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MISSION CE CLIMATE

Urban Heat Island Effect

Causes, Consequences, and Adaptation Strategies

Contents

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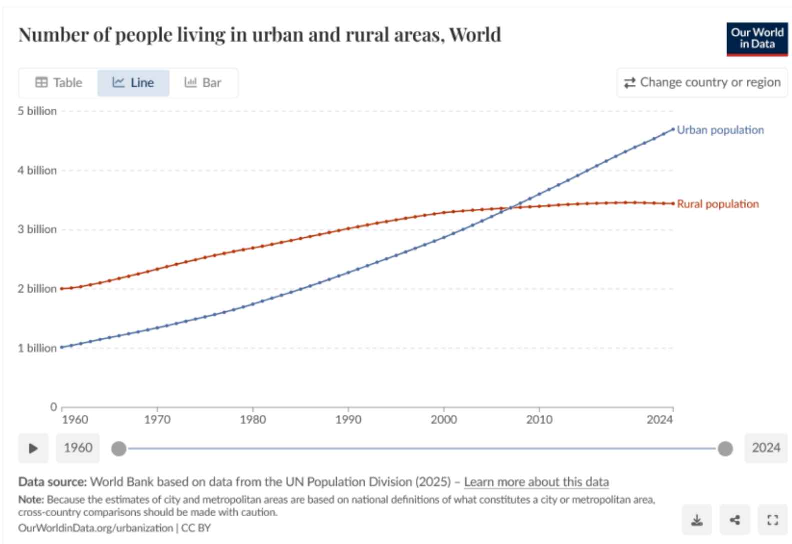
The increase in temperature due to global warming, especially the increasing of dry periods and (extreme) heat can have multiple, often interrelated consequences on human health, biodiversity, glaciers, agriculture, water cycles, energy generation and consumption, infrastructure as well as tourism. Further, cities are disproportionately affected by heat. The Urban Heat Island (UHI) effect describes localized areas where urban regions experience significantly higher temperatures than their rural surroundings, primarily due to human activities and altered land surfaces. This phenomenon intensifies health risks, energy consumption and air pollution, posing a growing challenge under global climate change. This learning material gives an overview of the causes and consequences of the UHI effect and shows evidence-based adaptation and mitigation strategies to enhance urban resilience. Heat is an often-underestimated natural hazard.

1. Introduction

Urbanization has transformed landscapes worldwide, with now over 56% of the global population now living in cities—a figure projected to reach 68% by 2050. By 2030, it is expected that there will be 43 megacities around the world, each home to more than 10 million people, with the majority situated in developing regions. Nevertheless, some of the most rapidly expanding urban areas are smaller cities with populations below 1 million, particularly across Asia and Africa. Although one in eight people currently lives in one of the 33 global megacities, nearly half of the world's urban population resides in small towns and cities with fewer than 500,000 residents (United Nations 2018). This urbanization trend highlights the importance of understanding climate risks for urban areas.



The replacement of natural vegetation with impermeable materials has led to a so-called *Urban Heat Island (UHI)* effect, where urban areas exhibit higher air and surface temperatures compared to rural surroundings. The effect has been shown for over 400 major cities (Santamouris 2015). Recent studies show that climate change is aggravating the urban heat island effect further (Kim & Brown 2021) and UHIs exacerbate local heat extremes, amplifying socio-economic and public health challenges (Zhao et al., 2014). Further, humidity can enhance heat stress and in turn, lower humidity can reduce the heat stress (Zhang et al., 2023).

2. Causes and Mechanisms

The formation of UHIs arises from a combination of physical, morphological, and anthropogenic factors. Surface properties play a central role: urban materials such as asphalt and concrete possess low albedo and high heat capacity, absorbing large quantities of solar radiation during the day and releasing it at night (Santamouris 2015; IPCC 2021). This leads to reduced nocturnal cooling, a defining feature of the UHI phenomenon. Further, the lack of sufficient vegetation aggravates warming by eliminating shading and evapotranspiration processes that naturally dissipate heat (IPCC 2021). Imran et al. (2021) emphasize that reduced canopy cover can increase local temperatures by up to 2°C. Additionally, also dense building clusters, narrow streets can create a “canyon effect” that traps longwave radiation and limits air circulation (Oke, 1987). Finally, anthropogenic heat emissions from vehicles, air conditioning, and industry add direct energy to the urban atmosphere (IPCC 2021).

According to the 6th Assessment Report of the IPCC, the geometry of a city, heat from human activities, materials and surfaces, lack of water and vegetation are the causes of the urban heat islands effect (Calvin et al. 2023).

Three key factors intensify the warming experienced in urban environments (IPCC, 2021):

- **Urban geometry:** Closely spaced tall buildings trap heat by absorbing solar radiation and limiting natural airflow, which hinders cooling.
- **Human-generated heat:** Everyday activities—such as energy use from heating and cooling systems, vehicle engines, and industrial processes—release additional heat into the atmosphere.
- **Buildings and surface materials:** Materials such as asphalt and concrete absorb large amounts of heat during the day and release it slowly at night, keeping urban areas warmer.

The urban heat island effect is further aggravated in places with limited vegetation or scarce water features, where the lack of shading and evaporative cooling allows heat to accumulate and persist.

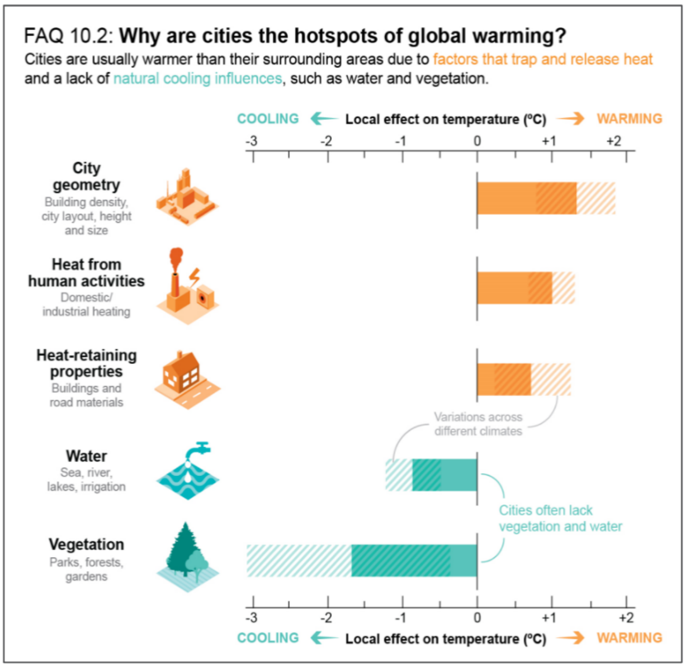


Figure 1: FAQ 10.2, Figure 1 in IPCC, 2021 | Efficiency of the various factors at warming up or cooling down neighbourhoods of urban areas[1].

3. Environmental and Socio-Economic Consequences

The implications of UHIs extend beyond temperature increases and affect human health, have hydrological and ecological effects, can affect energy demand and air quality and people with lower incomes are disproportionately more affected.

3.1. Public Health

Heat-related morbidity and mortality rise significantly in urban areas. Vulnerable groups — including the elderly, babies, people with pre-existing illnesses, outdoor workers and low-income populations are more exposed to heat stress and thus bear disproportionate impacts. Recent health data link extreme heat events with increased hospital admissions for cardiovascular and respiratory illnesses (Oleson, et al., 2015). Heat as a health risk is still often underestimated by citizens (Howe et al., 2019).

[1] FAQ 10.2 Figure 1 in IPCC, 2021: Chapter 10. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Doblas-Reyes, F.J., A.A. Sörensson, M. Almazroui, A. Dosio, W.J. Gutowski, R. Haarsma, R. Hamdi, B. Hewitson, W.-T. Kwon, B.L. Lamptey, D. Maraun, T.S. Stephenson, I. Takayabu, L. Terray, A. Turner, and Z. Zuo, 2021: Linking Global to Regional Climate Change. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1363–1512, doi: 10.1017/9781009157896.012 .]*

3.1. Energy and Air Quality

UHIs elevate energy demand by increasing air-conditioning use. Santamouris (2014) found that the electricity demand for cooling is by 13% higher for urban buildings compared to similar building ins rural areas (Santamouris, 2014). This feedback loop not only strains energy systems but it could also increase greenhouse gas emissions depending on the electricity mix. Thus, a positive feedback effect exists here. Additionally, warmer urban atmospheres accelerate the photochemical production of ground-level ozone, worsening air quality and respiratory health risks (Harlan & Ruddell, 2011).

3.2. Social Inequities

Urban heat exposure is unevenly distributed. Low-income neighborhoods often have less tree cover and higher surface imperviousness, making them UHI “hot spots” (Harlan & Ruddell, 2011). Addressing UHIs thus intersects with broader issues of urban equity and environmental justice.

4. Adaptation and Mitigation Strategies

Mitigating the UHI effect requires integrated strategies that address both surface and atmospheric processes.

(a) Urban greening. Increasing vegetation through urban forests, green roofs, and green walls enhance shading and evapotranspiration. Modeling studies show that extensive tree canopy cover can reduce local air temperatures by 1–3 °C (Bowler et al., 2010). The effect is even stronger if you look at surface temperature or perceived temperatures.

(b) Urban design and planning. Improving ventilation corridors, increasing open spaces, and orienting streets to optimize wind flow can enhance convective cooling (Oke, 1987). Zoning regulations can integrate these design principles into long-term urban development. Better insulation can allow people to flee the heat and offering so-called public “cool-spaces”, where people can meet and relax are also important steps. Further, unsealing certain areas can also help decreasing the UHI effect.

(c) Cool materials. The use of *cool roofs* and *cool pavements*—high-albedo surfaces that reflect more solar radiation—significantly reduces surface and air temperatures. Reflective roofing materials can decrease roof surface temperatures by up to 30°C (Santamouris, 2014).

(d) Energy efficiency and emission control. Reducing waste heat through efficient building design, renewable energy integration, and low-emission transport systems lessens anthropogenic contributions to UHIs (Han et al., 2023).

(e) Technological and policy tools. Remote sensing and thermal mapping are increasingly used to identify heat hotspots and guide targeted interventions.

5. Conclusion

The Urban Heat Island effect represents a critical intersection between local urban dynamics and global climate change. While driven by human modification of the landscape, its impacts on energy demand, health, and equity underscore the need for systemic adaptation. Greening cities, designing reflective infrastructure, and integrating climate-sensitive planning can collectively moderate UHI intensities and enhance urban resilience. As cities continue to expand, addressing UHIs offers an opportunity to align climate mitigation with human well-being and sustainable urban development.

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