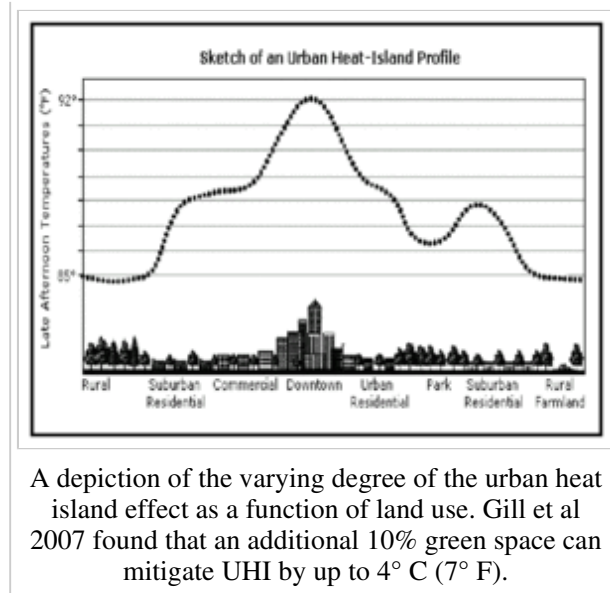
## Relation to global warming

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Because some parts of some cities may be several degrees hotter than their surroundings, concerns have been raised that the effects of urban sprawl might be misinterpreted as an increase in global temperature. While the 'heat island' warming is an important local effect, there is no evidence that it biases *trends* in historical temperature record; for example, urban and rural trends are very similar.

The IPCC (2001) says:

*However, over the Northern Hemisphere land areas where urban heat islands are most apparent, both the trends of lower-tropospheric temperature and surface air*



temperature show no significant differences. In fact, the lower-tropospheric temperatures warm at a slightly greater rate over North America (about 0.28°C/decade using satellite data) than do the surface temperatures (0.27°C/decade), although again the difference is not statistically significant.<sup>[12]</sup>

Note that not all cities show a warming relative to their rural surroundings. For example, Hansen et al. (JGR, 2001) adjusted trends in urban stations around the world to match rural stations in their regions, in an effort to homogenise the temperature record. Of these

adjustments, 42% warmed the urban trends: which is to say that in 42% of cases, the cities were getting cooler relative to their surroundings rather than warmer. One reason is that urban areas are heterogeneous, and weather stations are often sited in "cool islands" - parks, for example - within urban areas.

Peterson (2003) indicates that the effects of the urban heat island may have been overstated, finding that "Contrary to generally accepted wisdom, no statistically significant impact of urbanization could be found in annual temperatures." This was done by using satellite-based night-light detection of urban areas, and more thorough homogenisation of the time series (with corrections, for example, for the tendency of surrounding rural stations to be slightly higher, and thus cooler, than urban areas). As the paper says, if its conclusion is accepted, then it is necessary to "unravel the mystery of how a global temperature time series created partly from urban in situ stations could show no contamination from urban warming." The main conclusion is that micro- and local-scale impacts dominate the meso-scale impact of the urban heat island: many sections of towns may be warmer than rural sites, but meteorological observations are likely to be made in park "cool islands."

A study by David Parker published in *Nature* in November 2004 and in *Journal of Climate* in 2006 attempts to test the urban heat island theory, by comparing temperature readings taken on calm nights with those taken on windy nights. If the urban heat island theory is correct then instruments should have recorded a bigger temperature rise for calm nights than for windy ones, because wind blows excess heat away from cities and away from the measuring instruments. There was no difference between the calm and windy nights, and the author says: *we show that, globally, temperatures over land have risen as much on windy nights as on calm nights, indicating that the observed overall warming is not a consequence of urban development.*<sup>[13][14]</sup>

However, Roger A. Pielke has claimed that Parker 2004 has "serious issues with its conclusions" [2] due to his research published in *Geophysical Research Letters* which states: *"if the nocturnal boundary layer heat fluxes change over time, the trends of temperature under light winds in the surface layer will be a function of height, and that the same trends of temperature will not occur in the surface layer on windy and light wind*

*nights.*"[3].

Another view, often held by skeptics of global warming, is that much of the temperature increase seen in land based thermometers could be due to an increase in urbanisation and the siting of measurement stations in urban areas [4][5]. However, these views are mainly presented in "popular literature" and there are no known scientific peer-reviewed papers holding this view.<sup>[15]</sup>

The Fourth Assessment Report from the IPCC (2007: p.244) says the following.

Studies that have looked at hemispheric and global scales conclude that any urban-related trend is an order of magnitude smaller than decadal and longer time-scale trends evident in the series (e.g., Jones et al., 1990; Peterson et al., 1999). This result could partly be attributed to the omission from the gridded data set of a small number of sites (<1%) with clear urban-related warming trends. In a worldwide set of about 270 stations, Parker (2004, 2006) noted that warming trends in night minimum temperatures over the period 1950 to 2000 were not enhanced on calm nights, which would be the time most likely to be affected by urban warming. Thus, the global land warming trend discussed is very unlikely to be influenced significantly by increasing urbanisation (Parker, 2006). ... Accordingly, this assessment adds the same level of urban warming uncertainty as in the TAR: 0.006°C per decade since 1900 for land, and 0.002°C per decade since 1900 for blended land with ocean, as ocean UHI is zero.

## Notes

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- <sup>^</sup> Hinkel, Kenneth M. (March 2003). Barrow Urban Heat Island Study. Department of Geography, University of Cincinnati. Retrieved on 2007-08-02.
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- <sup>^</sup> NASA (2004-06-29). "Urban Heat Islands Make Cities Greener". Press release. Retrieved on 2007-08-02.
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- <sup>^</sup> grida.no
- <sup>^</sup> islandnet.com
- <sup>^</sup> earthsci.unimelb.edu.au
- <sup>^</sup> ams.confex.com
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- <sup>^</sup> Parker, David E. (2004), "Large-scale warming is not urban", *Nature* **432** (7015): 290-290, doi:10.1038/432290a, <[http://www.cru.uea.ac.uk/cru/projects/soap/pubs/papers/jones\\_Nature2004.pdf](http://www.cru.uea.ac.uk/cru/projects/soap/pubs/papers/jones_Nature2004.pdf)>. Retrieved on 2007-08-02
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## External links

- Land-Surface Air Temperature - from the IPCC
- Urban Heat Islands and Climate Change - from the University of Melbourne, Australia
- The Surface Temperature Record and the Urban Heat Island From RealClimate.org
- NASA Earth Observatory: The Earth's Big Cities, Urban Heat Islands
- Research and mitigation strategies on UHI - US EPA designated, National Center of Excellence on SMART Innovations at Arizona State University
- Urban Heat Island research group - NSF project, Department of Geography, Indiana State University

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