New nationwide modeling points to widespread racial disparities in urban heat stress

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In proposing a better way to measure heat exposure in U.S. cities, researchers find that the average Black urban resident is exposed to disproportionately higher heat stress. (Image by Timothy Holland | Pacific Northwest National Laboratory). Credit: Timothy Holland, Pacific Northwest National Laboratory

From densely built urban cores to sprawling suburbia, cities are complex. This complexity can lead to temperature hot spots within cities, with some neighborhoods (and their residents) facing more heat than others.

Understanding this environmental disparity forms the spirit of new research led by scientists at the Department of Energy's Pacific Northwest National Laboratory. In a new paper examining all major cities in the U.S., the authors find that the average Black resident is exposed to air that is warmer by 0.28 degrees Celsius relative to the city average. In contrast, the average white urban resident lives where air temperature is cooler by 0.22 degrees Celsius relative to the same average.

The new work, published last week in the journal *One Earth*, involved a two-part effort. The study's authors aimed to produce a more useful nationwide estimate of urban heat stress—a more accurate account of how our body responds to outdoor heat. By creating and comparing these estimates against demographic data, they also tried to better understand which populations are most exposed to urban heat stress.

The findings reveal pervasive income- and race-based disparities within U.S. cities. Nearly all the U.S. urban population—94 percent, or roughly 228 million people—live in cities where summertime peak heat stress exposure disproportionately burdens the poor.

The study's authors also find that people who now live within historically redlined neighborhoods, where loan applicants were once denied on racially discriminatory grounds, would be exposed to higher outdoor heat stress than their neighbors living in originally non-redlined parts of the city.

The work also highlights shortcomings in the typical approach scientists take in estimating urban heat stress at these scales, which frequently relies on satellite data. This conventional satellite-based method can overestimate such disparities, according to the new work. As the world warms, the findings stand to inform urban heat response plans put forward by local governments who seek to help vulnerable groups.

What is heat stress?

The human body has evolved to operate within a relatively narrow temperature range. Raise your core body temperature beyond just six or seven degrees and drastic physiological consequences soon follow. Cellular processes break down, the heart is taxed, and organs begin to fail.

Sweating helps. But the cooling power of sweating depends partly on how humid the environment is. When both heat and humidity are omnipresent and difficult to escape, the body struggles to adapt.

How is heat stress measured?

To measure heat stress, scientists use a handful of indicators, many of which depend on air temperature and humidity. Weather stations provide such data. Because most weather stations are outside of cities, though, scientists often rely on other means to get some idea about urban heat stress, including using sensors on satellites.

Those sensors infer the temperature of the land surface from measurements of thermal radiation. But such measurements fall short of delivering a full picture of heat stress, said lead author and Earth scientist TC Chakraborty. Measuring just the skin of the Earth, like the surface of a sidewalk or a patch of grass, said Chakraborty, offers only an idea of what it's like to lay flat on that surface.

"Unless you're walking around barefoot or lying naked on the ground, you're not really feeling that," said Chakraborty. "Land surface temperature is, at best, a crude proxy of urban heat stress."

Indeed, most of us are upright, moving through a world where air temperature and moisture dictate how heat actually feels. And these satellite data are only available for clear-sky days—another limiting factor. More complete and physiologically relevant estimates of heat stress incorporate a blend of factors, which models can provide, said Chakraborty.

To better understand differences between satellite-derived land surface temperature and ambient heat exposure within cities, Chakraborty's team examined 481 urbanized areas across the continental United States using both satellites and model simulations.

NASA's Aqua satellite provided the land surface temperature; and through model simulations that account for urban areas, the authors generated nationwide estimates of all variables required to calculate moist heat stress. Two such metrics of heat stress—the National Weather Service's heat index and the Humidex, often used by Canadian meteorologists—allowed the scientists to capture the combined impacts of air temperature and humidity on the human body.

They then identified heat stress hotspots across the country for summer days between 2014 and 2018. Overlaying maps of both historically redlined neighborhoods and census tracts, the team identified relationships between heat exposure and communities.

How is heat distributed within cities?

Residents in poorer neighborhoods often face greater heat stress. And a greater degree of income inequality in any given city often means greater heat stress exposure for its poorer residents.

Most U.S. cities, including heavily populated cities like New York, Los Angeles, Chicago, and Philadelphia, show this disparity. But the relationship between heat stress and race-based residential segregation is even more stark.

Roughly 87.5 percent of the cities studied show that Black populations live in parts of the city with higher land surface temperatures, warmer air, and greater moist heat stress. Moreover, the association between the degree of heat stress disparity and the degree of segregation between white and non-white populations across cities is particularly striking, said Chakraborty.

"The majority—83 percent—of non-white U.S. urban residents live in cities where outdoor moist heat stress disproportionately burdens them," said Chakraborty, "Further, higher percentages of all races other than white are positively correlated with greater heat exposure no matter which variable you use to assess it."

In the 1930s, the U.S. federal government's Home Owners' Loan Corporation graded neighborhoods in an effort to rank the suitability of real estate investments. This practice is known as "redlining," where lower grades (and consequently fewer loans) were issued to neighborhoods composed of poorer and minority groups. The authors find that these redlined neighborhoods still show worse environmental conditions.

Neighborhoods with lower ratings face higher heat exposure than their non-redlined neighbors. Neighborhoods with higher ratings, in contrast, generally get less heat exposure.

This is consistent with previous research on originally redlined urban neighborhoods showing lower tree cover and higher land surface temperature. Chakraborty, however, notes that using land surface temperature would generally overestimate these disparities across neighborhood grades compared to using air temperature or heat index.

"Satellites give us estimates of land surface temperature, which is a different variable from the temperature we feel while outdoors, especially within cities," said Chakraborty. "Moreover, the physiological response to heat also depends on humidity, which satellites cannot directly provide, and urbanization also modifies."

The findings are not without uncertainty, the authors added. "Ground-based weather stations helped to dwindle down, but not eliminate, model bias," said co-author Andrew Newman of the National Center for Atmospheric Research, who generated the model simulations. However, the results are still consistent with both theory and previous large-scale observational evidence.

What can be done?

Planting more trees often comes up as a potential solution to heat stress, said Chakraborty. But densely built urban cores, where poorer and minority populations in the U.S. often live, have limited space for trees. And many previous estimates of vegetation's potential to cool city surroundings are also based solely on land surface temperature—they are perhaps prone to similar overestimation, the authors suggest.

More robust measurements of urban heat stress would help, they added. Factors like wind speed and solar insolation contribute to how heat actually affects the human body. But those factors are left out of most scientific assessments of urban heat stress because they are difficult to measure or model at neighborhood scales.

In addition to Chakraborty, PNNL authors of the new work include Yun Qian. Andrew Newman at the National Center for Atmospheric Research, Angel Hsu at the University of North Carolina-Chapel Hill, and Glenn Sheriff at Arizona State University are also authors. This work was supported by DOE's Office of Science and the National Institutes of Health.

More information: TC Chakraborty et al, Residential segregation and outdoor urban moist heat stress disparities in the United States, *One Earth* (2023). DOI: 10.1016/j.oneear.2023.05.016

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