SCHOOL OF TRANSNATIONAL GOVERNANCE

STG Policy Papers

POLICY ANALYSIS

ASSESSING THE BURDENS OF URBAN HEAT: A DESCRIPTION OF FUNCTIONAL, ECONOMIC AND PUBLIC HEALTH IMPACTS OF INCREASING HEAT IN CITIES

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ISSUE 2023/02
FEBRUARY 2023

SCHOOL OF TRANSNATIONAL GOVERNANCE

EXECUTIVE SUMMARY

Urban Heat Islands (UHI), together with increasingly frequent heatwaves due to climate change, impose functional, economic and public health burdens for cities, urban dwellers and local administrations. This paper aims to examine how excess heat disturbs urban functioning and hence, contribute to the discussion on the urgent need to strengthen climate change adaptation and foster climate governance. It first describes two different but synergistic sources of heat: urban heat islands and heatwaves. It then outlines the human mechanism of temperature regulation and presents public health impacts in terms of heat-related morbidity and mortality. The paper continues by mentioning the economic burdens as well as infrastructure malfunction associated with this threat. It concludes with a call-to-action for decision-makers on the urgent need to address urban heat.

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1. INTRODUCTION

The world is warming at an unprecedented pace. The increase in greenhouse gas concentrations, unequivocally caused by humans, has led to a relentless increase in global land surface temperature (IPCC, 2021). All the world's regions are experiencing temperature increases, but such increases are not evenly distributed across the globe. Heat is especially felt in urban areas as cities concentrate population and, additionally, intensify anthropogenic warming locally (IPCC, 2021). Excessive heat affects peoples' health, especially among vulnerable social groups such as the elderly, children and people with mental or cardiac conditions. Moreover, heat impacts negatively on the economy, infrastructure, energy and water usage as well as on the communities themselves. In addition, on many occasions these impacts may go unnoticed, may not be directly associated to urban heat or, worse, may not perceived as preventable. In fact, the opposite of all the previous is true. Urban planners and decision-makers in public administrations have a great responsibility to recognise and then address this threat. In that regard, this policy analysis seeks to describe the cascading effects and disruptions in urban functioning caused by excessive heat. There are two different phenomena behind such heat increase in cities. On the one hand, there are urban heat islands, which behave like permanent hot spots around a specific area of a city and are expansion-led. On the other hand, there are heatwaves, which are extreme climatic events with long-lasting hot days and are caused by global warming. Though both heat sources have different origins and characteristics, they behave in a synergic manner, adding several degrees to the urban built environment.

2. DIFFERENT SOURCES, ONE SAME CONSEQUENCE: OVERHEATING

2.1 Urban heat islands

Forecasts show that urbanisation trends will add about 2.5 billion inhabitants to urban areas over the next 30 years (United Nations, 2019) which in turn leads to heat increase. Such population growth has a direct and corresponding impact in terms of urban expansion. As cities grow to accommodate an enlarging urban population, they transform the surface of the territory (Oke, 1987), and hence affect the thermal properties of the area. As the peri-urban edge advances, open spaces covered with vegetation and shade are replaced by impervious materials commonly used in city construction such as asphalt, brick, steel and concrete. During this process, solar radiation absorption increases as does the thermal capacity of the surface. Heat accumulates during the day but only a fraction is released during the night (Weng, 2001). The energy balance of the territory is affected in favour of greater heat accumulation, leading to a temperature difference between an urban area and its rural surroundings. This phenomenon is defined as 'Urban Heat Island' and is a clear expression of the impact of anthropogenic activity on the local climate (García-Cueto, Jáuregui-Ostos, Toudert, & Tejeda-Martínez, 2007), as well as at the regional and global scales (Carvajal & Pabón, 2016).

A cross-section representation of an Urban Heat Island is presented in Figure 1 (see page 5). highlighting the difference in temperature in relation to the degree of urban land transformation. Heat islands can occur at different scales and can manifest themselves around a building, a couple of blocks or over a large area of a city (Taha, 1997). Besides temperature, relative humidity and wind intensity are also affected. According to Oke (1987), the urban heat island effect is the clearest and best-documented example of inadvertent climate modification.

Territory waterproofing occurs alongside urban expansion. As asphalt, concrete, and other building elements replace absorbent surfaces such as trees and other vegetation, the soil reduces its capacity to absorb and retain water, thus affecting evapotranspiration. This reduces the ability of the land to cool itself. Figure 2 (see page 5) compares a natural ground cover to an urban impervious one. Vegetation loss also leads to lower rainfall interception capacity. That, together with reduced infiltration due to soil imperviousness, results in greater water surface runoff, which further reduces moisture available for evaporation (Christen & Vogt, 2004), and diminishes the potential for cooling through evaporation. Moreover, greater run-off causes water from rainwater to flow faster, which generates more pressure on rainfall infrastructure and may increase the incidence of flooding.

Current urbanisation leading to tree cover loss is mainstream. The world's urban tree cover experienced a significant reduction between 2012 and 2017, which conducted to an increase in urban impervious cover (Nowak & Greenfield, 2020) and to additional urban heat. Similar trends have been reported in Eastern Europe (Kabisch & Haase, 2013), China (Zhai, Yuan, Ma, Wang, & Jin, 2022) and North America. A US nationwide research analysed the 5-year evolution of the surface area of 20 major cities in the United States to assess recent changes in tree cover types and impervious surfaces. Results show that from 2005 to 2009, tree cover declined 5% while impervious surfaces such as roads and buildings increased by 2.7%. Although this work considers a short five-year period and is limited to a group of 20 major U.S. cities, it shows clearly how urban expansion worsens the intensity of heat spots (Nowak & Greenfield, 2012). In sum, urbanisation increases average temperature and heavy rains over cities, provokes stronger winds, and augments the intensity of the resulting run-off surface water. IPCC forecasts indicate that flooding in coastal cities will be much more likely due to synergic factors such as sea level rise, increased occurrence of extreme precipitation events and higher river flows (2021).

An additional cause of urban heat is anthropogenic heat. This type of heat is produced by human activities linked to transportation and energy use for lighting, heating and cooling buildings. Anthropogenic heat, also called waste heat, varies according to the characteristics of urban infrastructure and the built environment; that is buildings and means of transportation. If they rely heavily on private transportation and air conditioning, they consume more energy and thus contribute significantly to the intensification of heat islands (U.S. Environmental Protection Agency, 2008).
Urban morphology also affects the temperature, wind and humidity of the city and can intensify heat (Kelbaugh, 2019).

Urban morphology also affects local climate; by trapping incident solar radiation and long wave terrestrial radiation, affecting wind flows, increasing anthropogenic heat and are usually associated with a loss of green spaces and their consequent water availability for evapotranspiration. The relationship between building height and street width is also relevant. There is a strong relationship between the geometry of the "canyon" (the ratio between the height and width of the constructed buildings) of a central street and the maximum intensity of the urban heat island (Oke, 1987). The shape, colour, height, location and orientation of buildings, as well as the pattern and width of roadways modify the direction and wind speed at street level and determine the degree to which heat is trapped (Eliasson, 1999).

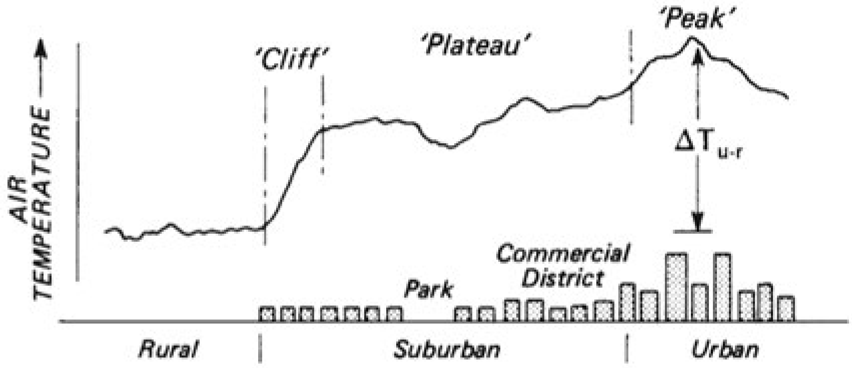
2.2 Heatwaves

Heatwaves are considered 'periods of statistically unusual hot weather persisting for a number of days and nights' (World Meteorological Organization, 2022a). In short, they are consecutive days of abnormally hot weather (IPCC, 2018). Heatwave occurrence is critical, as they provoke extremely adverse consequences, especially with regards to public health, economic burden and urban functioning.

Heatwaves are non-permanent climatic events and are not as directly caused by urban expansion as heat islands. However, they behave synergistically. Heat islands do not cause heat waves, but amplify them (Stone B. J., 2012) (IPCC, 2021). Cities intensify human-induced warming at the local level, and ongoing urbanization trends coupled with increased local heat urban heat island will further increase the severity of heatwaves. Due to the lack of vegetation and the prevalence of building materials that retain heat, cities absorb more energy than they release, and are consequently steadily heating up. On unusually warm days during a heatwave, the additional heatwave temperature is builds on the extra temperature due to the heat island.

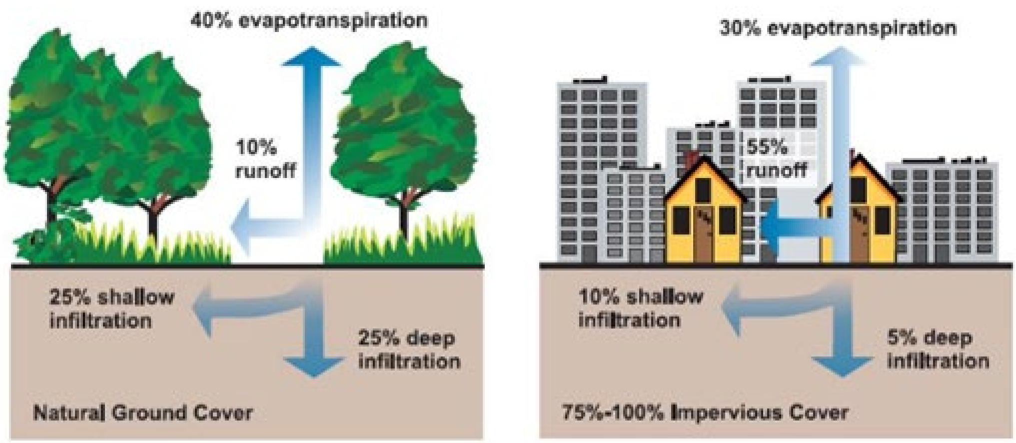
The frequency of heatwave occurrence has been increasing over the last few decades (Ca-

FIGURE 1: Cross-section of a typical urban heat island



Source: Oke T. R. 1987, Boundary Layer Climate, 2nd Edition. p. 288

FIGURE 2: Comparison of imperviousness and evapotranspiration between types of cover



Source: Taken from U.S. Environmental Protection Agency (2008).

milloni & Barros, 2016). According to the World Meteorological Organization, 'heatwave occurrence is the new normal' (2022b) and we should expect temperature records to be broken year after year. In the near future, heatwaves are to become more frequent and intense due to the ongoing process of climate change (IPCC, 2021).

There have been many recent examples of heatwaves that have had devastating effects. During the summer of 2003, Europe suffered the deadliest heatwave ever recorded. It had catastrophic consequences, affecting 12 countries and killing more than 80,000 people[1] (Robine, Cheung, Le Roy, Van Oyen, & Herrmann, 2007). In France alone, because of the additional heat more than 15,200 people died, in Italy the death toll reached 9,700, and in Spain over 6,400.

Just seven years later, in 2010, the strongest heatwave in Asia occurred, affecting Russia especially, where more than 55,000 people perished (Barriopedro, Fischer, Luterbacher, Trigo, & García-Herrera, 2011). India and Pakistan witnessed major heatwaves in 2015 where more than 3,500 people died (UNESCAP, 2016). In India, heatwaves are the third most important type of extreme weather event in terms of mortality based on 50-years data (Kamaljit, Giri, S.S., A.P., & M., 2021). This last summer a long and intense heatwave hit the United Kingdom, where 3,271 people died, 85% of whom where at least 70 years old (Office for National Statistics and UK Health Security Agency, 2022). That same heatwave also affected Portugal and Spain, killing another 1,700 people (World Health Organization, 2022).

Not surprisingly, heatwaves not only affect the northern hemisphere. In Australia, at least 354 people were killed by heatwaves between 2000 and 2018 (Lucinda, et al., 2022). During the summer of 2018-2019, South America witnessed a major heatwave with high temperature records broken in many countries. Paraguay registered its hottest day on record while Peru witnessed its most intense heatwave in 30 years. Moreover, Argentina registered 30°C in the city of Rio Grande, Santa Cruz located at 53.8° South Latitude, the hottest temperature ever measured so far south (World Meteorological Organization, 2020).

Taking a closer look to another example, during the summer of 2013/2014 Argentina suffered the longest and one of the most severe heatwaves ever. It affected the whole central region of Argentina, from Buenos Aires to Mendoza, which are 1,000 kilometres apart from each other. In the city of Buenos Aires alone, an additional 544 heat-related deaths were recorded in comparison with the average number of deaths during the previous 8 years. Estimates show that should all the affected areas have had registered deaths, the figure could have been six to eight times higher (Camilloni & Barros, 2016).

However, how exactly does heat affect human health? The following section examines the mechanism by which high temperatures strike body functioning, wellbeing and, ultimately, people's health.

3. TEMPERATURE, THERMAL COMFORT AND HEALTH IMPACTS

3.1 Temperature and thermal comfort

Thermal comfort, defined as 'the condition of the mind in which satisfaction is expressed with the thermal environment' (ANSI/ASHRAE, 2004) occurs when body temperatures are held within a narrow temperature range and physiological efforts are minimum (Djongyang, Tchinda, & Njomo, 2010). In thermal comfort conditions, the human body temperature is around 37°C and skin temperature ranges between 31°C and 34°C. Our body continuously and involuntarily produces heat to maintain a constant temperature through a series of physiological processes. An additional way of producing heat is through muscular metabolism, when the body performs a physical activity. To keep the body temperature within the comfort range, the human body produces heat that must be dissipated to the environment. There is a continuous transport of heat from the deep

1 To estimate the death toll and in order to be certain that such deaths were provoked by heat, researchers analysed the occurrence of deaths per day for the period 1998 to 2002 and then contrasted it with what was observed during the unusually warm months of 2003. They compared the number of deaths expected under 'normal conditions' with those recorded during these periods of extreme temperatures

When temperatures are lower or higher than the thermal comfort temperature range, our body has a series of physiological mechanisms that seek to maintain temperature in equilibrium. On the one hand, in case of low temperatures and if we lack sufficient clothing or insulation, our body first uses vasoconstriction. By doing this, it reduces blood circulation in peripheral tissues and the skin, resulting in a decrease in skin temperature and thus reducing the rate of heat dissipation. If this is insufficient, a process called thermogenesis is activated, which produces metabolic heat through muscle tension or shivering, seeking to reduce further loss of body temperature. If these physiological mechanisms fail to restore thermal equilibrium, hypothermia will occur. On the other hand, when the body temperature rises, the human body must activate the opposite mechanisms in order to increase heat dissipation along two mechanisms. This is firstly achieved through vasodilation, a process in which the subcutaneous blood vessels expand and increase the blood supply to the skin. Skin temperature increases in turn promotes heat dissipation. If this process cannot restore thermal equilibrium, the body begins to perspire to release heat. In this way, sweat glands are activated and the evaporative cooling mechanism is ignited. While sweat can be produced for short periods at a rate of 4 litres per hour, this mechanism is fatigable and cannot operate beyond a certain temperature threshold (Auliciems & Szokolay, 1997).

In the event that vasodilation and sweating cannot restore thermal equilibrium conditions, the human body inevitably heats up, leading to hyperthermia. When the body temperature reaches 40°C, heat stroke may occur. This circulatory failure leads to fainting and temporary loss of consciousness. Additional symptoms are fatigue, headache, and dizziness, loss of appetite, nausea, vomiting, breathing difficulties, accelerated pulse, glassy eyes, as well as mental disturbances such as poor judgment, apathy or irritability. If fluids are not replenished and the person does not re-hydrate immediately, the body cannot dissipate heat through perspiration and body temperature continues to rise above 41°C (41°F). At this point sweating stops, coma occurs and death is imminent. Even if a person is assisted at this point, the brain may have suffered irreparable damage. If the body temperature reaches 42°C, the person dies (U.S. Centers for Disease Control and Prevention, 2006). Table 1 (see page 8) presents different temperature stages and associated results.

3.2 Heat-related mortality

Due to an increasing frequency of extreme heat events, heat-related mortality has become an issue of major public health concern. In fact, the effect of temperature on mortality is the most extensively studied topic within the broad domain of climate and health research (Madrigano, McCormick, & Kinney, 2015). There is a direct association between high ambient temperature and increased premature mortality, which rises in case of pre-existing medical cardiovascular and respiratory conditions (Linney, 2018). This association is consistent with a large body of epidemiological research. Basu (2009) conducted a systematic review of more than 30 investigations published between 2001 and 2008 on heat mortality. Fourteen studies were epidemiological investigations on ambient temperature and mortality, while another 14 studies considered air pollutants as possible modifying factors. Six considered vulnerable groups. Eleven of these investigations were conducted in the United States, ten were published with European data, three in Latin America, three in Australia, two in Canada and elsewhere. Table 2 (see page 8) shows a selection of the research reviewed.

Results show that elevated temperature was associated with an increased risk of death from cardiovascular, respiratory, cerebrovascular and some specific cardiovascular diseases such as ischemic heart disease, congestive heart failure and myocardial infarction. Vulnerable subgroups were also included, with evidence that women, people of lower socioeconomic status, Black, Asian and minority etic groups, and the elderly over 65 years of age as well as infants and young children were at higher risk of heat death. For example, in Europe and South Korea, mortality estimates above a temperature threshold (23.3-29.7°C) showed that a 1°C increase in apparent temperature corresponded to a 3.12% increase in daily mortality in Med-

TABLE 1: Different stages in thermal (dis)comfort

Skin temperature	Body temperature	Result
45°C	42°C	Death
	40°C	Hyperthermia
		Sweating
		Vasodilation
31-34°C	37°C	Thermal Comfort
		Vasoconstriction
		Thermogenesis
	35°C	Hipothermia
10°C	25°C	Death

Source: Auliciems y Szokolay (1997)

TABLE 2: Examples of heat-related mortality studies

#	Source	Study Population	Result (95% CI)
1	Baccini (2008)	15 European cities, summers between 1990 and 2000	With 1°C increase above threshold, 3.12% mortality increase in Mediterranean and 1.84% in the north-continental region. Higher percentages in elderly and people with prevailing respiratory diseases
2	Basu and Ostro (2008)	9 California (US) counties, May to September 1999-2003	Every 5.5° Celsius temperature grow, mortality increases 2.3%
3	Bell (2008)	San Pablo, Santiago de Chile, Ciudad de Méjico entre 1998 y 2002	Mortality increase in Santiago de Chile 1.82% (2.69% adults>65 y.o.); San Pablo 4.43% (6.51% adults> 65 y.o.) and Mexican City 1.26% (3.22% adults > 65 y.o.).
4	McMichael (2008)	Delhi, Monterrey, Mexico City, Bangkok, Salvador, San Pablo, Cape Town, Santiago de Chile, Sofia, Bucharest, Chiang Mai and Liubliana	1°C increase above threshold increased death rates with increasing heat in all cities: (ranging from 0.77-18.8) except Chiang Mai and Cape Town

Source: Adapted from 'High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008', Basu (2009) iterranean cities and a much larger effect in Korea (6.73%-16.3% in six cities) over a similar time period.

During such an extreme event, the chances of death substantially increase. A study analysed heat wave mortality in the City of Buenos Aires between 2005 and 2015 and found that during a heat wave there is a 14% higher chance of dying from 'natural causes'. Evidence shows that deaths occur in both males and females and all ages, but heat affects much more children under 15 years old and the elderly, especially those over 85 years old (Chesini, Abrutzky, & de Tito, 2019), as they are more susceptible to heat and dehydration. Another factor that increases the risk of death is the prevalence of heart and respiratory diseases. Looking specifically at the 2013-2014 heat wave, the risk of death increased fourfold to 43%. This figure rose to 51% for the elderly group.

To put this mortality in context, it is useful to compare it with flooding-led mortality. There were more deaths due to the 2013/2014 heatwave in the city of Buenos Aires alone than deaths due to flooding in Argentina as a whole between 1985 and 2015 (Camilloni and Barros 2016).

The contrast between heat and floor mortality is necessary to put into perspective the lethality of heat and the low public perception of such lethality. This comparison is also valid for the US, where heat is the deadliest weather-related hazard, killing more people than any of the other weather events combined (Keith & Meerow, 2021). As a large number of the deceased are elderly and/or have pre-existing diseases, these deaths are somehow perceived as 'expected'. Moreover, heat is usually tagged as a 'silent killer' (Baughman McLeod, 2020), as it largely remains an invisible threat. However, evidence shows that deaths occurring during a heat event are attributable to the phenomenon itself and should therefore be perceived as a risk to people's health and, consequently, as a climatic threat. Indeed, with regard to heatwaves, the Third National Communication (TNC) of the Argentine Republic to the United Nations Framework Convention on Climate Change argued that "there is insufficient public awareness of the damage and deaths they cause" (2015).

Heat vulnerability is affected by additional elements such as socio-economic status, loneliness, access to green space or to an air conditioning device. The analysis of increased death risk during the 1995 five-day heatwave in Chicago, Illinois, United States where over 700 people died, revealed that risk was significantly higher when: (a) people had health conditions that required them to be on bed rest; (b) they could not take care of themselves; (c) they did not leave their homes every day; (d) they lived alone; or (e) they lived on the top floor of a building. By contrast, participating in social activities and having contacts with other people decreased the probability of dying during a heat wave since higher levels of networking and social cohesion made it more likely that an acquaintance would be concerned about verifying that 'everything was all right'. In addition, those who worked in an air-conditioned location or who had access to one via nearby transportation were less likely to suffer from stress conditions (Semenza, et al., 1996).

Similarly and more recently, a detailed analysis of underlying components of heat-related risk for the 2018 heatwave in Montreal reveals that social conditions where major drivers. Fifty-four residents of this Canadian city died from the heat and, according to the regional public health department, most were over 50 years old, lived alone with no other companions at home, and had underlying physical or mental health problems. None of the victims had air conditioning. Authorities reported that many of the corpses examined by the forensic team "were in an advanced state of decomposition, having sometimes spent up to two days in the heat before being found". During this heat wave, it was the poorest people and those who were socially isolated who suffered the most. According to the evidence, pre-existing mental illness severely augmented risk. Though people with schizophrenia only represent 0.6% percent of the city's population, they accounted for over 25% of reported deaths (Ha, 2021). In light of the role that social cohesion plays in terms of strengthening resilience, some cities (Paris for example) are promoting activities and programs that strengthen cohesion, solidarity, and the bonds of socially isolated people (Maire de Paris, 2018).

Proximity to green areas plays a major role. Evidence shows people living in areas with less vegetation have a five percent higher risk of dying from heat-related causes (Schinasi, Benmarhnia, & De Roos, 2018). Here it is worth noting that informal settlements have very low and poor provision of green infrastructure and, consequently, risk increases significantly in this type of settlement (Saez Reale & Nacke, 2021). Today more than one billion people live in such conditions, where access to basic services are of very poor quality (UN-Habitat, 2022). The impacts of heat are magnified by aspects of social vulnerability related to the housing conditions of the population. The extent of this is such that today the lack of domestic cooling systems is beginning to be considered a component of vulnerability to rising urban temperatures. Research has estimated the number of hospitalisations as a function of rising temperatures and analysed to what extent hospitalisations had been associated to whether or not people had air conditioning equipment at home. With a 5.6° Celsius increase in apparent outdoor temperature, the risk of hospitalisation increased substantially for a wide range of conditions: cardiovascular disease, ischemic heart disease, ischemic stroke, respiratory disease, pneumonia, dehydration, and acute renal failure. Owning and using air conditioning equipment significantly reduced the prevalence of these diseases (Ostro, Rauch, Green, Malig, & Basu, 2010). Table 3 (see page 11) provides more information in this regard.

Interestingly, air-conditioning devices presents a strong duality. On the one hand, they improve thermal comfort and drastically reduce heat-related vulnerability, behaving as an essential device to cope with high temperatures. On the other hand, they are at the same time responsible for increasing anthropogenic heat, one of the causes that generate greater intensity of the urban heat island. This suggests that in order to reduce the temperature and mitigate its impacts, it will be necessary to identify and promote other cooling solutions such as promoting air flow, boosting green infrastructure, improving thermal efficiency in buildings and shifting towards better-reflecting urban surfaces, among others (United Nations Environment Programme, 2021).

3.3 Additional impacts: Aedes aegypti habitat modification

Besides directly affecting people's health, increasing heat improves the conditions for the proliferation of the Aedes aegypti mosquito, a vector of viral diseases such as dengue, zika, chikungunya and yellow fever. This mosquito lives in tropical and subtropical climates and is currently present in all five continents and in more than 100 countries around the world. In Europe, it is only present in certain coastal areas, but with further climate change most of southern Europe could be infested (Liu-Helmersson & Brännström, 2019).

The mosquito's current geographical distribution depends heavily on average temperature, since this is one of the main variables affecting its habitat (Gil, et al., 2019). Additional factors that shorten the life cycle and speed its multiplication are humidity and the presence of still water where the mosquito lays its eggs. The adult female mosquito feeds on blood to obtain the protein needed for her eggs to mature, and if they have food shelter and oviposition sites, they do not usually disperse more than 20 meters (Gil, et al., 2019). This allows the mosquito to thrive better in places with a certain concentration of people, proliferating in urban and peri-urban settings.

The fact that mosquitoes are exothermic makes temperature a factor of huge relevance to their life cycle and, consequently, to the disease dynamics. Temperature not only affects mosquito survival and the length of its life cycle, but also the extrinsic incubation period of the pathogen. Temperatures above 30 °C can reduce the dengue virus replication-cycle from 12 to 7 days and alter infection rates from 67 to 95% (Watts, Burke, Harrison, & Nisalak, 1987). Consequently, the increase in temperature favours mosquito reproduction and the incidence of the diseases they transmit, negatively affecting human welfare and public health.

Just a few additional degrees can have major

TABLE 3: Effect of a 10% increase in air conditioning ownership on different diseases

Outcome	Relative reduction in excess risk
Respiratory disease	19.9%
Pneumonia	19.4%
Chronic obstructive pulmonary disease	4.2%
Cardiovascular disease	49.1%
Ischemic heart disease	36.2%
Stroke	38.4%
Diabetes	1%
Acute renal failure	2.1%
Dehydration	11.5%

Source: Adapted from Odstro et al (2010)

FIGURE 3: Rail buckling due to high ambient temperatures

Source: Image taken from Queensland University of Technology (2010) outcomes in these disease dynamics. The link between dengue mosquito prevalence and urban heat islands has been assessed in Brazil. Researchers have explored the associations between the temporal and spatial distribution of Aedes aegypti larval habitats, the presence of urban heat islands and local socioeconomic factors. After collecting data on larval habitats in the city of São Paulo, Brazil, researchers analysed spatial and temporal variations of the mosquito and quantified urban heat islands using satellite images. Azevedo, et al. (2018) concluded that the existence of urban heat islands, as temperature increases in certain areas of the city, favours the proliferation of larval habitats of the Aedes aegypti mosquito. This poses further unseen risk factors for urban dwellers.

4. FUNCTIONAL DISTRESSES & ECONOMIC BURDENS

In addition to the impacts on the health of the population, urban heat causes a wide range of impacts on the normal functioning of cities (Leal Filho, Echevarría Icaza, Neht, Klavins, & Morgan, 2017). High temperatures affect people's behaviour, the transportation system, the lifespan of several devices and the operating capacity of urban infrastructures. Some of the impacts are strictly associated to heatwave occurrence, and some others to urban heat islands, but all have direct negative consequences on life quality. The following section describes the nature of these types of impacts, establishing the relationship between urban heat and effects on different urban components, providing arguments in favour of addressing the issue of rising temperatures.

4.1 Economic costs of the impact on public health

The impacts of heat on public health have a direct economic effect in the form of increased costs. Illness and mortality associated with excessive heat have economic consequences, whether for individuals, their families, organizations and for public administrations (World Health Organization, 2009). According to the WHO's 'Guide to identifying the economic consequences of disease', poor health directly affects the main determinants of economic well-being. Consumption of non-related health goods and services and leisure are also affected, especially for three major social actors.

One of these actors is households. Poor health has an impact on the household economy as it diminishes a family's income and its capacity to consume goods and services. There are multiple mechanisms that lessens current and future consumption, especially in developing countries with high direct health expenditure. Poor health provokes increased consumption of health-related goods and services by households at the expense of non-health-related goods and services. In addition, time spent seeking medical care or in health conditions that impede work reduce the production of market and non-market goods. The economic impact on households is not limited to the current time. Health services and goods can be paid for using current income, but could also be financed from cash savings, if available. This can also be achieved by borrowing or selling household assets, which implies a dissaving. Reductions in household income, savings and assets due to the consumption of health goods and services can lead to disinvestment in physical, financial and human capital.

Businesses and governments are also affected. Poor health conditions can reduce the productivity of workers and, consequently, the overall productivity and efficiency of any business and organizations. If sustained over time, this results in a negative effect on its medium-term revenues and profits in the cases of businesses. Their capacity to invest profits diminishes as well, preventing new investments or the reproduction of wealth. As recently reported by the International Labour Organization (ILO), excessive heat during work hours limits workers' physical capabilities, generates occupational health risks and drastically reduces workforce productivity, consequently affecting organizations (ILO, 2019). Heat affects workers in all economic sectors; however, certain occupations are especially at risk because they involve greater physical exertion or are developed outdoors (Melillo, Terese, and Yohe, & Eds., 2014). Jobs in activities such as agricultural production, construction, waste collection, transportation and tourism are especially at risk while being, at the same time, the main economic sectors in many countries. In the case of government employees, when they become ill the production of public goods either reduces or the cost of producing them escalates, just as in the case of businesses.

Projections estimate that 2.2% of total working hours worldwide will be lost to heat in 2030, a loss of productivity equivalent to 80 million current full-time jobs. It should be noted that these estimates are conservative, as they are based on a global temperature increase of 1.5°C by 2100. Today, realistic estimates of temperature increase under business-as-usual scenarios indicate an increase of 2.7°C (Climate Action Tracker, 2021) by 2100. As global warming grows above 1.5°C, temperature increase is expected to decrease labour productivity even further. Economic losses due to heat stress at work are projected to rocket from $280 billion in 1995 to $2,400 billion in 2030, especially in lower and middle-income countries, where decent work conditions are lagging and safety deficits are most pronounced (ILO, 2019).

4.2 Impacts on urban transport performance

Heat affects urban transportation systems in a wide range of ways. Elevated temperatures impact both the operation of trains and cars, as well as buses and private automobiles. Following the 2009 heat wave in Melbourne, Australia, the Australian National Climate Change Adaptation Research Facility (NCCARF) commissioned a report to assess how and to what extent infrastructure had been distressed. During this extreme event, more than 750 train services out of 2,400 had to be cancelled (Queensland University of Technology, 2010). Due to failures in the air conditioning equipment of the cars, lack of electric power and the sudden buckling and bending of the rails' tracks, the number of train journeys fell by one third. Such rail bending (as pictured in Figure 3) occurs when the rails expand due to exposure to heat. When lacking expansion joints they are susceptible to buckling at weak points. Weak spots can arise for a number of reasons. Tracks may be in poor condition due to lack of maintenance, not being pre-stressed or welded properly or loosening bolts from sleepers. During the heat wave, streetcar tracks buckled at Port Melbourne, Airport West and Royal Park.

Heat also caused major distress on the thermal comfort of tram passengers. In Melbourne, only half of the units are air-conditioned. Fifty percent of the fleet of 485 streetcars only have AC devices for drivers but not passengers. Moreover, the other half have AC units that are not designed to operate above 34.5 degrees Celsius. Therefore, at higher temperatures these units could not operate either. While this did not result in the tram service cancellation, it did have a direct impact on people's thermal comfort and increased the likelihood of heat stroke. Tram and train cancellations did occur during power outages as they are both run on electric power.

Buses were also affected by the heat wave, mainly due to the failure of air AC units. Above 35 °C, they start having problems to operate, and above 40 °C they tend to simply blow hot air. This generated discomfort for bus drivers and passengers. Unlike trains, there is no protocol for interrupting a service due to air conditioning malfunction, so bus services continued to run. In fact, the buses served as a back-up service for cancelled train services. However, during the heat wave there was a shortage of buses, highlighting that the existing fleet was unable to provide a full back-up service. High temperatures also affected the surface on which buses and private vehicles travel. Concrete or street asphalt also expands due to heat, and if it expand above a certain threshold, the asphalt can melt and the concrete crack, leaving streets impassable (Stone B. J., 2012), especially in high-traffic areas (U.S. Environmental Protection Agency, 2017). Similarly, during this year's heatwave in UK, Luton's Airport runway melted in certain areas and the airport had to close until repaired (Topham, 2022).

The cost of decreased efficiency to cars and air conditioning equipment.

The performance of air conditioning devices and automobile engines as well as their lifespan is subject to degradations from just a small increase in temperature (Miner, Taylor, Jones, & Phelan, 2017). Based on the first principle of thermodynamics, air conditioning devices operate more efficiently as the temperatures of the hot side (external unit) and the cold side (internal unit) converge. When the temperature of the external unit increases due to higher ambient temperature, as it occurs in a heat island, the device needs more electricity to achieve the same cooling indoors in the refrigerated environment. It is also going to be used more. This additional energy, as well as the resultant reduction in the device's lifespan, comes at a cost. Similarly, the same principle affects combustion engines that convert heat into work, such as automobiles.

Table 4 (see page 15) shows the estimated economic impact due to increased heat for a group of cities with registered heat islands and takes into account both the longevity of the devices and the cost of operating the air conditioning systems.

To add further detail, a case study for Phoenix, Arizona, US illustrates the scope of the effects by breaking down the economic cost per each additional temperature degree. Table 5 exhibits the reduction in the coefficient of performance of a fixed air conditioner (R-COP), for the total effect on cars (R-car), and for the AC's lifespan reduction (R-device) for each 1°C of outside temperature during the period June-September (summer months in the Northern Hemisphere).

The annual cost of urban heat to Phoenix is estimated at U$S 158,5 Million per each additional Celsius degree, and an overall cost of almost $480 million, based on the urban heat island magnitude estimate of 3°C. The economic impact is measured as a percentage of the gross geographic product of the Phoenix metropolitan area using 2012 annual data from the Bureau of Economic Analysis, and assuming that each month contributes equally to annual GDP. This is a conservative assumption in Arizona's seasonal economy, where the percentage impacts in the summer and winter are higher due to reduced tourism and service sector activity in the hot season. Considering that this analysis only takes into account four summer months and restricts device costs to AC units, these results are conservative. However, they are surprising. It should be noted that these are also often invisible to the consumer, as they are included in bills for common repairs and services, which are perceived as expected. Yet again: silent costs. Although the additional costs may be indistinguishable from what might be considered the expected cost of energy or repair, the urban heat island is a purely artificial phenomenon, and acts as a development tax; imperceptible to on residents, businesses and local governments.

Reduced economic activity.
Another economic consequence of heat is that it decreases economic activity. When temperatures soar, people avoid leaving their homes to engage in economic activities in order to avoid low thermal comfort. Evidence shows there is an effect of rising temperatures on commercial interactions between businesses and their suppliers (Custódio, Ferreira, & Lam, 2021). To explore this, researchers have used transaction data from 2000 to 2015 from more than 2,200 U.S. companies and cross-referenced it with weather data, assessing fluctuations in transactions when temperatures increased. Results show that a local increase in average temperature led to a decrease in sales for local suppliers. Even a slight increase in local temperatures may have significant consequences for businesses and the economy as analysis has shown that 1°C increase caused a 2% decrease in sales to a retailer over a year. This finding is similar with heat-related impacts presented in the Athens Resilience Strategy, a city that has suffered several major heatwaves over recent decades. The City of Athens argued that for each 1°C increase in ambient temperature above 36°C, retail sales could drop by up to 10% (2018).

3.3 Increased energy and water demand

Another direct effect of rising temperatures is that it increases the use of cooling equipment (mainly air conditioners) and with it, the demand for electricity. This adds pressure to the electrical infrastructure networks during peak-demand periods, which generally occur in the midday and late afternoon on hot summer weekday afternoons, when offices and homes run lights, appliances and cooling systems (U.S. Environmental Protection Agency, 2008). This increase in electricity demand is exacerbated in the event of a heat wave because, as already mentioned, additional degrees from

TABLE 4: Excess cost due to urban heat island in a selection of cities

City and Country	GDP as of 2005 (million USD)	Excess Cost AC Repair (million USD)	Excess Cost AC Operation (million USD)	Cost of both as % of GDP
Phoenix, US	U$D 156,000	U$D 60	U$D 376	0.28%
Delhi, India	U$D 93,000	U$D 29	U$D 186	0.23%
Seoul, South Korea	U$D 218,000	U$D 364	U$D 83	0.21%
Beijing, China	U$D 99,000	U$D 77	U$D 89	0.17%
Athens, Greece	U$D 73,000	U$D 50	U$D 62	0.15%
Dallas-Fort Worth, US	U$D 268,000	U$D 24	U$D 238	0.10%
Tokyo, Japan	U$D 1,191,000	U$D 720	U$D 147	0.07%
London, England	U$D 452,000	U$D 174	U$D 4.1	0.04%
Paris, France	U$D 460,000	U$D 100	U$D 18	0.03%
New York, US	U$D 1,133,000	U$D 58	U$D 31	0.01%

Source: Adapted from Miner et al. (2017)

TABLE 5: Efficiency reduction parameters and economic cost of temperature increase

	Reduction parameters for 1°C			*Cost of 1°C increase (million U$S)*			
	R-COP	R-car	R-device	COP	Car	Device	Total cost for 1°C (million U$S)
June	1.12	1.01	1.09	USD 30.1	USD 3.5	USD 4.4	USD 38.1
July	1.11	1.01	1.09	USD 27.4	USD 3.2	USD 4.4	USD 35.1
August	1.12	1.01	1.09	USD 30.6	USD 3.5	USD 4.4	USD 38.6
September	1.15	1.01	1.09	USD 37.8	USD 4.3	USD 4.5	USD 46.7

Sum: 158.5 U$S Million

Source: Adapted from Miner et al. (2017)

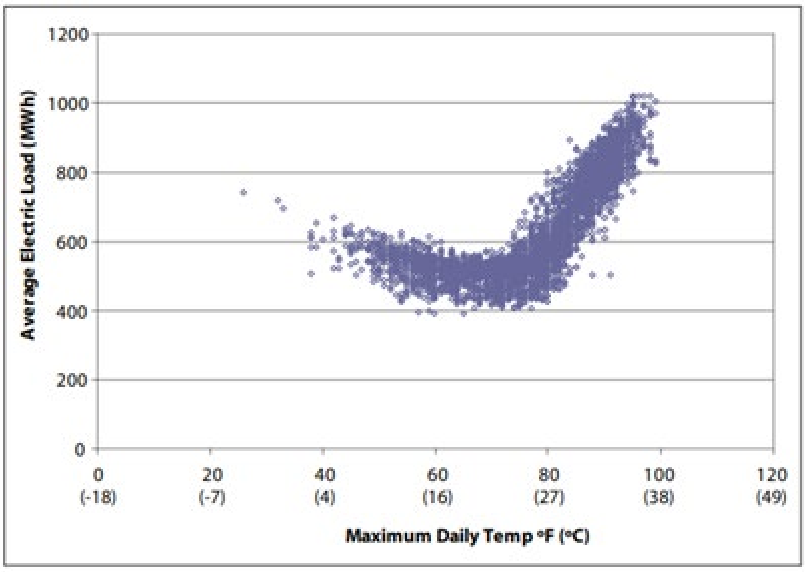
heatwaves builds on the already imperceptible but substantial increase due to heat islands.

Estimates suggest that the peak in urban electricity demand increases between 2% and 4% for every 1°C increase in temperature due to the urban heat island (Akbari, Pomerantz, & Taha, 2001). A similar finding by the City of Athens (2018) indicates that for every 1°C increase in temperature, electricity demand increases by 4.1%. This relationship can be seen in figure 4 (see below).

The steady temperature rise in the city centre over the last few decades due to heat islands means that between 5% and 10% of the entire community's electricity demand is used to offset the heat island effect. During extreme heat events such as heat waves, which are exacerbated by urban heat islands, the resulting demand for cooling can overload systems and force the utility to establish controlled blackouts or brownouts to avoid overloads and failures in the electrical system. On certain occasions, the electricity suppliers fail to carry out preventive measures and massive and uncontrolled power outages occur.
A recent example is what was experienced in mid-January 2022, when Argentina suffered a heat wave that had direct impacts on the electrical infrastructure. High temperatures broke records in numerous locations: the temperature record was broken in Mar del Plata on January 14 with 42.4°C and the city of Buenos Aires reached 41.4°C, the second highest temperature in history. Temperatures in the Buenos Aires metropolitan area remained very high for several days. In the middle of the heat wave, and because of the intensive use of air conditioning equipment, electricity consumption in Argentina reached an all-time high of 27,495 Megawatts. Precisely during these days of electricity demand peaks, due to a failure in the high voltage cables, more than 700,000 users suffered power cuts in the most populated urban area of Argentina (Dolabjian & Diamante, 2022).

Increased use of air conditioners means an increase in grid infrastructure as well as an increase in greenhouse gas emissions and waste heat being expelled into the environment. A recent United Nations Environment Programme (UNEP) report about increasing urban heat argues the about the boom in the use of air conditioners: "this further exacerbates the urban heat island effect, perpetuating a vicious cycle in which mechanical cooling deepens the warming of cities - necessitating even more cooling - and disproportionately affecting those without adequate economic resources to purchase mechanical cooling solutions" (United Nations Environment Programme, 2021).

FIGURE 4: Relationship between maximum daily temperature and average electric load



Source: Taken from U.S. Environmental protection Agency (2008). In this example from New Orleans, Louisiana, United States, electricity demand grows

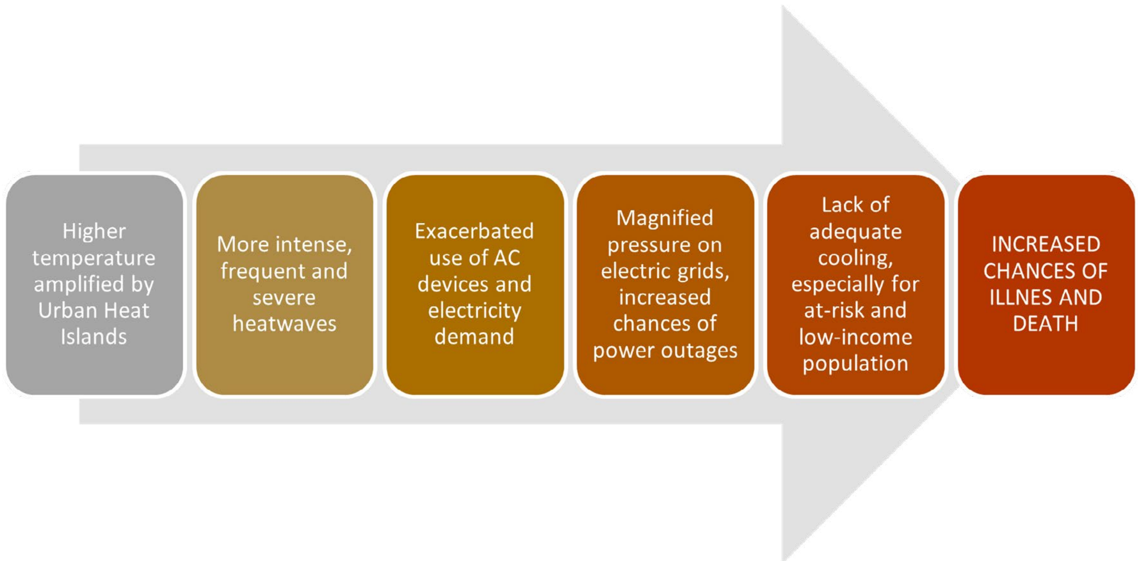
The economic implications for managing grid impacts and additional capacity are severe and often underestimated. Many cities that have a low level of appliance and air-conditioning system ownership are beginning to see a steep increase in the purchase of these devices. These cities may have difficulty adapting high-capacity networks to existing urban areas due to limited space for the new cables and substations required for cooling. The contribution of cooling to peak electricity demand increases the risk of brownouts and blackouts, which can create a critical situation during extreme heat events. The number of large grid outages (those lasting more than an hour and affecting 50,000 or more utility customers) have increased by more than 60% over the past five years (US Energy Information Administration, 2020). Below, Figure 5 shows the interrelation between higher temperature, increased electricity demand and higher mortality risk.

Moreover, the health risk associated with the occurence of these compound events (extreme heat and electric grid failure), and how that risk differs among subpopulations, is largely unknown (Stone, et al., 2021). To overcome this, a study has run simulations to explore what effects extreme heat exposure had when coinciding with an electrical infrastructure failure in different cities in the US. Results highlighted that these events expose the majority of the population to health conditions, including heat exhaustion and heat stroke (variations between 68% and 100% depending on the type of building involved). Surprisingly, none of the cities had developed an emergency response plan to manage a compound weather event associated with widespread power outages under heat wave conditions.

In the face of rising temperatures, water demand is also growing, both residentially and industrially (Texas Tree Foundation, 2017). Consequently, the improvement of water infrastructure is increasingly necessary as a climate change adaptation measure. This is true to the extent that during heat waves several national governments, such as the UK's, ask the population to drastically reduce water consumption (Water UK, 2021). There is evidence of a non-linear response in water consumption to changes in temperature. Researchers analysed the relationship between temperature and water consumption in nine U.S. cities and found no variation in consumption when daily maximum air temperatures ranged from 4°C to 21°C. They did find a moderate increase when the air temperature was higher than 21°C and lower than 29°C, and there was a three to five-fold increase in water use when the temperature exceeded 32°C (Madiment & Miaou, 1986).

Something similar happened in Australia

FIGURE 5: Cascading effects of increasing urban heat



Source: Adapted from Melillo, Terese, and Yohe, & Eds. (2014)

during the 2009 heat wave. The government of Victoria, the state where Melbourne is located, had previously established an objective to reduce water consumption to 155 litres per person per day. When temperatures exceeded 30°C, the objective was not met. Contrary to expectations, on especially hot days, water consumption soared. At temperatures above 40°C, consumption exceeded the city's average consumption by 50% (Queensland University of Technology, 2010). Higher consumption put additional pressure on water treatment plants to operate at increased capacity, further placing demands on the electricity supply. In addition, at high temperatures, pumping and aeration equipment overheated in both water treatment and purification plants. This further reduces capacity to treat and supply much-needed drinkable water to urban dwellers. Lastly, heat also increases the evaporation rate of drinking water reservoirs.

5. FINAL REMARKS

The consequences of urban heat affect the normal functioning of cities and their inhabitants in numerous ways and with diverse degrees of severity. This is especially the case during heat waves, when cascading impacts multiply in a snowball effect and overall consequences can be catastrophic. One of the most salient features is that many of the effects of urban heat go unnoticed, are not directly linked to increasing heat, or are misleadingly perceived as not preventable. However, evidence shows that these impacts do occur, are in fact caused by heat and are, thankfully, preventable. Be it reduced thermal comfort, high mortality, reduced equipment performance or habitat modification of disease vector mosquitoes, there are many causes for concern and reasons why action must be taken.

One additional element is that when heatwaves occur, electric grid failures tend to occur, provoking further cascading negative effects. Transportation, water supply and sanitation services are largely affected and even interrupted. All this can cause additional mortality since electrical refrigeration equipment is what protects people from the heat. Paradoxically, AC devices are part of the problem since they generate additional electrical demand and anthropogenic heat. Moreover, each one of these consequences incurs in considerable costs. Heat-related illnesses and, more seriously, deaths, entail economic burdens for households, businesses and public administrations. Furthermore, heat reduces commercial activity, and in the event of a power failure, industrial and economic activity are greatly hampered.

Urban heat is becoming a complex and multi-causal challenge, with consequences that threaten urban sustainability. Its impacts span the local economy, overall functioning and the health of the population, especially affecting those who are most vulnerable. This situation calls for immediate action by urban planners and local decision-makers as well as by state and federal regulators to promote measures to contain the impacts and ensure a better quality of life in cities. It is, in essence, a matter of life and death.

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Co-funded by the Erasmus+ Programme of the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them.

doi: 10.2870/998115
ISBN: 978-92-9466-382-5
ISSN: 2600-271X
QM-BA-23-002-EN-N