Atlantic Council | Adrienne Arsht-Rockefeller Foundation Resilience Center

Heat Action Platform
Technical Resource

The Arsht-Rock Compendium of Heat Risk, Adaptation, and Mitigation Research

ONEBILLIONRESILIENT.ORG/HEAT-ACTION-PLATFORM

ATTRIBUTION

Please cite the work as follows: Adrienne Arsht-Rockefeller Foundation Resilience Center. 2023. The Arsht-Rock Compendium of Heat Risk, Adaptation, and Mitigation Research. Adrienne Arsht-Rockefeller Foundation Resilience Center Compendium. Fall 2023. Washington, DC: Atlantic Council.

ACKNOWLEDGMENTS

The lead author for this compendium was Yuval Baharav (Adrienne Arsht-Rockefeller Foundation Resilience Center). Additional contributors to this report are Owen Gow, Lilly Nichols, Brigid Deegan, Abhisvara Sinha, Anya Wahal, and Maya Edwards. Kurt Shickman and Owen Gow (Adrienne Arsht-Rockefeller Foundation Resilience Center) provided guidance, resources and feedback throughout drafting. The authors would like to thank the Arsht-Rock's Senior Fellows, partner Chief Heat Officers, and other collaborators named and unnamed in this compendium, for their contributions and insights. A special thank you to the Arsht-Rock staff and to Kathy Baughman McLeod (Adrienne Arsht-Rockefeller Foundation Resilience Center) for her support and guidance on this work. Editing and review support was provided by Megan Finke (Boston University School of Public Health).

This compendium benefitted from the financial support provided by the Adrienne Arsht-Rockefeller Foundation Resilience Center's primary funders, American philanthropist Adrienne Arsht and the Rockefeller Foundation. This work is not necessarily a reflection of the views of any of the Adrienne Arsht-Rockefeller Foundation Resilience Center's funders and donors.

Published September 2023 with research and articles, and other sources published between November 2008 and August 2023.

Atlantic Council | Adrienne Arsht-Rockefeller Foundation Resilience Center

Atlantic Council | Adrienne Arsht-Rockefeller Foundation Resilience Center

ADRIENNE ARSHT-ROCKEFELLER FOUNDATION RESILIENCE CENTER, ATLANTIC COUNCIL

Arsht-Rock builds individual and community resilience in the face of climate impacts. We pledge to reach one billion people around the world with resilience solutions to climate change by 2030.

ATLANTIC COUNCIL

The Atlantic Council is a nonpartisan organization that promotes constructive US leadership and engagement in international affairs based on the central role of the Atlantic community in meeting today's global challenges.

11030 15th St NW 12th floor,
Washington, DC 20005,
United States

onebillionresilient.org/heat-action-platform

heatactionplatform@atlanticcouncil.org

@ArshtRock

September 2023

Table of Contents

USER GUIDELINES AND RECOMMENDATIONS

What is this compendium?: This compendium is an informal collection of contextualized extreme heat statistics from 100 key sources spanning economic, health, social, and environmental impacts, extreme heat solutions and governance, trends, and more. The compendium is an introductory resource and reference guide on heat risk, adaptation, and mitigation. It is intended for use as a starting point for further inquiry and is non-comprehensive in its scope.

Who is it for? This compendium may be particularly useful for researchers, city practitioners, public health officials, and others who are seeking to quickly identify research on heat-related risks and opportunities.

What are the criteria for research to be included? This compendium was originally developed as an informal document to track studies that the Arsht-Rock team considered useful sources of evidence and/or context in making the case for its work on extreme heat. It does not reflect the full depth or breadth of high-quality research that has been published on heat-related topics, and contains sources published between November 2008 and August 2023.

Please keep in mind:

- While statistics included in the compendium are contextualized to assist users in identifying key findings relevant to their work, complete documentation of cited works should be referenced and sought out when further context is necessary.
- While many statistics reported are discussed in a global context, we recognize the geographic limitations of this compendium due to inclusion of English-language publications and geographic focus areas of Arsht-Rock.
- As a living, informal document, updates to the compendium are ongoing and will periodically be uploaded to the Heat Action Platform. Information compiled in the compendium is not comprehensive.
- The compendium itself is not a peer reviewed publication. Many of the resources cited in the compendium are peer-reviewed. However, the compendium also includes articles, government websites, reports, and anecdotal evidence.

Economic Impact

Heat vs. Other Extreme Weather

Under current climate conditions, the cost of heat on lost labor productivity in the United States is at least $100 billion annually.[2] This is $35-$40 billion more, per year, than the loss and damages from the record breaking 2020 Atlantic hurricane season, including physical damages, lost economic activity, and health impacts.[2]

Heat Related Mortality

The monetized value of global heat-related mortality (in people 65 years or older) was 0.27% of gross world product in 2018, and 0.28% of gross world product in 2019, a 6.7% increase.[14] Europe in 2020, as in 2019, continues to be the region with highest recorded heat-related mortality, "facing costs equivalent to the combined average incomes of 6.1 million of its citizens" and 0.66% of regional GDP.[14] While the costs of heat-related mortality in Europe were lower in 2019 than in 2018, due to fewer estimated heat-related deaths, heat-related mortality costs were higher in 2019 than in 2018 in other regions, particularly in South-East Asia.[14]

Labor and Productivity

United States

Under current climate conditions, the cost of labor productivity in the United States lost to heat is at least $100 billion annually.[2] These losses could double to $200 billion by 2030 and quintuple to $500 billion by 2050 without meaningful greenhouse gas emissions reductions or adaptation to extreme heat.[2]

Outdoor workers

"The income losses due to extreme heat would add to the economic burden on households already stretched thin. For example, the nation's 7.6 million construction and extraction workers—one-third of whom are Hispanic/Latino—would on average risk losing nearly $1,900 in income annually by midcentury as a result of extreme heat if no action is taken on climate change; approximately one quarter of these workers would risk losing $3,000 or more each year... If we don't take action on climate change, extreme heat would cause tens of millions of outdoor workers in the US to risk losing a collective $55.4 billion in earnings each year by midcentury."[83,94]

Globally

The big picture

Multiple studies have demonstrated that heat waves induce economic losses from reduced labor productivity globally,[2,8,5,9,13,14] with greater losses of earnings in low and medium Human Development Index (HDI) countries due to reduced labor capacity.[14] *See page 23, indicator 4.1.3, of the Lancet Countdown 2022 report for heat related GDP loss across HDI groups, as a share of GDP by sector of employment*.[90] "Climate hazards, such as storms, flooding, wildfires, and heat waves can affect countries' wealth through direct damage to their physical capital stock and potential income flow--for example, heat waves can reduce labor productivity. Stock losses may result in using resources to rebuild, diverting investments away from innovation toward reconstruction activities. Over time, these missed productivity gains are likely to reduce the potential level of future incomes."[84]

Losses in 2018-2021

In 2021, 470 billion hours of potential work (an average of 139 hours per person) were lost globally due to heat exposure—a 37% increase from the period 1990–99.[90] Comparatively, in 2020 "295 billion hours of potential work [or 88 work hours per employed person], were lost [globally] due to extreme heat exposure,"[14] and in 2019, 302 billion hours of potential work were lost to extreme heat exposure, which is 103 billion more hours than that lost in 2000.[13] "The global potential loss of earnings was US$669 billion in 2021, equivalent to 0.72% of gross world product in 2021."[90] Additionally,"82% of all [heat-related potential hours of work] losses in countries with a low HDI occur[ed] in the agricultural sector [and] the average relative earnings lost in countries in the low HDI group [are] equivalent to 5.6% of the national gross domestic product."[90]

Projected losses

With 1.3°C of warming, 2.2% of total working hours are expected to be lost as a result of high heat globally, this "a productivity loss equivalent to 80 million full-time jobs. The loss in monetary terms is then expected to total US$2,400 billion [2.4 trillion] in purchasing power parity terms (PPP). Lower-middle- and low-income countries would be the worst affected, losing 4 and 1.5 per cent of their GDP in 2030, respectively." [11] Other estimates are aligned with this projection, considered an underestimate as it assumes that the global mean temperature will not exceed 1.5°C by the end of the century, and agricultural and construction work will occur under shade cover.[11]

For instance, "The International Labour Organization (ILO) projects – based on a global temperature rise of 1.5°C by the end of this century – that in 2030, the equivalent of 80 million full-time jobs could be lost worldwide due to heat stress, resulting in global economic losses of US$2.3 trillion (ILO 2019).[15] The impact will be unequally distributed around the world: low-income countries (which have fewer resources to adapt to excessive heat), especially in the hot regions of southern Asia and western Africa, are likely to be the worst hit, losing around 5 per cent of working hours due to excessive heat (Kjellstrom *et al.* 2019)"[15] "As heatwaves become more frequent, the ILO estimates that 2.5 million Latin American and Caribbean jobs could be lost to heat stress alone by 2030, affecting particularly outdoor workers in construction, agriculture, and street vendors."[63]

Country/Region Specific Losses

In 2020 India, Bangladesh, and Pakistan had losses 2.5-3 times the world average, "equivalent to 216–261 hours lost per employed person in 2020."[14] India suffered the greatest total loss of potential work hours to heat 2019, and Cambodia had the highest per-capita loss of potential work hours to heat of any country in 2019.[13] Like in 2020, agricultural workers in many countries experienced the greatest losses in 2019.[13,14] During the 2013-2014 heatwave, the Australian workforce is estimated to have lost 6.2 billion USD, or 0.33 to 0.47% of Australia's GDP.[9]

Economic Impact

European Union Losses

HEAT-SHIELD's report details regional and sector specific vulnerability to occupational heat-stress – industry specific observations, recommendations and guidance for effective mitigation, and case studies and lessons from countries in the European Union.

Country Specific Projections

Physiological models of heat exposure suggest that "productivity may decrease by 11–27% by 2080 in hot regions such as Asia and the Caribbean, and globally by up to 20% in hot months by 2050."[9] Loss of earnings could also exacerbate the health impacts of heat by amplifying the socioeconomic factors which contribute to good health.[14]

India and global implications

"Loss of productivity due to extreme heat […] could cost the Indian economy $450 billion by 2030."[82] A study examining the impact of temperature on productivity and labor supply in India's manufacturing sector found that "In hotter years countries tend to produce lower economic output, an effect that is especially marked in developing countries," but present globally [;] productivity drops by as much as 4 percent per degree when temperatures rise above 27° Celsius (80° Fahrenheit) in workplaces requiring manual labor [;] a 1-degree increase in the ten-day temperature average raises the probability that a worker will be absent by as much as 5 percent [; and] when the average daily high over the year rises by 1 degree, output falls by about 3 percent. This decline is large enough to explain the entire reduction in India's economic output in hot years."[5]

The study concludes that because "human physiology is the same [globally], the effects of temperature on labor productivity are likely to be of widespread importance."[5] While "richer countries may be able to adapt by adopting climate control technology, the study suggests this approach will not entirely address the effects of heat on worker productivity and the economy. In poor countries, air conditioning (A/C) may be too expensive for small manufacturing plants to adopt."[5]

Gender

Heat affects labor capacity across all genders.[14] In high-income countries, like the USA, workers in the construction sector experienced the greatest burdens of heat in 2019.[13] Men are 80% of total employees in the construction sector.[14] "Women in rural areas, [especially] indigenous women in rural areas, who are dependent on local natural resources for their livelihood, would be particularly affected by the impacts of climate change on labor capacity."[14] In slum communities, women are particularly susceptible to income loss as a result of extreme heat given "the majority of women work from home, in jobs like textile manufacturing or food preparation, and are forced to slow down when conditions become severe."[82]

Including unpaid work in estimates of heat-related labor losses increases estimates by 260% for women, compared to 76% for men.[91] Compounded with the 20 percent wage gap experienced by women on average, heat-related income losses among women are estimated to be $120 billion across India, Nigeria, and the United States alone.[91] "Without action to mitigate or adapt to climate change, time losses in paid work experienced by women are projected to increase by 18 to 44 percent by 2050."[91]

Economic Impact

Health Costs

Gender: Women

One study found that an additional day of exposure to extreme heat for pregnant women results in over 2,000 excess hospitalizations costing over 23 million dollars, not including other costs associated with lower pregnancy health including lost wages and health incidents that do not lead to hospitalization.[35]

The Context of Cities

The importance of cities

A seminal 2017 paper by Estrada, Botzen, and Tol examines the economic costs of climate change for the 1,692 largest cities globally.[8] "The city scale is especially relevant for climate policy. Although cities cover around 1% of the Earth's surface, they produce about 80% of gross world product, consume about 78% of the world's energy and produce more than 60% of all CO2 emissions. Moreover, 54% of the world's population live in cities, and this is expected to grow to about 66% by 2050."[8]

Relative warming of cities

"Between 1950 and 2015, 27% of [the 1,692 largest cities in the world] and 65% of the urban population warmed more than the world average (about 0.6 °C)."[8] During this period, "about 60% of the urban population experienced warming twice as large as the world."[8]

Projections of city warming and cost

About 20% of the most populated cities "could experience a total warming higher than 4°C in 2050 and about 25% could warm more than 7°C by [2100]."[8] Under an RCP4.5 and RCP8.5 scenario, the median city could lose 1.4% and 1.7% of GDP in 2050 and 2.3% and 5.6% of GDP in 2100, respectively, when considering both global climate change and the urban heat island effect.[8] Under a business-as-usual scenario, the worst off cities could lose 10.9% of GDP to heat-related losses by 2100.[8,15] If the urban heat island effect is not controlled, it could more than offset the impacts avoided by global mitigation efforts in large cities.[8] Furthermore, if local action to reduce the impacts of the urban heat island effect is not taken, mitigation of global climate change will be significantly less effective in reducing climate impacts.[8] As a result of the urban heat island effect, cities face climate change costs that are more than twice as high as the rest of the world.[15]

Agriculture and Food Security

See Wider Social Impacts > Food Security, for connections between reduced crop yields, food insecurity, and disproportionate gender impacts.

Global crop yields

"Wheat, rice, maize, and soybean provide two-thirds of human caloric intake. Without CO2 fertilization, effective adaptation, and genetic improvement, each one-degree-Celsius increase in global mean temperature would, on average, reduce global yields of wheat by 6.0%, rice by 3.2%, maize by 7.4%, and soybean by 3.1%," with some regions, particularly those that are already hot, suffering greater losses than others.[7] "In parallel with drought, warm temperatures are affecting the yield potential of the world's major staple crops— [relative to 1981-2010, 2020 saw a] 6.0% reduction for maize; 3.0% for winter wheat; 5.4% for soybean; and 1.8% for rice—exposing the rising risk of food insecurity"[14]

Agricultural workers

Both the 2020 and 2021 Lancet Countdown reports found that workers in the agricultural sector are burdened with greatest number of work hours lost to extreme heat, particularly in low Human Development Index (HDI) countries.[13,14]

Heat Mitigation via A/C and Other Cooling

For further discussion of A/C's challenges, drawbacks, and importance see [Solutions > Active Cooling: Air Conditioning (A/C).](#) For a discussion of social factors, growing A/C consumption, and inequitable access, go to [Trends > Heat, Energy, and Cooling Inequity > A/C cooling](#)

A/C Costs/Negatives

With rising temperatures, increased demand for thermal comfort, and increased economic access to cooling, the use of air conditioning, often through the least expensive and less-energy-efficient entry-level units, is only projected to grow.[3,14,15] To meet anticipated space cooling needs, US$1.7 trillion would need to be invested in global power generation capacity alone, not including costs associated with fuel, transmission, distribution, and infrastructure.[15] "The economic consequences to manage the grid impacts and additional capacity are severe and underestimated."[15] " Household spending to achieve space cooling already accounts for 5-15 per cent of the median income in many parts of the world, making cooling unaffordable for much of the population."[15]

The cooling unit a family purchases locks-in the fraction of income allocated to air conditioning. "For example, a study based on the [United States] city of Phoenix, Arizona estimates an excess cost of air conditioning (operation and repair) of $436 million due to the seasonal 3°C heat island effect (Miner *et al.* 2016)."[15] These costs are often invisible to consumers, and do not account for air conditioning exacerbating the urban heat island effect, and the resulting productivity losses and health impacts.[15] While Phoenix is a relatively low-density UHI, in cities that are higher-density UHIs, the economic impacts can be even more severe.[15]

Efficient Cooling Savings/Positives

"Coordinated international action on energy-efficient, climate-friendly cooling could avoid as much as 460 billion tons of greenhouse gas emissions – roughly equal to eight years of global emissions at 2018 levels – over the next four decades and avoid $3.5 billion of the renewable energy build-out by 2030 (UNEP and IEA 2020). While these estimates are for cooling across all sectors, the major share is attributable to keeping our cities and communities cool."[15]

Cool Surfaces Savings/Positives

A global 1% net increase in the albedo of rooftops and pavements would be equivalent to offsetting 44 Gt of CO2 emissions[30] (10.4 Gt of CO2 more than was emitted in 2019, a peak CO2 emissions year)[29]. This emissions offset, at $25/ton of CO2, is worth about US$1,100 billion.[30] If a building's rooftop albedo is increased from 10-20% to 60%, cooling costs go down by over 20%, and the potential savings in net annual energy bills in the United States from such a change exceed $1 billion per year.[30]

Health

Heat-Related Mortality vs. Other Weather Hazards

Overview

Heat is the deadliest weather-related hazard,[3,16,17,19] and "heat stress is the leading cause of weather-related death."[19] From 2015-2019, heatwaves were the deadliest metrological hazard globally.[16] "In an average year, heat is the world's deadliest natural disaster, but its effects are often not as visible as the physical destruction of typhoons, tornadoes, or other disasters."[3] "Globally, future increases in heat-related deaths are expected to outweigh those related to cold by the end of the century."[62]

Global comparisons

In the United States, extreme heat is the number-one weather related cause of death.[17] Between 2018 and 2019 India and Brazil suffered the largest absolute increases in heat-related mortalities.[14] Europe was the region most affected by extreme heat, "with almost 108 000 deaths attributable to heat exposure in 2019."[14] Further, the warming observed in Europe since 2015 was associated with 18,547 additional summer heat-related deaths for every +1°C increase in temperature.[89]

Estimated deaths among people over the age of 65 attributable to heat exposure

In 2019, 72,000 deaths in China, 20,500 deaths in the United States, 12,400 deaths in Japan, and 46,600 deaths in India. [14] In 2019, over 130,000 people over the age of 65 in China, Japan, and India are estimated to have died from heat exposure.[14] "Heat-related mortality for people over 65 increased by approximately 68% between 2000-2004 and 2017-2021.[90]

2020 and 2019 comparisons, hurricane vs heat-related death (mortality)

Approximately 430 people died from hurricanes in the 2020 Atlantic hurricane season.[32]

The below comparisons use numbers referenced in the footnotes to arrive at the multiplier but were calculated by Arsht-Rock.

1. In 2019 heat killed over 350 times as many people in China, the United States, Japan, and India alone as did hurricanes in the entire 2020 Atlantic hurricane season. [14,32]
2. One study finds that there are between 304,216 and 732,518 annual heat-related excess deaths around the world, with a median of 489,075.[31] **Assuming the median number for 2020 would mean heat killed over 1,100 times as many people as hurricanes in the 2020 Atlantic hurricane season. (In an average year, heat kills 1100 times as many people globally as the record-breaking 2020 Atlantic hurricane season.)** [31,32]
3. Just in Arizona, there were 522 heat related deaths in 2020.[14] ***Just in Arizona*, heat killed 1.2 times as many people as hurricanes killed around the world during the 2020 Atlantic season.**
4. In the June 2021 heatwave, there were 803 officially reported heat-related deaths in Washington State, Oregon, and British Columbia, and almost 1,200 suspected excess heat-

related deaths.[1,20,21,22] ***In these three regions alone, over three weeks*, heat killed 2.8 times as many people as the 2020 Atlantic hurricane season.**[1,20,21,22,32]

5. Heat-related deaths in people older than 65 years reached a record high of an estimated 345,000 deaths in 2019, which is 80.6% more deaths than recorded on average in 2000-2005.[14] **Heat killed over 800 times as many people in 2019 as the 2020 Atlantic hurricane season, *only accounting for heat-related deaths in people over the age of 65***.[14,32]
6. In Europe there were 108,000 deaths attributable to heat exposure in 2019.[14] ***Just in Europe*, heat in 2019 killed over 250 times as many people as hurricanes in the entire 2020 Atlantic hurricane season.**[14,32]

Heat-Related Death (Mortality)

Actual Mortality

Global mortality

A key study finds that there are 489,075 annual heat-related excess deaths around the world (95% CI 304,216 -- 732,518).[31] They estimate that non-optimal temperatures kill 5 million people per year, just under 10% of all deaths. Of that 10% excess mortality, 8.5% is caused by cold and 0.91% is from heat. Thus, heat accounts for about 10% of those deaths, or approximately half a million people per year.[31]

Pacific Northwest + British Columbia 2021 mortality

In the June 2021 heatwave that struck the Pacific Northwest and British Columbia, regions that are historically cooler and less prepared for high temperatures, there were 803 officially reported heat-related deaths in Washington State, Oregon, and British Columbia, and almost 1,200 suspected excess heat-related deaths.[1,20,21,22]

Low intensity heat in regions with hot, humid summers mortality

"Low-intensity heatwaves can increase all-cause non-accidental [mortality], cardiovascular-, respiratory- and diabetes-related mortality, in regions experiencing hot, humid summers."[59] Heat-related mortality and risks of occupational heat stress in small island states are projected to increase with higher temperatures.[62]

Mortality Projections

Global mortality projections

A 2014 World Health Organization global projection estimates that by 2030 there will be 92,207 additional heat-related deaths annually and that by 2050 there will be 255,486 additional heat-related deaths annually, if no adaptation measures are taken.[15] "The situation is further compounded by the rising potential for major electric grid failures during extreme weather, which, when coinciding with heatwave conditions, can expose large populations to severe heat stress both outside and within buildings (Stone *et al.* 2021)."[15]

United States mortality projections

Heat stroke-related deaths are expected to more than double by the 2050s in the United States, reaching approximately 5,000 annual deaths.[18] [likely undercount] "Factors like poorly designed infrastructure, limited access to air conditioning (A/C), and a lack of acclimatization can lead to heat-related harms occurring at lower-than-expected temperatures in historically cooler parts of [the United States].”[1]

European Union (EU) mortality projections

Without climate mitigation and adaptation, by 2100 extreme heat could kill 30 times more people than it does today (2019-2021) in the European Union alone.[33] One study found that in the absence of adaptation to future summer warming, the expected heat-related mortality burden in Europe would be 68,116 deaths on average every summer by the year 2030, 94,363 deaths by 2040 and 120,610 deaths by 2050.”[89]

Heat-Related Illness (Morbidity)

For infants and children see: *Health > Vulnerable Groups > Infants and Children*

For pregnant women and fetal health see: *Health > Vulnerable Groups > Gender: Pregnant Women*

Overall

Heat-related deaths and injuries are underreported and poorly registered globally. “Although heat-related morbidities are poorly registered worldwide, studies show a marked increase in the risk of death and hospitalization from [chronic noncommunicable diseases] when patients are exposed to excessive heat.”[19] “Heat affects health in many ways, and warmer temperatures increase the risk for a diverse range of health risks. For example:

- An increased risk of hospitalization for heart disease.
- Heat exhaustion, which can lead to heat stroke if not treated, can cause critical illness, brain injury, and even death.
- Worsening asthma and chronic obstructive pulmonary disease (COPD) as heat increases the production of ground-level ozone.
- Dehydration, which can lead to kidney injury and blood pressure problems. Some kidney damage can become irreversible with repeated or untreated injury.
- Violence, crime, and suicide may increase with temperature, adding to the rates of depression and anxiety already associated with climate change.”[68]

“Some medications increase the risk of heat-related illness. These include diuretic medicines (sometimes called “water pills”), antihistamine medicines (including many allergy medicines), and many antipsychotic medicines used to treat a variety of psychiatric and neurologic illnesses.”[68]

United States (US) adults

- NOAA and NIHHIS produce seasonal Climate and Health Outlook: Extreme Heat reports in an effort to inform of how “health may be affected in the next 30 and 90 days by climate events and provide resources to take proactive action.” “In June [2022], 132 counties across 13 states are projected to have more than 5 extremely hot days.” “In these 132 counties, the total population at risk is 21,729,969 people.” “For June–August 2022, the North American Multi-Model Ensemble (NMME) predicts that the average temperature will be 1.8 to 3.6°F (1 to 2°C) above-normal for most of the continental United States. However, the U.S. Central and Western regions may experience a higher 90-day average that is 3.6 to 5.4°F (2 to 3°C) above the normal average temperature for this time period.”[68]

- Among "all commercial and Medicare Advantage beneficiaries (74.2 million) aged 18 years and older between May and September 2010 to 2019 […] days of extreme heat—defined as the 95th centile of the local warm season (May through September)—were associated with a 7.8% *excess relative risk* of emergency department visits for any cause, 66.3% for heat related illness, 30.4% for renal disease, and 7.9% for mental disorders. Days of extreme heat were associated with an *excess absolute risk* of emergency department visits for heat related illness of 24.3 per 100,000 people at risk per day. Heat was not associated with a higher risk of emergency department visits for cardiovascular or respiratory diseases. Associations were more pronounced among men and in counties in the northeast of the US or with a continental climate. Among both younger and older adults, days of extreme heat are associated with a higher risk of emergency department visits for any cause, heat related illness, renal disease, and mental disorders. These results suggest that the adverse health effects of extreme heat are not limited to older adults and carry important implications for the health of adults across the age spectrum."[58]
- A study of California health data revealed that from 2005 to 2015, the rates of emergency department visits for heat-related illnesses increased by 67% for African Americans, 63% for Hispanic people, 53% for Asian Americans, compared to 27% for White people.[81]

Covid-19 and heat-related impact interactions, United States

Race and Income related vulnerability

A study assessing the impact of COVID-19 pandemic on the heat vulnerability of over 3000 American adults across the country surveyed between July-September 2020 found that while "over a quarter of the US population experienced heat-related symptoms during the summer of 2020", among all socio-economic groups those who were "most vulnerable were women, those in low-income households, unemployed or on furlough, and people who identify as Hispanic or Latino or as other non-white census categories (including Asian, American Indian or Alaska Native, Native Hawaiian or other Pacific Islander, and multi-racial US residents)"[76] "Key factors that contributed to increased heat risk and decreased coping capacity during the time of COVID-19 were (a) limited or reduced household resources, preventing access to cooling and (b) pandemic-related social isolation, reducing social capital and access to available community resources"[76]

Among surveyed individuals, "the ability to cool homes effectively proved to be difficult for millions of US residents, especially those who have low incomes and those who reported losing income, jobs or being placed on furlough since the beginning of the pandemic."[76] "Communities faced greater heat risks during the pandemic as "healthcare seeking behavior was initially altered as early messages discouraged people from seeking medical attention unless they were acutely ill because of concern that health-care facilities would be overburdened (Lange et al 2020)."[76]

Exposure, Energy Insecurity, Cooling Access

The covid-19 pandemic further exacerbated heat-related exposure, with job losses fueling energy insecurity thereby restricting access to cooling infrastructure amongst vulnerable groups.[80] "Black and Hispanic households have been particularly affected, as they have been more likely to experience energy insecurity in the home —receiving disconnection notices or having utility services disconnected— during the pandemic, compared to their White counterparts."[80.] At a community level, reliance on public spaces to provide cooling shelters for those in need was challenged by social distancing measures as traditional sources of cooling such as libraries may have been inaccessible in many cities due to COVID-19 closures."[76]

Low intensity heat in regions with hot, humid summers

A review of studies examining low intensity heat wave events in regions with hot, humid summers found that low intensity heat events had a small but statistically significant impact on both mortality and morbidity, which can be important at a population level,[59] and contribute to the cumulative impacts of heat. The findings "point to the importance of population-based and health system-related interventions to reduce the health impact of low-intensity heat events, with particular attention to the elderly, young children and those with chronic conditions. [The] findings also suggest that, even in warm climates where populations and infrastructure are adapted to heat, there is a need for additional heat adaptation measures, particularly in the context of a warming climate."[59]

Mental Health, Sleep, Suicide Rates

Overall

In addition to the multiple other threats heat poses to health, heat exposure is linked to poor sleep quality, worse mental health, higher mental-health related hospital admission rates, and higher suicide rates.[1,14] "Violence, crime, and suicide may increase with temperature, adding to the rates of depression and anxiety already associated with climate change."[68]

Mental health + medication vulnerability

Because heat can alter human behavior, health service delivery, and brain functioning, individuals with mental health issues who are prescribed medications that limit the body's ability to cool itself are especially vulnerable to high heat.[19] "Many antipsychotic medicines used to treat a variety of psychiatric and neurologic illnesses [increase the risk of heat-related illness."[68] Linked are common psychiatric medications that can impair the body's normal ability to cool itself.[68]

Global mental health and sentiments

To capture correlations between heat and people's sentiments (a proxy for mental health), the Lancet Countdown report examined sentiments during heatwave days expressed on Twitter. They found that exposure to a local heatwave significantly reduced positive expressions and increased negative expressions, "with a 155% increase in negative expressions on Twitter during heatwaves in 2020 from the 2015–19 average."[14]

Vulnerable Groups

Pre-Existing Conditions

Overall

Exposure to high temperatures exacerbates and increases mortality rates in 90% of the existing global causes of death, including ischemic heart disease, stroke, COPD, lower respiratory infections, Alzheimer's disease and other dementias, lung cancers, diabetes mellitus, road injury and diarrheal disease."[19]

Chronic conditions

People with chronic health conditions are particularly at risk from exposure to extreme heat and heat stress.[14,19,33] "Many physical and mental health conditions increase vulnerability to adverse temperatures through a direct effect on the body's physiology or through the effect of certain medications. Heat stress "can exacerbate underlying illnesses including cardiovascular disease, diabetes, psychological distress, asthma, and increase the risk of accidents and infectious disease."[19]

Disability

For people with physical and mental disabilities, "Reduced mobility and dependency on others and a reduced ability to understand or act on measures to cool themselves may increase risk" of heat-related illness or death.[19]

The Elderly

Overall

Individuals over the age of 65 are particularly at risk from extreme heat and heat stress.[1,14,19,33,34] Individuals over 65 years of age, particularly those with chronic medical conditions, are more vulnerable "to psychological stress, exacerbated illness, and an increased risk of death from exposure to hot weather."[19]

"Physiological risk factors for heat-related deaths include chronic health conditions such as cardiovascular, pulmonary and mental illnesses, polypharmacy, and lower fitness levels. Socio-economic and behavioral factors that increase the risk of dying during a heat wave include living alone; being unable to care for oneself; having a lack of mobility; living on the top floor; lack of air conditioning; and reluctance to change behavior during a heat wave (Vandentorren et al. 2006; Bouchama et al. 2007; Hansen et al. 2011). Having multiple risk factors, the elderly have been reported to be a major risk group for heat-related mortality in several reviews (Bouchama et al. 2007; Kovats and Hajat 2008; Basu 2009; Åström et al. 2011; Kenney et al. 2014)."[75]

Gender

A review of 13 peer-reviewed papers on the health impacts of heatwaves on elderly humans aged over 65 in Europe between January 1st 2000 to December 31st 2016 found that "the majority of these papers (8) provide data that support the hypothesis that elderly women are more vulnerable during heatwaves than men."[75] "most studies seem to indicate that the differences in risk between men and women cannot be fully explained by age."[75] "postmenopausal changes in estrogen levels may partly explain why especially elderly women experience worse health outcomes during a heat wave [as decreased estrogen levels can impact cardiovascular fitness and heat dissipation], although still a lot remains to be unknown about the precise role of estrogen during heat stress."[75]

Several socio-cultural factors may also influence women's heightened heat vulnerability such as elderly women being more active around the house than men, poorer financial status limiting access to housing or air-conditioning, race/ethnicity influencing access to medical care, among other explanations. However, these "complex interactions still have to be further analyzed."[75]

Global increased exposure

Globally, adults over the age of 65 experienced 3.1 billion more person-days of heatwave exposure annually in 2012-2021 than in 1986-2005.[90]

United States increased exposure

"In 2020, adults over the age of 65 experienced a total of nearly 300 million more days of heatwave exposure in the U.S. compared to the 1986-2005 average baseline, making it the second highest year of exposure recorded since 1986"[1]

Air pollution and heat

Growing evidence suggests that when air pollution levels are high, heatwaves are more deadly, especially for the elderly. [19]

Gender: Women

"Heat is already a major global public health risk, and women are particularly vulnerable due to factors including their physiological differences, particularly during pregnancy, lower access to healthcare services, and greater vulnerability to gender-based violence. By 2050, even with the limited data currently available for heat morbidity and mortality, extreme heat could claim the lives of 204,000 women annually across India, Nigeria, and the United States in hot years. Furthermore, heat creates a double burden for women, who are not only more physically susceptible to its effects than men but who also more frequently shoulder additional paid and unpaid care responsibilities associated with heat-related illness."[91] In one study on heat-related mortality in Europe during summer 2022, there were 56% more heat deaths estimated for women compared to men.[89]

Pregnant women overall risk

Pregnant women have an increased risk of death or injury from exposure to excess heat,[19,34,92,98] and are more vulnerable "to psychological stress and exacerbated illness," from exposure to hot weather.[19] Pregnant women […] are not able to regulate body temperature as efficiently as non-pregnant individuals due to the physiological changes they undergo during gestation.[73] Heat exposure can alter blood flow in the placenta, which can weaken the placenta and lead to complications.[73] And high heat can lead to other pregnancy complications, such as hypertension, preeclampsia and prolonged premature rupture of membranes."[73]

Pregnancy and birth outcomes overall risk

- Extreme heat adversely impacts birth outcomes through effects including "changes in length of gestation, birth weight, still birth, and neonatal stress."[19]
- "Pregnant women […] are not able to regulate body temperature as efficiently as non-pregnant individuals due to the physiological changes they undergo during gestation. Heat exposure can alter blood flow in the placenta, which can weaken the placenta and lead to complications. And high heat can lead to other pregnancy complications, such as hypertension, preeclampsia and prolonged premature rupture of membranes."[73]
- "Emerging epidemiological evidence indicates that increased temperatures may be associated with multiple birth outcomes such as increased risk of low birthweight, stillbirth and preterm

birth."[70] The association between heat exposure during pregnancy and risk of pre-term birth can be explained through several biological mechanisms. Possible biological pathways include increased secretion of hormones (e.g., oxytocin, prostaglandin, antidiuretic hormone) under heat stress, decreased uterine activity, and heat-related dehydration, which could reduce maternal fluid level, uterine blood flow and induce preterm birth."[71]

- However, with the right combination of cooling infrastructure and social welfare policies in place, the impact of heat exposure on pre-term birth could be minimized.[70] For example, despite most medical research suggesting a positive association between extreme heat exposure and pre-term birth, a study of 550,000+ child births between 2014 and 2019 in Sweden found no statistically significant relationship between the two variables.[70] The authors suggest the lack of a statistically robust relationship could be explained by the high quality and accessibility of ante-natal care combined with the above average standard of housing in Sweden which is both well insulated as well as includes cooling infrastructure such as AC's and fans.[70]
- "A lack of globally consistent definitions and criteria for heat exposure limits researcher and practitioner ability to provide guidance on which heat conditions are dangerous for pregnant individuals and neonates" however, "midwives and other health care providers are critical in modifying patient response to elevated heat and can advise on reducing and mediating heat risks to pregnant individuals and neonates."[92]

United States heat exposure and hospitalization (racial disparities)

Exposure to temperatures of 90°F or above in historically cooler counties of the United States increases the likelihood of an emergency or urgent hospitalization during pregnancy by 5.1%[35] An additional day of extreme heat exposure during pregnancy raises the likelihood that a mother in the United States is hospitalized for emergency and urgent reasons by 2.2%, with black women hospitalized at higher rates (see Wider Social Impacts > Racial Inequality).[35] Exposure to extreme heat during the second or third trimester of pregnancy increases the likelihood of hospitalization by 4.8%.[36]

United States heat exposure and delivery outcomes (racial disparities)

- Heat exposure during pregnancy leads to worse health outcomes at delivery— an additional day of extreme heat exposure during the first trimester raises the likelihood of a complication at childbirth by 1%, and exposure in the third trimester raises the likelihood of a hypertension diagnosis at childbirth (a life-threatening complication) by 2.9%.[36]
- One study of spring-fall pregnancies between 1999-2006 in California found that "high ambient temperature was significantly associated with preterm birth for all mothers, regardless of maternal racial/ethnic group, maternal age, maternal education, or sex of the infant," and that a 10°F increase in weekly average temperature was associated with an 8.6% increase in preterm delivery, with younger mothers, black mothers, and Asian mothers experiencing higher associations.[37] Contrary to previous research, the study found that extreme heat had statistically significant associations with pre-term delivery independent of air pollutant levels.[37]
- Exposure to extreme heat is associated with an increase in the risk of stillbirth for pregnant women, with a U.S. study published in the Environmental Health journal assessing pregnant mothers across 6 U.S. states—California, Florida, Georgia, Kansas, New Jersey and Oregon—from 1990 until 2017 finding that across all 6 states over the studied time period "four consecutive hot days during the previous week was associated with a 3% increase in stillbirth risk, and a 1 °C average increase over the threshold [county specific 97.5th percentile temperature] was associated with a 10% increase in stillbirth risk."[69]

- A study of 540,000+ births between peak heat months of May-September 2003-2014 in North Carolina estimated that "higher heat exposure during the last week before delivery was significantly associated with higher risk of preterm birth."[71] Further, the authors noted that "the highest association between heat exposure during the last week of gestation and the risk of pre-term birth was found in mothers living in areas with low greenness and low socio-economic status"[71] Notably, despite utilizing 3 different definitions for heatwaves (≥ 2 consecutive days with daily individual-level mean temperature at or above the 95th, 97th, or 99th percentile warm season mean temperature), the study did not find any statistically significant association between exposure to heatwaves during last week of gestation and pre-term birth. The authors suggest this could be explained by the use of early warning systems, adaptation strategies like AC, or pregnant women taking more protective measures during heatwaves than times of moderate temperature.[71]
- Heat exposure at night versus the day had differential impacts on birth outcomes in a study of pregnant mothers in North Carolina between 2011-2015 found that "extreme heat at night generally posed a greater hazard than extreme heat in the day.[72] In the Mountain counties, the risk of a woman experiencing preterm labor jumped by 6% when overnight low temperatures reached the range of 74-75°Fahrenheit"[73] Across both day and nighttime and geographic regions, rising temperatures were associated with higher risk of pre-term birth.[72]
- A study of 2.7 million inpatient records of pregnant mothers and infants in 3 U.S. States with varying climates—Washington, New York, and Arizona—estimated that "each additional day with heat that is at least 3 [standard deviations]—or substantially higher than the historic county-month average—during the second trimester of pregnancy increases the likelihood that a newborn is diagnosed with dehydration by .008 percentage points." The researchers noted that this finding is particularly stark given dehydration is one of the leading causes of morbidity and mortality in children.[73]

Infants and Children

Overall

Young children are especially vulnerable to physiological stress, exacerbated illness, and increased risk of death from exposure to high temperatures and heatwaves, including higher risk of sudden death among infants and children under the age of 5 and increased diarrheal diseases.[1,14,19,34,36, 57,98] Infants and children are more vulnerable to "to psychological stress exacerbated illness, and an increased risk of death from exposure to hot weather."[19] "Newborns are also highly susceptible to heat-related morbidity and mortality, such as that caused by malarial febrile seizures." [19] Even on days that are not extremely hot, a significant proportion of illness was attributable to heat in a study of 3.8 million U.S. pediatric emergency department visits.[57]

Why are children more at risk?

Children can be particularly at risk from extreme heat "because they are often dependent on adults and others to make the decisions about their exposure and wellbeing. They may not recognize risks, have access to water, can be locked in dangerously hot cars, or may not recognize that they are hot and know to take cooling measures." [19] They also have physiologic differences in thermoregulatory capacity.[57]

Emergency Department Visits

"Temperatures above the minimum morbidity temperature [days that are not necessarily extremely hot] accounted for an estimated 11.8% of warm season emergency department visits for any cause and 31.0% of emergency department visits for heat-related illnesses" in a sample of 3.8 million emergency department visits of children under the age of 18 in 47 U.S. children's hospitals.[57] Extreme heat was associated with a relative risk of all-cause emergency department visits of 1.17 relative to hospital-specific minimum morbidity temperature.[57] For heat-related illness, associations were more pronounced; the relative risk of emergency department visits from dehydration and electrolyte disorders was 1.83, 1.35 for bacterial enteritis, and 1.30 for ear inflammations/infections.[57]

Increased exposure

Between 2012-2021, children younger than 1 year of age were affected by 600 million more person-days of heatwave exposure annually compared to the 1986-2005 average.[90] Compared to the 1986-2005 average baseline, "infants under one year experienced a total of nearly 22 million more days of heatwave exposure in 2020."[1]

Exposure during gestation effects

An additional day with extreme heat exposure "during the second trimester increases the likelihood of a newborn being diagnosed with dehydration by 31%" and "increases the probability that the infant is readmitted to the hospital within the first year of life by 3.4%."[36]

Inequality

"Days of extreme heat were more strongly associated with emergency department visits for all causes among children who belonged to minority racial groups (relative risk=1.21) vs. White children (relative risk =1.12) and in children with public health insurance or other/unknown insurance than in children with private insurance" in a study of 3.8 million emergency department visits of children under the age of 18 in the U.S.[57]

Malnutrition

Heat exposure exacerbates infant malnutrition.[74] A study of 5 west African countries—Benin, Burkina Faso, Cote d'Ivoire, Ghana and Togo—estimates that a "2°C rise in temperature increases the prevalence of stunting by 7.4 percentage points [among infants aged 3-36 months]"[74] Heat exposure was found to be associated with reduced protein consumption among infants in the 5 west African countries; this relationship could be explained by decreased milk or egg production as a result of increased livestock mortality, reduced agricultural income impacting food availability in the household, or reduced food consumption due to illness during extended exposure to extreme heat.[74] "Extreme heat may also stunt child growth through reduced agricultural production as well as through increasing the risk of infectious disease (because microbes tend to thrive in warm environments) or through direct, physiological effects on child health."[74]

Urban Residents

Overall

Populations in urban environments are particularly at risk from extreme heat and heat stress.[1,14,19] "Due to the urban heat island effect, populations in urban environments often face magnif[ied] exposures to heat stress, on top of other conditions of vulnerability such as poor housing in informal urban settlements."[19] People living, working, or studying in buildings (including homes, hospitals, schools, and prisons) that are not suitable for extreme heat are also at greater risk of heat injury.[19]

Air pollution + heat effects

The combined effect of heat and air pollution puts people exposed to high levels of air pollution at greater risk,[19] and urban residents are more often exposed to higher levels of air pollution than rural residents.

Informal Settlements, Slums, Marginalized groups

Overall

"Policy failures continue to disproportionately expose specific groups to extreme heat, such as outdoor workers, incarcerated persons, people of color, historically redlined communities, and those living below the poverty line"[1] in addition to those who are marginalized or under-resourced and that have little access to cooling or health care, further magnifying health and social inequities.[14]

Women (India)

A survey of women in slum communities in India identified socio-cultural factors as the main contributors exacerbating heat-risks faced by women.[77] As a result of not having access to a toilet within their homes, "to avoid having to urinate during long days inside [during heatwaves], [women] may drink no water at all. In a heat wave, this significantly increases the risks of dehydration and death."[77] "Indoor cooking presents another hazard exacerbated by heat waves. Most of the windowless shacks that pass as households don't have a separate kitchen. Cow dung cakes, or wood dust commonly used as fuel cause the indoors to be hot and smoke-filled. This makeshift cookstove exposure compounds the environmental summer heat."[77] Additionally, "Women's clothes become a heat trap. A six-yard-long sari wrapped several times around the body with an inner petticoat and blouse is not comfortable to wear in the heat. It leaves little room for air circulation. Core body temperatures of the Indian women measured tend to be 1-2 degrees Celsius higher during summer noon times."[77]

Nairobi, Kenya

"Temperature, humidity and heat index differ in several informal settlements, including in Kibera, the largest slum neighborhood in Africa, […] temperature and a thermal comfort index known colloquially as the heat index regularly exceed measurements at the Dagoretti observation station by [up to 3] degrees Celsius. These temperatures are within the range of temperatures previously associated with mortality increases of several percent in youth and elderly populations in informal settlements."[60] "Negative health effects have been seen in children and the elderly in Kibera at temperature thresholds as low as the 75th percentile [of the long-term temperature record], found to be 20°*C*, as measured at the Moi Airbase weather station in Nairobi. Mortality in age groups 0-4 and 50+ increased by 1% for every 1°C increase in mean daily temperature above 20°*C*."[60]

Dhaka, Bangladesh

A comprehensive 2021 FbF heat wave feasibility study led by the German Red Cross (GRC), the Bangladesh Red Crescent Society (BDRCS), the Red Cross Red Crescent Climate Centre (RCCC), the International Federation of Red Cross and Red Crescent Societies (IFRC), and the Bangladesh Meteorological Department (BMD) analyzed [historical] forecast data, studied the impact of heat waves on the city, identified the available sources of forecast and proposed thresholds, triggers and early actions for piloting anticipatory action.[61]

Outdoor Workers, Indoor Workers Exposed to Heat

Possible risks

Outdoor and manual workers (whether indoor or outdoor) exposed to high temperatures are especially vulnerable to physiological stress, exacerbated illness, and increased risk of heat-related death.[19,34]

"Workplace heat stress is a well-known occupational health hazard. Indoor and outdoor workers exposed to hot and humid conditions are at risk of heat-related illnesses, and long-term exposures can exacerbate underlying health conditions. Core temperature elevation and dehydration cause physical fatigue, irritability, lethargy, impaired judgment, vigilance decrement, and loss of dexterity, coordination and concentration, which can compromise occupational safety and lead to increased accidents."[19]

"Noncitizen and Latino migrant workers make up 50% and 75% of agricultural workers in the United States, respectively, [and] are about 20 times more likely to die from heat-related illnesses compared to other US-based workers."[80]

Outdoor Exercise

High temperatures can make people want to exercise less, exercise less often, and for shorter periods of time.[14] Over the last 40 years "the number of hours in which temperatures were too high for safe outdoor exercise" have increased, and people in low HDI countries lost an average of 3.7 hours of safe exercise per day in 2020 to heat.[14] "Physical exercise provides mental health benefits and reduces the risk of cardiovascular disease, diabetes, cancer, cognitive decline, and all-cause mortality."[14] As higher temperatures reduce people's desire and ability to exercise safely outdoors, as even limited physical activity in high temperatures can pose a health risk,[14,34] the compounded risk of heat and lower exercise rates threatens the health of groups that are already highly vulnerable, like those with poorer mental health, chronic health conditions, and the elderly.

Wider Social Impacts

Gender: Women and Girls

For a discussion of health impacts of heat on women and girls, see Health > Vulnerable Groups > *Gender: Pregnant Women* and *Infants and Children*.

Women-led Solutions

Housing and Cool Roofs

Mahila Housing SEWA Trust (MHT) works with women in Ahmedabad, India to "to organize and empower women in poor communities to improve their habitat."

Negative Impacts of Heat on Women and Girls

"Preliminary analysis shows the accentuation of gender inequities as a result of weather events, including drought episodes driving spikes in child marriage for girls in almost all Asian countries analyzed" by the Lancet Countdown 2021 report.[14]

Racial Inequality

United States

Race-based housing and heat

People of color are more likely to live in poorer, hotter neighborhoods as a result of discriminatory race-based housing practices and policies[42] and be disadvantaged in access to cooling and heat health, resulting in a disproportionate risk of heat illness and death.[39]

"In all but six of the 175 largest urbanized areas in the continental US, people of color endure much greater heat impacts in summer."[78] Even though low-income levels and race were closely tied factors to an individuals' heat exposure due to an overlap in residential patterns of settlement, "in around half the cities, the average person of color faced higher summertime heat than people living below the poverty line" likely due to 20th century residential redlining.[78] Black individuals in America are "exposed to an extra 3.12°C of heating, on average, living in urban neighborhoods, compared to an extra 1.47°C for white people"[78]

Historical policies of redlining have been identified as a key contributor to Black communities' heightened heat exposure with a study of 108 urban areas in the U.S. finding consistently higher temperatures in formerly redlined areas across 94% of the cities surveyed.[79] Potential explanations for the higher concentration of surface urban heat island effects in these areas could be (a) the construction of public buildings (e.g. universities, public housing) out of cinder block and brick due to the low cost/value of the land, (b) construction of highways using heat-retaining, low cost, or (c) the lack of investment in tree canopy cover due to historic dis-investment.[79]

Cooling access

The cost of electricity, exacerbated by inequitable polices, is an additional barrier to access to mechanical cooling, such as air conditioners;[1] "in the U.S., energy cost disparities are higher for Black and Latinx households compared to non-Hispanic white households, and a lack of access to affordable, renewable energy puts Black households at disproportionate risk" of heat stress.[1] "Additionally, inequitable access to weatherized, energy efficient homes limits adaptability for low-income communities and people of color."[1]

Gender: Pregnant women

Pregnant black women in the United States have more than double the risk of hospitalization from exposure to extreme temperatures than white women.[35,41] One study found that an additional day of exposure to extreme heat during pregnancy increases the likelihood of prenatal hospitalization by 5% for non-Hispanic black mothers, but for non-Hispanic white mothers, the risk was 2.4%.[35] Each additional day of extreme heat exposure during pregnancy is associated with an increase in Black women's likelihood of hospitalization during pregnancy.[73]

Learning Outcomes and Racial and Socioeconomic Inequality

Global

Cumulative learning and human capital accumulation

There is evidence suggesting that heat-exposure on learning days causally influences cumulative learning rather than only momentary reductions in cognition or cognitive capacity globally, with heat driving lower standardized test scores in younger students, students in hotter climates, and racial and ethnic minorities within the Unites States.[45] This is a "seemingly universal physiological channel through which heat affects human capital accumulation […] the universal physiological burden of heat reduces students' capacity to learn and teachers' capacity to teach, independent of intelligence or disposition. Hotter climates may thus interfere with economic development by reducing the human capital stock of nations, which implies that investments [and policies] aimed at protecting students from heat exposure may confer important economic benefits, particularly in hotter, poorer countries."[45]

Heat and human capital literature evolution (racial inequality)

This research provides a more policy-relevant explanation of the observed associations between heat and human capital than older literature that is in some cases racially charged and argues that genetic or cultural factors are a driving factor of human capital differences between hotter and cooler countries.[45]

Social cost of carbon

The findings also suggests that current estimates of the social costs of carbon may be understated, as the costs of carbon are often modeled as non-accumulating reduction in GDP as opposed to direct, cumulative impacts on human capital.[45]

Global impact of heat on rate of learning

"The rate of learning decreases with an increase in the number of hot school days", whereas heat during non-school days (summer vacation and weekends)has little effect, suggesting "that heat directly interferes with learning time." [45] "[…] climatic differences may contribute to differences in educational achievement both across countries and within countries by socioeconomic status"[45] "Both across and within countries, people living in hotter climates complete less formal schooling, score lower on standardized tests and exhibit worse economic outcomes than those living in cooler climates."[45]

Global, cumulative impacts of heat on education disparities

"Even small marginal effects of heat on learning could result in large educational disparities over time. Students in Indonesia and Thailand, for instance, experience over 200 days above 26.7 °C (80 °F) per school year, compared with approximately 40 such days in the United States and South Korea. Causal estimates of the returns to schooling suggest that small changes in educational achievement can result in persistent differences in lifetime earnings potential"[45] Students in school during hotter periods score worse on standardized tests than peers in the same country schooled in cooler periods, as "each additional day above 26.7°C (80°F) during the 3 years preceding an exam lowered scores by 0.18% of a standard deviation."[45]

Socioeconomic disparities

Both across the 58 countries studied and within the United States, "the marginal damage associated with hotter temperature appears to be larger for lower-income populations."[45] "Learning impacts of a hotter climate could result in large real consequences, especially given that students in many tropical economies regularly experience more than 100 such days per school year. Put differently, greater heat exposure during the school year may lead students in Brazil to learn 6% less than their South Korean counterparts per year, which, over time, might explain around one-third of the difference in their PISA performance."[45]

United States

Overall

"US analyses suggest that, even with relatively high levels of air conditioning, a school year with 30 additional days above 26.7 °C reduces learning by approximately 2.1% of a standard deviation. This is large enough to offset the gains of reducing class sizes by approximately 3–4%, or to offset improving teacher quality by 20% of a standard deviation."[45]

United States socioeconomic and racial disparities in school

For lower-income students, the effect of the same temperature event appears to be nearly three times larger."[45] "In the United States, heat's effects appear to be larger for racial or ethnic minorities and students in lower-income school districts, who probably have less access to potentially compensatory resources."[45] "hot temperature affects disadvantaged students much more than advantaged ones. Heat has substantially larger impacts on the achievement of students in lower-income school districts [in the United States, where each additional hot school day lowers achievement by 0.12%] and little [discernable] impact in higher-income districts."[45] "Each hot school day lowers the achievement of Black and Hispanic students by 0.10–0.12% of a standard deviation but has no statistically significant impact on non-Hispanic white students […] One week above 80 °F for the average Black or Hispanic student reduces learning by an amount equivalent to reducing teacher value added by 5–6% of a standard deviation."[45]

United States heat impacts on younger students

"The effect of hot school days is also larger for younger students than for older students. Each additional such day lowers the achievement of third to fifth graders by 0.08–0.13% of a standard deviation but has a statistically insignificant impact on those in grades six to eight."[45]

Socio-Economic and Income Inequity

Global

Health services

"Health services need robust plans in order to manage the potential disruption and increased demand during and following temperature extremes; their ability to respond influences population vulnerability." [19]

Social isolation and poverty

"People who are socially isolated are more at risk from temperature extremes because they are less able to access community support and may also have additional health issues or other vulnerabilities."[19] The poor are also more vulnerable to "to psychological stress exacerbated illness, and an increased risk of death from exposure to hot weather."[19]

Access to cooling (mechanical (A/C) and nature based), energy poverty

"Those with few economic resources may not have access to air conditioning or transportation to access cooling and may live in inadequate housing conditions making indoor temperatures excessively hot."[19] "Energy poverty is one of the factors driving extreme heat vulnerability, with unemployed, low-income, African American and Hispanic/Latino residents disproportionately lacking thermal comfort in their homes (Hayden et al 2011, 2017, Baniassadi et al 2020, Bednar and Reames 2020)."[76] "Impoverished districts and populations are usually the most vulnerable to heat, placing the negative impacts of excess warming disproportionately on those who are least likely to be able to afford or access thermal comfort."[15] For instance, the urban poor in 24 cities expected to reach average summertime highs of at least 35°C (95°F) by 2050 in India remain the most vulnerable to heat (Vijayawada 2018).[15] "In the United States, immigrant workers—typically minimum-wage employees—are three times more likely to die from heat exposure than the average American (Fleming *et al.* 2018)."[15] Additionally, people living in areas with less vegetation often have less wealth and a 5% higher risk of dying from heat-related causes, highlighting the correlation between green space, wealth, and heat-health risk (Schinasi, Benmarhnia and De Roos 2018).[15]

United States

United States low-income housing

See additionally Racial Inequality > United States > Race-based housing and heat

Low-income neighborhoods are significantly hotter than middle- and high-income neighborhoods in the **United States**.[39] People living in areas with poorly prepared or equipped health services, less access to cooling technology or infrastructure, the homeless, and low-wage earners are particularly susceptible to heat illness and death. [19,33] For example, during Arizona's record-breaking heatwave in 2020, more than half of the individuals who died from heat related causes in Maricopa County were without housing, and Black and Indigenous people had the highest rates of deaths.[1] "There is an increased likelihood that those who are poor and communities of color are more likely living in areas with fewer trees and poorer air quality" thereby resulting in greater heat exposure.[79]

Food Security

See Economic Impact > Agriculture and Food Security section for a connection to heat's economic and other impacts on food sources.

Increased warming's impact on land-based food security

"Food insecurity is increasing and has affected 2 billion people in 2019."[14] Increased warming will likely further exacerbate food insecurity, and will continue to disproportionally affect those already facing undernutrition.[14] Higher temperatures lead to shorter growing seasons and crop yields in the absence of adaptation, and with higher temperatures crop yields are continuing to decline, “adding additional pressure to already strained food systems around the world.”[14] Globally, every 1°C of temperature increase was associated with a 1.4% increase in the likelihood of severe food insecurity in 2014 and a 1.64% increase in food insecurity likelihood in 2019.[14] The rate of agricultural productivity improvements has declined by 30-33% in the Caribbean, with heat affecting both airable land area and livestock productivity, which could further increase the food security gender gap.[62] Latin America and the Caribbean face the largest gender gap in terms of food security globally.[62] “Livestock is an important protein source in some small islands and is particularly vulnerable to changes in temperature through heat stress. Even with breeding practices that increase animal resilience to heat, an integrated approach to heat-stress adaptation will still be needed.”[62]

Marine food sources

About 3.3 billion people worldwide depend on marine food for their nutrition and livelihood, particularly costal populations in low-medium HDI countries, small island developing states, and indigenous people.[14] In 2018-2020, the territorial waters of 95 countries showed increases in average sea surface temperature when compared with 2003-05 temperatures, “reflecting an increasing threat to their marine food productivity and marine food security.”[14]

Gender: women and food insecurity

Rural women are disproportionately affected by food insecurity “due to socially defined gender roles and less empowerment than men.”[14] Food insecurity also “reinforce[s] their disadvantaged position through reduced educational attainment, income, and socioeconomic status.”[14]

Violence and Crime

Crime rates

Heat exposure is linked with worsened mental health and increased crime.[1,3] Rates of violent crime increase as temperatures rise, particularly in low-income neighborhoods, "primarily because hot weather increases mental stress and the number of people outside."[3] Within countries, heat can aggravate “differences in urban quality of life between neighborhoods through [its] effect on crime,” and can particularly negatively impact individuals with mental illness, those living in sub-standard housing, and those who have limited access to cooling.[3]

Homicide rates and inequality

A study of 57 countries found that on average, “each degree Celsius increase in annual temperatures is associated with a nearly 6% average increase in homicides.”[4] Economic factors and pressures remain an important predictor of increased homicides, but the study also revealed that heat worsens crime rates unequally. While there were "no apparent effects in former Soviet countries, far stronger effects [were] found in Africa. Such variation indicates that climate change may acutely increase violence in areas that already are affected by higher levels of homicides and other social dislocations."[4]

Wider Environmental Impacts

Marine Heatwaves

Biodiversity

Marine heatwaves have been associated with "shifts in species ranges and local extinctions (Southward and Crisp, 1954; Garrabou et al., 2009; Wernberg et al., 2016)" along with "mass habitat loss (Wernberg et al., 2016), coral bleaching (Hughes et al., 2017), and mass seabird mortality (Jones et al., 2018)."[47]

Economic Impact

Marine heatwaves have been associated with "economic impacts on aquaculture (Oliver et al., 2017) and seafood industries through declines in important fishery species (Mills et al., 2013; Caputi et al., 2016; Hobday et al., 2016)."[47] The biological impacts of marine heat waves "disrupt dependent human systems (Mills et al., 2013; Frölicher and Laufkötter, 2018)."[47]

Trends

Analysis of historical data (Zhang et al., 2007; Oliver et al., 2018) show trends in MHW intensity and frequency as a result of anthropogenic climate change.[47]

Loss of Biodiversity

Extreme heat events drive species extinction

Examining 538 plant and animal species, one study found that locations with local extinctions had larger and faster changes in their hottest yearly temperatures, or the maximum temperature reached locally, and significantly smaller changes in mean annual temperatures, suggesting that extreme heat events are important in causing species extinction.[43]

Heatwaves disrupt ecosystems and drive species loss and die-off

A 2018 analysis of a massive 2011 heatwave in Western Australia found that marine and land-based ecosystems were significantly disrupted following the heatwave. The effects spanned over 300,000 square kilometers, about the size of California, and included species death and altered distributions, tree and terrestrial plant die-off, coral bleaching, seagrass and kelp loss [with 36% of seagrass meadows in Shark Bay damaged], a [60% population decline] for an endangered bird species, "plummeting breeding success in marine penguins, and outbreaks of terrestrial wood-boring insects."[44] Shrub and tree die-off was particularly high, with a 19% mortality rate after the heatwave, greatly exceeding usual forest die-off.[44]

Solutions

Nature Based and Passive Cooling

Green Infrastructure

Benefits

One of the most attractive and effective means of cooling cities is increasing vegetation. Access to urban green space cools locally and sequesters carbon, and there is growing evidence that urban green space aids human physical and mental health by "reducing exposure to air pollution, relieving stress, and increasing social interaction and physical activity, with overall improved general health outcomes and lower mortality risk."[14]

Return on investment

"Globally, investing $100 million annually in street trees would give 77 million people a 1°C reduction in maximum temperatures on hot days (McDonald *et al.* 2016; McDonald *et al.* 2020)."[15] Further, one report found that the maximum possible tree planting […] would reduce high temperature-related mortality by 2.4 percent to 5.6 percent, saving between 200 and 700 lives annually" among study cities."[95]

How green infrastructure cools

"Tree canopies and vegetation can lower surface and air temperatures in urban areas through a combination of shading and evapotranspiration, helping to reduce peak summer temperatures by 1° to 5°C (US EPA 2021)."[15] US EPA 2021: "trees and vegetation lower surface and air temperatures by providing shade and through evapotranspiration. Shaded surfaces, for example, may be 20–45°F (11–25°C) cooler than the peak temperatures of unshaded materials. Evapotranspiration, alone or in combination with shading, can help reduce peak summer temperatures by 2–9°F (1–5°C)."[56]

Green infrastructure use increases

Optimistically, urban greening has increased since 2010; globally in 2020, "27% of urban centers were classified as being moderately green or above (an increase from 14% in 2010)."[14]

Global socioeconomic disparities in green infrastructure access and use

Disparities between high and low HDI groups are still existent, as only 17% of urban centers in low HDI countries were at least moderately green, while 39% of urban centers in very high HDI countries were at least moderately green.[14]

A word of caution, important considerations

"Urban green spaces should be carefully designed and managed to conserve biodiversity, ensure they do not provide habitats and breeding sites for vectors of human diseases, or contribute to social inequities."[14]

Blue Infrastructure

How blue infrastructure works

Bodies of water can act as heat sinks, cooling the surrounding air, and helping to reduce local and ambient temperature.[15] "The cooling effect increases as the area of water increases, allowing cooling up to one kilometer away."[15]

Case study, Seoul, South Korea

"In Seoul, an effort to restore the Cheonggyecheon stream that runs through the city replaced 5.8 kilometers of elevated expressway that covered the stream with a mixed-use waterfront corridor. […] The project increased green space (and made existing blue space usable), wind speed, biodiversity, pedestrian use, public transit use, tourism, property values and business growth. It decreased temperature 3.3°C to 5.9°C compared to a parallel road a few blocks away, as well as reducing air pollution, noise and car traffic (Wicht, Wicht and Osińska-Skotak 2017; Landscape Performance Series n.d.)."[15]

Case study, step wells in India

"In India, step wells provide cooling at different levels plus shaded spaces for recreation. A descending staircase from ground level allows access to the well, even as the water level fluctuates (Zagyi 2013)."[15]

A word of caution, important considerations

"An important caution about water is that standing water can increase vector-borne diseases by providing breeding grounds for vectors like mosquitoes. Holistic measures such as integrated vector management are critical, and they are largely compatible with cooling goals. Flowing water is less hospitable for breeding, so restoring natural bodies of water and adding aeration in constructed ones can mitigate disease risk (Eder *et al.* 2018; WHO n.d.b)."[15]

Passive Cooling

Urban Form and Planning

Overall

"Passive cooling strategies have been proven to achieve a reduction in cooling loads of more than 25 per cent, even in very hot climates (ESMAP 2020b)"[15]

Land-use Planning

"Land-use planning and design control is generally the biggest lever for a developing city to proactively plan for mitigating future challenges related to the urban heat island effect. Appropriate changes to land use and design controls that prioritize green space and green infrastructure, and promote water-sensitive urban design, will help change the way that buildings and communities are constructed and designed. Land use and building design controls must be adjusted at several different scales – at the city, district and neighborhood level – in order to maximize effectiveness and ensure that the density and form of new development is appropriate for future climate conditions."[15]

Solutions

Cool and Reflective Surfaces

How reflective surfaces work

Reflective urban surfaces reduce the quantity of heat that radiates from the earth's surface and gets trapped in the air because they have a higher solar reflectance, or albedo, than non-reflective surfaces.[15] The fraction of sunlight reflected back into space is determined by solar reflectance/albedo.[15]

Reflective rooftops

"when sunlight hits a dark-colored roof, 38 per cent of its energy heats the atmosphere, 52 per cent heats the city air, and only 5 per cent is reflected back; in comparison, when sunlight hits a light-colored reflective roof, 10 per cent heats the atmosphere, 8 per cent heats the city air, and 80 per cent is reflected (Global Cool Cities Alliance 2012)."[15] A 2009 analysis found that increasing the albedo of roofs by 25% and pavements by 15% would result in urban areas' net albedo increasing by 1%.[30] This 1% increase in net albedo, on a global basis, would be "equivalent to offsetting about 44 [gigatons] of CO2 emissions" in one fell swoop.[30] This is greater than the world-wide CO2 emissions for 2019 (over 33.6 gigatons of CO2)[29] and the projected world-wide CO2 emissions for 2025 (37 gigatons of CO2).[15]

Case studies: Birmingham and West Midlands region, United Kingdom (UK)

A series of studies examined the effect of cool roofs on mortality in Birmingham and the West Midlands region.[14] The initial urban heat island effect in the region was on average around 3°C during summer and up to 9°C during heatwaves. The excess heat resulting from the urban heat island was estimated to contribute to approximately 40% of heat-related deaths during summer seasons and up to 50% during heatwaves; the most underserved populations groups were particularly exposed to urban heat.[14] Cool roofs had an overwhelmingly positive effect in both warm and cold temperatures. They could reduce maximum daytime air temperatures by 0.5°C on average and up to 3°C during heatwaves.[14] This cooling has the potential to reduce heat-related mortality due to the UHI effect by 18% during a summer season and 25% during a heatwave.[14]

Permeable Surfaces

Overall

"Permeable surfaces in urban areas facilitates evaporative cooling and also reduces the need for storm run-off infrastructure. This can be achieved by using porous or permeable paved surfaces and by increasing vegetated cover."[15] "While permeable pavements have been used for stormwater management, they also contribute to cooling as the moisture they contain evaporates and reduces air temperature."[15]

Cooling potential

"It seems that these technologies have a role to play in stormwater management, but their cooling applications may be more limited, *e.g.*, flood-prone parking lots or off-street walking paths. Otherwise, green infrastructure and shading structures can provide desired cooling benefits."[15]

A word of caution, important considerations

"Permeable pavements work in low-traffic areas where stormwater management would be helpful. It is important to make sure permeable pavements are sited so they do not pick up high pollutant loads or release the water they collect directly into natural water bodies. Permeable pavements do not provide cooling benefits when they are dry.

Cost and maintenance

Permeable pavements have a cost premium and require regular maintenance. The Energy Sector Management Assistance Program recommends that "cities...work with the private sector and others to demonstrate the local performance and capacity of permeable pavements and to send a signal to the market" (ESMAP 2020a).

Energy Efficient and Thermally Efficient Buildings

Key Principles

"Key principles of passive cooling that help reduce mechanical cooling loads in buildings include: climate-appropriate building orientation; appropriate materials and design features in the building envelope – including insulation, windows and shading – to minimize heat gain due to thermal transmittance; natural ventilation (where temperature, humidity and air quality allow); and thermal mass to stabilize interior temperatures. […] Passive design strategies should be utilized and optimized based on the climate condition for a region."[15] "Some passive cooling strategies that are particularly suited to existing buildings include installing high-performance windows, adding insulation, adding shading devices and implementing cool roofs."[15]

Active Cooling: Air Conditioning (A/C)

For a discussion of social factors, growing A/C consumption, and inequitable access, *go to* *Trends > Heat, Energy and Cooling Inequity > A/C Cooling**. For the economic impact of cooling on households, local, national, and global economies see* *Economic Impact > Heat Mitigation via A/C and Other Cooling**.*

Overall

While A/C is offers protection from life-threatening exposure to extreme heat and is an important cooling strategy, as a primary health protective strategy from extreme heat, it is insufficient and risks exacerbating the problem it aims to solve by contributing to climate change, the intensification of the urban heat island effect, contributing to peak electricity demand, associated greenhouse gas emissions, and urban air pollution.[1,14,15,90] "More air conditioning alone – as is the market default response – to combat oppressive city heat is not a sustainable solution. It only makes matters worse for the city as a collective whole. Instead, the urban cooling challenge has to be addressed sustainably and systemically – with parallel efforts to minimize sensible heat in cities, facilitate natural cooling to the fullest extent possible, and serve mechanical cooling requirements with the lowest possible environmental footprint."[15] In summary, "A/C is a vital but flawed health protection, as it contributes to [greenhouse gas] emissions and air pollution."[1]

Benefits

Effect on mortality

"Indoor cooling is an effective strategy for preventing heat related mortality."[14] In 2019, air conditioning prevented an estimated 195,400 heat related deaths globally among those over the age of 65,[14] and averted an estimated 48,000 heat related deaths in the United States among people over the age of 65.[1] In 2019 "air conditioning averted an estimated 69,500 deaths in China (where 72,000 deaths attributable to heat exposure are estimated to have occurred in 2019 and 65% of households had air conditioning), 47,800 in the [United States] (where 20,500 deaths are estimated to have occurred and 92% of households had air conditioning), 30,400 in Japan (where 12,400 deaths are estimated to have occurred and 93% of households had air conditioning), but only 2,400 in India (where 46,600 deaths are estimated to have occurred and 6% of households had air conditioning). These figures show the power of indoor cooling to prevent death and the inequities in access to indoor cooling across countries."[14]

Drawbacks

Greenhouse gas emissions

"Space cooling is one of the fastest growing causes of greenhouse gas emissions, further intensifying urban heat."[15] "Between 2000 and 2019, the global proportion of households with air conditioning rose 57% and CO2 emissions from air conditioning use rose 61%"[14] If today's cooling practices continue and remain largely dependent on fossil fuel-powered grids, " the projected increase in global electricity consumption for space cooling will result in 18 per cent of the total increase in global carbon dioxide (CO2) emissions between 2016 and 2050 (IEA 2018). Peak loads, which are often disproportionately served by fossil fuel-based generation, further exacerbate the power sector emissions associated with cooling. Despite the grid's declining emissions intensity due to ongoing clean energy efforts, an analysis by the International Energy Agency shows that the global annual indirect emissions associated with space cooling will almost double, from 1,135 million tons in 2016 to 2,070 million tons in 20502. This doubling does not even take into account the direct emissions originating from many common refrigerants used in air-conditioning systems. […the estimated] cumulative emissions for air conditioning our residential buildings alone (not factoring in the commercial buildings) could result in up to 0.5°C of global warming by 2100 (Sachar, Campbell and Kalanki 2018)."[15]

Fossil-fuel dependency, air pollution, mortality

Because the energy for A/C is currently largely derived from burning fossil fuels, globally, in 2019, "an estimated 21,000 deaths were attributable to exposure to PM2·5 from fossil-fuel powered electricity used for air conditioning,"[14] and "the use of A/C contributed to an estimated 500 additional deaths [in the United States] from air pollution exposure and worsened climate change by emitting over 260 megatons of carbon dioxide."[1] Furthermore, A/C leaks hydrofluorocarbons, that act as potent greenhouse gases and contribute to urban air pollution.[14]

Challenges

Energy use and grid infrastructure

The energy demands necessary to meet increased A/C projections are staggering, and the "rising use of air conditioners results in additions to grid infrastructure as well as increased greenhouse gas emissions and waste heat expelled into the environment. This further exacerbates the urban heat island effect, perpetuating a vicious cycle where mechanical cooling is further warming our cities – necessitating even more cooling – and disproportionately impacting those who lack adequate financial resources to procure mechanical cooling solutions."[15]

Around the world, A/C can be unreliable due to power outages[1,15] which it can contribute to by significantly increasing peak electricity demand, thus raising the risk of electrical grid failure.[15]

Additionally, when high heat coincides with other natural disasters that can lead to electrical grid failures, A/C and mechanical cooling methods become useless without power, and risk of heat injury rises.[15] To meet anticipated cooling needs, "under a business-as-usual scenario, the energy requirement for space cooling is predicted to jump 300 per cent – from 2,020 terawatt-hours (TWh) in 2016 to 6,200 TWh in 2050. This is almost equivalent to the electricity consumption of the United States and Europe/Japan combined."[15]

Additionally, as temperatures rise, more electricity is needed to power cooling equipment and offset reduced electrical efficiency.[3,15] By 2050, cooling is expected to account for over 40% of peak electrical load in developing economies such as India and Indonesia[3], and "it is estimated that "by 2050, space cooling will account for an estimated 30-50 per cent of the peak electricity load in many countries (versus a global average of around 15 per cent today), with the biggest increase occurring in India (International Energy Agency [IEA] 2018)."[15] In some of the local grids serving large metropolitan areas around the world, it is anticipated that by 2050 the cooling load will exceed 50 percent of the total peak demand.[15]

In historically cooler regions of the United States, 30-56% of households lack air conditioning.[1] Even when buildings have A/C, heat-related injury and death is still possible. In 2020, over 80% of people who died a heat-related death indoors in the United States "had an A/C unit present within their building, but two-thirds of the units were not functioning, and one-third were not running."[1] "1.12 billion people among the rural and urban poor are considered to be at high risk due to a lack of access to cooling" where high risk indicates "no access to electricity, income below poverty line, poor ventilations and construction, no access to refrigeration for food, farmers lack access to cold chains, and vaccines exposed to high temperature."[97]

Additionally, "2.9 billion lower-middle-income people are at medium risk of a lack of access to cooling, [which is] an increase of approximately 11 million people [since 2022]"—medium risk indicates "access to electricity, lower income levels, ability to run a fan, buildings constructed to lower standards, food is refrigerated, farmers only have access to intermittently reliable cold chains, and vaccines may have exposure to occasional high temperatures."[97] Mozambique, Nigeria, Sudan, India, Bangladesh, Pakistan, Brazil, Indonesia, and China are included in the *Chilling Prospects 2023* analysis's 'Critical 9' based on proportion of people at high risk.[97]

Increased use and need for thermal comfort

"Increased purchasing power will provide increased access to cooling; as a result, many lower- and middle-income families around the world will be able to purchase their first air conditioner to combat the rising temperatures. Such purchases will not only have significant implications for growing energy demand and associated greenhouse gas emissions but will also add dramatically to the waste (rejected) heat in urban areas, further compounding the problem."[15]

Opportunities for Better Active Cooling

Replacing today's space cooling equipment stock (1.6 billion residential and commercial air-conditioning units) with already commercially available, higher-efficiency air conditioning units, in conjunction with cost effective building improvements, would reduce today's space cooling energy use by about 58% or 1,177 terawatt hours.[15] It would also eliminate "more than half (540 million tons CO2) of the current total indirect emissions (1,135 million tons CO2) from space cooling operations" (RMI) and result in substantially lower use of refrigerants, reducing their direct emissions (ESMAP 2020b).[15] There is a wide range of solutions for increasing the energy efficiency of cooling and electrical systems (pg. 20-21) that would lead to greater health and productivity, power system, environmental, and economic benefits (pg. 22-23).[15]

Financing and Investment

Women-led credit and loans

Home cooling

The women-led credit cooperative Mahila Housing SEWA Trust is providing loans to low-income women to upgrade their tin roofs to cool modular roofs that have been found to reduce indoor temperatures by 7-9°F during the summers.[82] "Made from recycled coconut husks and paper waste, removable and waterproof ModRoofs are safer replacements for leak-prone roofs made with asbestos or corrugated tin—building materials common across India's slums."[82] "In addition to providing loans to more than 500 women for the installation of ModRoofs, MHT, together with NRDC, promotes a more cost-effective and scalable cool roof strategy of painting existing roofs with solar-reflective paint."[82] "Women in these communities play critical roles in building climate resilience by monitoring weather forecasts, working closely with government officials, and educating their neighbors about the dangers of extreme heat."[82]

Adaptation Finance Gap

Latin America and Caribbean

A lack of financing is a fundamental limit to adaptation in small Caribbean islands States. Latin America and Caribbean States received just 7% of public adaptation finance and grants according to data from OECD (2020).[62] Overall, Latin America and the Caribbean, for the period 2015–2016, obtained 22% of climate finance from multilateral climate funds but most (76%) went to mitigation projects, according to UNFCCC.[62] "Latin America and the Caribbean, for the period 2015–2016, obtained 22% of climate finance from multilateral climate funds. 76% went to mitigation projects with the remaining 24% going to adaptation, according to UNFCCC."[62]

Financial Flows

Latin America and Caribbean

"In the Caribbean, 38% of flows were concessional loans and 62% were grants; the situation in the Atlantic and Indian Oceans is starkly different—nearly 75% of the flows were in the form of concessional loans and grants accounted for the remaining 25%. This raises questions about fairness and justice for small islands having to finance adaptation to climate impacts to which they have made a negligible contribution. Direct budget support was rare, signaling the importance of works such as Rambarran (2018) that support cross-regional lesson-learning by, for example, showcasing the experience of Seychelles with successfully devising innovative financing mechanisms for supporting adaptation and conservation goals, and reducing its public debt."[62] "Latin America & Caribbean has the highest proportion of non-concessional debt (48%).[62]

Insurance and Reinsurance

Addressing the Protection Gap

"In what is known as the protection gap, some 70% of global losses from natural catastrophes are not insured, equating to $1.3 trillion over the past 10 years. In 2017 alone, uninsured losses for weather-related disasters were estimated to be around $180 billion."[86]

Insurance can provide a "flow of capital to support communities and infrastructure to recover from disasters. Without adequate insurance, the burden of paying for losses falls largely on individual citizens, governments or aid organizations, with significant impact upon already straining government budgets, and economic and social hardship for those affected [...] Countries with high insurance cover recover faster from disasters, and increasingly, governments are recognizing the role and benefits of insurance in transferring risk from disasters." Additionally, "insurance contributes to the wider understanding of climate-change risks and helps promote measures that individuals and communities can use to improve their protection from climate-change-driven disasters."[85] "Insurance is just one piece of the larger climate adaptation finance strategy.

Some recommendations to maximize the benefits of insurance for climate adaptation include investing in open-source models that provide long-term views of climate risk and links to insurance solutions. Additionally, the Centre for Disaster Protection suggests to, "Put climate-risk models at the heart of national adaptation strategies […] Develop consistent climate adaptation regulations and standards across countries […] Foster insurance innovations that can respond to a changing climate risk landscape […] Strengthen dialogue between policymakers and insurers […and] Promote and invest in risk literacy throughout society."[85]

Latin America and the Caribbean

"Solutions to financing barriers are being explored and some small islands have started adopting enablers such as insurance and microfinance at both the national and local levels in responding to adaptation needs and to facilitate resiliency building."[62] CCRIF is one such actor leading on weather catastrophe insurance approaches.[64] In most Latin American and Caribbean countries, the public sector plays an important role in providing insurance or reinsurance and coexists with private sector companies (IPCC, 2022).[62]

Africa

Individual and Household Protection Gap

"[T]here is much scope to increase the contribution of the insurance sector towards improving individual and household welfare, building business resilience and developing the demand and supply of capital in the economy, thereby promoting the role of the insurance sector in broader economic development."[87] When considering the insurance household gap, their study found that, "Fifty-one percent (51%) of adults across the four countries indicated that they faced a risk-event within the last year, but only 1% used insurance and over 20% turned to welfare-reducing strategies, such as selling assets or reducing expenditure, to cope with the impact of the shocks. Outside of state-provided health insurance, only 4.1 million adults – about two percent of the total adult population – in the study countries are covered by insurance. Yet 5.3 million adults across the four countries [Ghana, Kenya, Nigeria, Rwanda] are within easy reach as they have a bank account, mobile phone, are formally employed and earn the equivalent of USD$5 or more a day."[87]

Business Protection Gap

"While corporate insurance is the mainstay of the insurance sector in all four countries [Ghana, Kenya, Nigeria, Rwanda], SME cover remains low to absent due to distribution challenges in reaching small businesses, a lack of a sector value chain appreciation among insurers and a mismatch between the product offering and the tailored needs of SMEs. Complex, large corporate risks are often carried offshore and, where localization requirements are in place to onshore some of these risks, inefficiencies and concerning market practices are observed. The focus has also not shifted from risk transfer to a proactive risk management role for corporate insurance in any of the countries. More broadly, disaster risk management for resilient cities and communities is not yet entrenched as a major consideration in the insurance discourse."[87]

"In none of the four study countries [Ghana, Kenya, Nigeria, Rwanda] is the insurance sector large enough to play a substantial role in building demand and supply of capital. The combined size of insurance assets across all four was less than USD10 billion in 2016, ranging from 0.8% to 7.7% of GDP. A reliance on shorter term non-life rather than life insurance for the bulk of premium volumes leads to largely short-term assets and liabilities, with limited need for long-term investments. This is exacerbated by a limited supply of long-term investment instruments."[87]

"All four countries [Ghana, Kenya, Nigeria, Rwanda] face structural innovation constraints. While each country's insurance sector and context are unique, a dearth of good quality data, skills and capacity constraints, inefficiencies, cannibalistic competition on the back of compulsory insurance and various enabling environment constraints drive alarmingly high-cost structures (with one in three insurers across the four countries having expense ratios of over 80%) and a general lack of innovation."[87]

Governance and Policy

Policy

Building codes and energy performance standards

"Mandatory or voluntary building energy codes are the means to drive passive cooling strategies in buildings. Code adoption is commonplace in developed economies such as the European Union and the United States, and the cumulative positive outcomes are well acknowledged. For example, the model energy codes in the United States are projected to result in cumulative benefits, from 2010 to 2040, of 841 million metric tons of avoided CO2 emissions and 3,757 TWh of avoided primary energy. These savings equate to the annual emissions of 177 million passenger vehicles or 245 coal power plants (US DOE, n.d.)."[15] Other sources also argue that *strong, enforced* codes *mandating* energy-efficient buildings and *stringent minimum energy performance standards* for air conditioners, in addition to a return to traditional tropical and subtropical building designs, use of fans in climate zones where they provide effective cooling, cool roofs, and increased urban green space are essential.[14] In developing countries, there is low adoption and implementation of building energy codes, primarily due to a number of implementation and enforcement barriers resulting from factors including "institutional challenges, regulatory challenges, lack of enabling mechanisms to create and sustain markets, low stakeholder motivation due to split incentives, and lack of awareness and capacities."[15]

Enhanced Electrical Grid Resilience

The "concurrence of electrical grid failure events in time with extreme temperatures [compounds] population health risks of extreme weather episodes."[96] A study including three major U.S. cities found "the concurrence of a multiday blackout event with heat wave conditions to more than double the estimated rate of heat-related mortality across all three cities, and to require medical attention for between 3% (Atlanta) and more than 50% (Phoenix) of the total urban population in present and future time periods."[96] These results indicate a need for enhanced electrical grid resilience and implementation of other strategies such as improved tree canopy cover and high albedo roofing in preparation for anticipated electrical grid failure events.[96]

Green building programs

Voluntary green building programs, such as US Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) Green Building Rating System and BREEAM (Building Research Establishment Environmental Assessment Method) promote energy and thermally efficient building design.[15]

Barriers

"The key barriers to holistic and sustainable urban cooling practices can be distilled into the following five: 1) lack of awareness, 2) lack of supportive policies and regulation, 3) financial barriers, 4) limited institutional capacities and 5) complexity of the solution set."[15] More detail on pg. 24-28.[15]
Implementation of a national health and climate change plan was a challenge for countries from all HDI levels in 2020 due to insufficient human resource capacity, COVID-19 related constraints, insufficient research, technologies, or tools, and most importantly insufficient financing, with 10 countries reporting that they have "no current sources of funding available for the priorities set out in their strategies and plans."[14]

City Specific

Overall

The impacts of global climate change in cities will likely be amplified by the impacts of the urban heat island effect, however "local impacts can be limited by city-level adaptation polices, such as cool pavements, cool and green roofs and expanding vegetation in cities."[8]

Case-study: Cool Communities in Los Angeles

"A hypothetical "cool communities" program in Los Angeles projected – two decades ago – that urban temperatures could be reduced by around 3°C after planting 10 million trees, reroofing 5 million homes and painting one-quarter of the roads; the estimated cost would be $1 billion, giving estimated annual benefits of $170 million from reduced air-conditioning costs and $360 million in smog-related health savings – that is, a simple payback period of under two years (Rosenfeld *et al.* 1997). While the theoretical knowledge has existed, making this more accessible to cities through adequate capacity-building and raising stakeholder awareness will support greater implementation."[15]

Sustainable Cooling

Overall benefits

"Sustainable cooling can be an important enabler and significant contributor to cities' goals to lower emissions and reach net zero energy targets cost-effectively. It can also be an important contributor to national climate commitments as cities take targeted actions and demonstrate "local" leadership to align with national priorities. The multiple co-benefits to cities include the enhanced health, well-being, and productivity of citizens; a more attractive environment for economic development; improved energy systems; and wider and equitable access to thermal comfort. Last, but not least, the positive impacts of local interventions to promote sustainable urban cooling will amplify global efforts to fight climate change."[15]

Urban cooling whole-system approach

Because multiple factors contribute to higher heat and rates of warming in cities, urban cooling strategies must utilize a whole-system approach, addressing the urban heat island effect, neutralize the emissions impact of current and future active and mechanical cooling, and enable access to cooling while avoiding further local warming. [15] Three core steps are recommended to keep cities cool, sustainably: the first is improving city and district urban planning and infrastructure by emphasizing heat-minimizing planning, the use of thermally favorable materials, and nature based cooling practices that reduce the urban heat island effect and thus reduce cooling loads and electrical demand in buildings.[15]

The second step is reducing the cooling needs of buildings by increasing energy and thermal efficiency, thereby reducing the need for mechanical cooling and the overall energy and emissions footprint of the building using passive building design practices.[15] Finally, to cool people within buildings, cooling equipment should: be optimally fitted for the application (a warehouse requires different cooling mechanisms than a small storefront), be highly energy efficient, and minimize the use of high-global-warming-potential refrigerants. Operations, including "optimal operations and maintenance practices, refrigerant management, and demand-side management of cooling energy consumption including building automation and user-adaptation, etc. – designed to minimize energy use and emissions from the cooling of buildings."[15]

City-scale intervention categories

City interventions to advance sustainable urban cooling would fall within three broad categories: 1) Control strategies, such as city-wide legislation, regulation, planning, and standards, directly control and steer actions towards sustainable urban cooling. 2) Combination strategies, when cities do not have full and direct control, include leading by example through beyond-code efficiency mandates for city-occupied budlings, can demonstrate benefits and influence broader confidence and adoption. 3) Facilitative strategies, such as raising awareness, helping to develop financial instruments to spur demand, reducing barriers, and building capacity to meet demand can amplify the impact of the previous two methods and re-enforce actions that are often regulated at the national or state level. [15] Detailed recommendations for cities are on pgs. 30-52. [15]

Addressing Heat in City Governance and Planning

In a study examining "175 municipal plans from the 50 most populous cities in the United States," it was found that a majority of the plans reference heat, although few strategies to address heat are discussed.[93] 'Extreme heat event (EHE)' and 'urban heat island (UHI)' were the most prevalent in heat governance frameworks for addressing heat. While EHE and UHI frameworks establish governance on heat that is either rooted in a 'heat-as-hazard' or a 'heat-as-land-planning' approach, the two frameworks were not correlated with each other.[93]

Early Warning Systems

"One of the most promising climate services for the health sector [and a key longer-term adaptation option] are heat early warning and alert systems. These have been developed by the national meteorological institutes in Peru, Argentina, and Uruguay. A heat alert system was implemented in Argentina in 2017 and daily alerts are issued for 57 localities across the country. A stoplight color scheme is used to issue alerts, identifying specific groups at risk and actions to be taken to reduce the risk. The public dissemination of climate-health warnings via bulletins, websites, and other outlets can be an adaptation measure to climate change and weather variability to diminish health risk."[62]

"Early warning capabilities in the Caribbean have improved in detection, monitoring, analysis and forecasting of severe weather systems but there is a need to strengthen early warning systems for other climate-related hazards including heatwaves and a need for effective communication of warning messages to populations at risk."[62]

"Spending US$800 million on early warning systems in developing countries could reduce climate related disaster losses by US$3–16 billion per year."[88]

Naming and Categorizing Rationale and Efficacy

Naming heatwaves

Scarcity of Research

There is limited research on naming and categorizing of storms and heat waves. A Google Scholar search for "naming and categorizing" "heat waves" (and heatwaves) returns three relevant studies, all on marine heat waves, one a literature review, and two citing the literature review, all written by the same main authors. A search for "categorizing heat waves OR categorizing heatwaves OR ranking heatwaves OR ranking heat waves" returns one paper on heat wave categorization for feedlot cattle productivity. "naming heat waves OR naming heatwaves" returns no relevant papers, and "naming" "heatwaves" and variations returns 900-~2,000 results. On a quick scan of these results many either focus on marine heatwaves or appear irrelevant.

Naming and categorizing marine heat waves

The literature on naming and categorizing marine heatwaves is limited. "While categorization or naming is commonly applied to a range of extreme environmental events such as tropical cyclones, earthquakes, or atmospheric heatwaves, it is not currently used consistently for [marine heat waves]."[47] However, scientists are advocating for the naming and categorization of marine heat waves and developing categorization systems to enhance the existing classification, enhance scientific and public awareness, provide a consistent way to compare marine heat waves, and explain variation in the biological impact of marine heat waves.[47]

Naming and categorizing natural hazards

"There is a long tradition of categorizing extreme events according to some intensity measure, and/or to name them following certain conventions. Categorization enables comparison of events across different regions and facilitates comparison of the different events in a globally consistent framework. Naming provides a unique and unambiguous identifier for each event in a certain period, which greatly facilitates communication among experts as well as to the general public (Nairn and Fawcett, 2013)."[47] "Providing names and measurements of intensity has a number of benefits, including clarity when discussing historical events, which aids identification and communication with the general public (Nairn and Fawcett, 2013).

The familiarity that names provide also builds public awareness regarding these events away from their impact region and enhances risk awareness regarding future events. Scientists also benefit from naming and categorization, via improved metanalyses (events can be clearly recognized in published literature) and in retrospective studies that seek to relate the magnitude of an event to some observed impact."[47]

TABLE 1. Examples of naming and categorization schemes used for extreme events and natural disasters. Single events may have attracted a name in popular media, without formal naming.

	WITH FORMAL NAMING	WITHOUT FORMAL NAMING
With category/ scale	• Hurricanes (Saffir-Simpson scale, e.g., Katrina, Category 5) • Earthquakes (Richter scale, e.g., Kobe) • Storms (UK since 2015, e.g., Abigail)	• Atmospheric heatwaves (e.g., heatwave index, but European heatwave (2003)) • Storms (e.g., Beaufort wind scale) • Droughts (e.g., Palmer drought severity index)
Without category/ scale	• Fires (e.g., Black Saturday) • Droughts (e.g., Millennium Drought in Australia, Dust Bowl in USA)	• Deoxygenation events • Hail storms • Floods (but, e.g., 1931 China floods) • Acidification events • Marine heatwaves

Table 1. provides an overview of different types of extreme weather events and natural disasters and whether they are subject to formal categorization or naming systems. [47]

Why wildfires are named

"Wildfires need to be named quickly in order to start fighting them efficiently." Cal Fire's Assistant Deputy Director Daniel Berlant explains that "All fires [in the United States] get a name. That allows the firefighters that are responding to them to quickly understand where they're going and allows those back in our emergency command centers to prioritize our resources and to quickly track them down."[46]

Efficacy of storm naming

Three efficacy studies were identified. A 2021 study of all-season storm naming in Greece finds a significant increases in readiness, risk perception, acceptance of storm naming, and access to information among the citizens who already had a negative experience of adverse impacts from a named storm, using survey data.[52] Greece has been naming storms for 4 years according to the study.[52]

The study used 17-question internet-based questionnaire, gathering a nationwide sample of 2088 respondents.[52] Males were overrepresented, accounting for 73% of the respondents, respondents' ages were approximately normally distributed, 80% of respondents lived in urban areas and 23% of the respondents had been adversely affected by at least one named storm.[52] “Overall, results indicate a significant impact of the storm naming on the readiness of citizens.”[52]

The second study (2018) is an experimental study of US college student risk perception using a fake NOAA Twitter feed.[53] The sampled population was in the Southeastern US but not from a coastal region (N= 211).[53] Results are mixed but show a modest delayed impact of naming.[53] This study could also be relevant to the Naming and Categorizing messaging group work.[53]

The third (2017), also a study of US undergraduates (N=407) in the Northeast finds no effect of naming.[54] Their findings suggest "that little difference exists between individual perceptions dependent on whether a name is used, or the type of name used.[54] The results indicate that individuals do not differ in levels of perceived severity or susceptibility toward a fictional winter storm dependent on the type of name used.[54] Similarly, perceptions of the credibility of media organizations do not change dependent on the storm name."[54]

Categorizing

Overall

A 2018 study of heat warning systems in the United States found that the only city with a heat warning system that saves lives in the United States is Philadelphia,[65] which uses a health-based metrics categorized warning system[66] developed by Dr. Laurence (Larry) Kalkstein. Measuring and categorizing extreme events “can also provide advantages for communication and comparison. The best-known examples have been the development of magnitude scales for earthquakes (the Richter scale) and hurricanes (the Saffir-Simpson scale; Table 1 [above]). Lesser-known magnitude scales have also been assigned for other types of extreme events, including for droughts in the United States (Palmer drought severity index) and fire risk in Australia (e.g., McArthur Forest Fire Danger Index).”[47]

Trends

It’s Getting Hotter

Global

July 2021 was the hottest month ever recorded on Earth.[23] 2020 was the hottest year recorded; the average global surface temperature was 2.2°F (approximately 1.3°C) higher than the late 19th century average[15], and the world is now 1.2°C warmer than in the pre-industrial period (1850–1900).[14] The last seven years, from 2014 to 2020, have been the hottest years since record keeping began 140 years ago.[14,15]

Global Projections

By 2030 the global temperature is expected to rise by at least 1.3°C. This is almost certainly an underestimate,[10] as the global mean temperature for 2020 was 1.1-1.3°C above pre-industrial levels, [11] and Earth’s temperature has risen by 0.08°C per decade since 1880, and by 0.18° C per decade since

1981.[12] The Caribbean is getting warmer, with an increase in daily minimum air temperature of almost 0.3°C/decade.[62]

United States

The summer of 2021 was the hottest summer on record for the United States, and the hottest summer most Americans have lived through.[24,25] The summer of 2021 narrowly surpassed the now second hottest summer on record: the 1936 Dust Bowl summer.[24,25] In NOAA predictions, 2022's "90-day NMME average temperature forecast for June–August is much warmer than [2021's] temperature forecast for the same period. [In the summer of 2021], temperatures were predicted to be 0.9 to 3.6°F (0.5 to 2°C) above normal, whereas this summer's forecast predicts temperatures 1.8 to 5.4°F (1 to 3°C) above normal for most of the continental United States."[68]

Cities

Some estimates suggest that, on average, cities around the world could warm by as much as 4°C by 2100 (Zhao *et al.* 2021).[15]

Intensity/Magnitude, Frequency, and Duration of Extreme Heat Events

Globally overall

Since the 1990s and early 2000s, climate change has further increased the intensity, frequency, and duration of heatwaves globally, leaving more people vulnerable to heat-injury and heat-related death.[1,34] Other estimates find that heatwaves have increased in their frequency and duration in every region of the world since the 1950s.[27]

Global projections

With climate change, heatwaves and extreme heat are expected to become more frequent and intense.[33] Marine and terrestrial heat waves are predicted to continue to increase in frequency and magnitude, the "land area affected by heat waves is expected to double by 2020 and quadruple by 2040," and "marine heat waves now occur 4–5 times more often than in the 1980s."[44]

Cities

Due to the urban heat island effect, cities are heating up at a rate twice that of the global average.[15] "Severe heatwaves could affect 13.8% of the world population, or about 1.09 billion people, at least once every five years under 1.5°C of global warming-- a threshold that could be reached as soon as 2030. Under 2°C of global warming, 36.9% of the world population could be affected by severe heatwaves."[55]

Europe (European Union (EU))

"Heat waves are expected to become more pronounced, especially in Mediterranean economies and countries of similar latitude (such as Turkey), while northern European countries have comparatively limited exposure to physical climate risks, according to our scenario analysis. Nonetheless, as the impacts of chronic hazards, like sea level rise and changing temperature and precipitation patterns, play out over longer timescales, we expect the impacts to become more prevalent after the midcentury, absent adaptation."[84]

Exposure

Globally

With increasing frequency, duration, and magnitude of heatwaves the number of people exposed to extreme heat is increasing. According to the WHO, "between 2000 and 2016, the number of people exposed to heat waves globally increased by around 125 million. In 2015 alone, 175 million additional people were exposed to heat waves compared to average years."[34, 15] "Globally, the last eight years have been the warmest on record, and 2022 was the fifth warmest year on record. Several regions of the globe saw record-breaking temperatures. In Europe, summer was the warmest on record, at 1.4°C above average, and 0.3–0.4°C above the previous warmest summer, in 2021. Most of western Europe saw heatwave conditions and temperatures in the United Kingdom reached above 40°C for the first time. The average sea surface temperature across Europe's seas was the warmest on record."[99] Further, preliminary analysis by the World Meteorological Organization (WMO), Copernicus Climate Change Service (C3S), and Leipzig University in Germany showed that this July [2023] is set to be the hottest month ever record on Earth—and likely hottest in about 120,000 years.[100]

Projections

Global Projections

By 2070, one out of every three people globally will live with annual average temperatures of more than 29°C, in the absence of migration (Xu *et al.* 2020). Currently, less than 1% of the Earth, mostly in the Sahara, has such extreme heat conditions (Xu *et al.* 2020).[15] "Under current conditions (1985 – 2005), Latin America and the Caribbean experience 803-million-person days of exposure to extreme heat. This number could rise to 45,612 million-person days of exposure to extreme heat under an RCP8.5/SSP3 scenario in the 2016-2080 timeframe."[62]

Europe Projections

With 1.5°C of warming, more than 100 million Europeans a year would be exposed to intense, one-in-fifty-years heatwaves. At 2°C of warming, this number increases to 176 million Europeans per year, and with 3°C of warming in 2100, nearly 300 million people per year, or more than half of the European population, will be exposed to extreme heat and severe heatwaves.[33] Even the most ambitious scenario of limiting warming to 1.5°C leads to a dramatic rise in heat exposure compared to the 1981-2010 climate, under which less than 10 million Europeans per year were exposed to a one-in-fifty-years heatwave.[33]

Central, South, and Latin America, Caribbean Projections

"Caribbean islands--including Aruba, Bahamas, Barbados, and others--and Central American countries--for example, Nicaragua and Honduras--are significantly more exposed in 2050 than other Latin American regional peers (see table 5). Damaging storms, wildfires, sea level rise, and flooding are the main drivers of exposure in these countries, though heat waves are also likely to affect the entire population in most countries. The impact of these climate hazards could be significant as on average these countries' readiness to adapt to physical climate risks is relatively low in our assessment […] The islands are likely to be much more affected by physical risks--like storms and sea level rise--similarly to Pacific islands. We expect that heat waves will also grow in prominence in the southern part of the region, but exposure to physical risks could be much lower in countries south of the equator and even Mexico."[84]

Africa Projections

"Heat waves will drive [physical risk] exposure of Sub-Saharan African countries. By 2050, 80% of countries in Sub-Saharan Africa are likely to have more than 45 days of heat waves per year, compared with less than 15% currently, coupled with more severe and frequent acute physical risks."[84]

Lacking Visibility and Awareness

Health-risks

Awareness of the health risks posed by heatwaves and exposure to higher temperatures remains insufficient, and "health professionals must adjust their planning and interventions to account for increasing temperatures and heatwaves. Practical, feasible, and often low-cost interventions at the individual, community, organizational, governmental, and societal levels, can save lives."[34]

United Kingdom (UK)

A metanalysis of heatwave visibility and communications in the United Kingdom found that "heatwaves remain largely an invisible risk in the UK. Communication over what UK residents should do, the support needed to make changes, and their capacity to enact those changes, is often lacking. In turn, there is an inherent bias where research focuses too narrowly on the health and building sectors over other critical sectors, such as agriculture. An increased amount of action and leadership is therefore necessary from the UK government to address this."[38]

Urbanization

Globally, "by 2050, 68% of the world's growing population will be living in urban areas, up from 55% in 2018 (UN DESA 2018). A major portion of this growth will be in developing countries in Asia and Africa: just three countries – India, China and Nigeria, which are already hot and populous – will account for 35% of the projected growth in the world's urban population. If current growth trends continue, urban areas could increase in population by 80% between 2018 and 2030 (Mahendra and Seto 2019) and will experience dramatic land-use changes such as reduced vegetation and a sharp increase in heat- trapping materials and surfaces."[15]

Vulnerability

Vulnerability to heat is increasing globally for countries across all HDI groups.[14]

Increasing Importance: Adaptation

"With a world facing an unavoidable temperature rise, even with the most ambitious climate change mitigation, accelerated adaptation is essential to reduce the vulnerabilities of populations to climate change and protect the health of people around the world."[14]

Trends

Heat-Related Loss Attributable to Climate Change

Deaths/Mortality

"More than a third of urban heat-related deaths in the 1990s and early 2000s can be attributed to climate change." [1] Due to climate change, the number of deaths from heat-stroke is increasing.[18]

Heat, Energy, and Cooling Inequity

Overall

"If current trends continue, the existing heat inequity in cities, often reflecting social and racial disparities, will only deepen in the coming decades as our cities become warmer, posing a daunting challenge for cities to bridge."[15]

Energy Poverty

Globally

The high cost of air conditioning is amplifying the energy poverty gap globally.[14] This has been seen by Chief Heat Officers (CHOs) in Athens and Miami-Dade County, Florida. In their city and county, energy poverty means that many residents must make painful choices about whether to cool their home or pay other expenses even if they have an A/C unit. If people do not have access to cooling or work in high-heat conditions, cities must do even more to protect them. In Athens, 24% of the population can't afford the electricity to power A/C.[26] When energy poverty meets a substantial elderly population and a culture of outdoor leisure and work, people become even more vulnerable to heat death and illness. Indeed, there were 2,300 excess deaths in three weeks during the summer 2021 heatwave in Greece, which reached a peak temperature of 44°C.[26]

United States

In 2015, nearly one third (31%) of households in the United States reported struggling to pay energy bills or sustain adequate temperature control in their home; about one in five households reporting that they reduce for forgo necessities like food and medicine to pay an energy bill; and 11% of households surveyed in the U.S. Energy Information Administration's Residential Energy Consumption Survey keeping their home at an unsafe or unhealthy temperature.[40] The demographics that experienced the most energy insecurity were household residents from minority racial groups, low income individuals or families, and households with children. "Households experiencing energy insecurity were also more likely to live in homes built before 1990."[40]

A/C cooling

For further discussion of A/C's challenges, drawbacks, and importance see Solutions > Active Cooling: Air Conditioning (A/C). For the economic impact of cooling on households, local, national, and global economies see Economic Impact > Heat Mitigation via A/C and Other Cooling.

Cooling access and poverty

Since 2020 the cooling access gap grew in Africa, Asia, the Middle East, Latin America, and the Caribbean, leaving behind the rural and urban poor at highest risk of a lack of cooling.[28] In the year between 2020 and 2021, the number of people at high risk of a lack of cooling increased by approximately 50 million. Among the urban poor, 19 million more people are at risk since 2020.[27] They increase is partially related to the combined effect of 2020 and 2021 being two of the hottest years on record and global poverty levels rising during the COVID-19 pandemic.[27] As of 2021, "1.09 billion people among the rural and urban poor are at high risk due to a lack of access to cooling" across 54 countries.[27]

Cooling access improvements

By 2025, increases in GDP will enable increased access to cooling, and many families around the world will be able to purchase their first air conditioner. Already, 2.34 billion lower middle income people in developing countries will soon be able to purchase the most affordable, and likely least efficient, air conditioner on the market.[15,27] This is an important step in thermal comfort equity, but there will be significant implications for growing energy demand and associated greenhouse gas emissions along with heat generated from space cooling further exacerbating the urban heat island effect in these communities.[15] The challenge for cities lies in "how to equitably serve the growing demand for cooling without multiplying the negative impacts, causing further warming and undermining the energy transition."[15]

Increase in Disease Transmission & Malaria

Overall

Higher temperatures and other environmental conditions are "increasing the suitability for the transmission of many water-borne, airborne, food-borne, and vector-borne pathogens" potentially negating the advances of "socioeconomic development, public health interventions, and advances in medicine [in reducing] the global burden of infectious disease transmission."[14]

Global risk increases

In densely populated highland areas in low HDI countries there was a 39% increase in the number of months with environmental conditions suitable for malaria transmission from 1950-59 to 2010-19.[14] This increase threatens highly disadvantaged populations who were safer from this disease when compared to lowland regions.[14] "The epidemic potential for dengue virus, Zika virus, and chikungunya virus, which currently primarily affect populations in Central America, South America, the Caribbean, Africa, and south Asia, increased globally" with the biggest increases in the vectors' reproductive rates occurring in countries with very high HDIs, however people in low HDI regions remain the most vulnerable to these viruses.[14] Additionally, the environmental suitability for cholera transmission increased substantially in all HDI groups, but in the low HDI country group, 98% of the coastline is suitable for cholera transmission.

References

1. Salas, R. N., Knappenberger Lester, P., & Hess, J. J. (2021). *The Lancet Countdown on Health and Climate Change Policy Brief for the United States of America*. The Lancet Countdown: Tracking Progress on Health and Climate Change & The American Public Health Association (APHA). https://www.lancetcountdownus.org/wp-content/uploads/2021/10/USA-2021-English-Lancet-Countdown-Policy-Brief.pdf
2. Adrienne Arsht Rockefeller Foundation Resilience Center & Vivid Economics. (2021, August). *EXTREME HEAT The Economic and Social Consequences for the United States*, 2-3. https://www.atlanticcouncil.org/wp-content/uploads/2021/08/Extreme-Heat-Report-2021.pdf
3. ESMAP. 2020. *Primer for cool cities: Reducing excessive urban heat*. Energy Sector Management Assistance Program (ESMAP) Knowledge Series 031/20. Washington, DC: World Bank. https://documents1.worldbank.org/curated/en/605601595393390081/pdf/Primer-for-Cool-Cities-Reducing-Excessive-Urban-Heat-with-a-Focus-on-Passive-Measures.pdf
4. Mares, D.M., Moffett, K.W. (2016). Climate change and interpersonal violence: A "global" estimate and regional inequities. *Climatic Change* **135,** 297–310. https://doi.org/10.1007/s10584-015-1566-0
5. Somanathan, E., Somanathan, R., Sudarshan, A., & Tewari, M. (2018). *The impact of temperature on productivity and labor supply: Evidence from Indian manufacturing*. Energy Policy Institute at the University of Chicago (EPIC). Chicago, IL: Becker Friedman Institute. https://bfi.uchicago.edu/wp-content/uploads/UCH-110116_IndianManufacturingResearchSummary_v04.pdf There is an updated version of the study for 2021 https://www.journals.uchicago.edu/doi/10.1086/713733
6. Centers for Disease Control and Prevention. (2017, June 19). *About extreme heat*. Centers for Disease Control and Prevention. Retrieved November 3, 2021, from https://www.cdc.gov/disasters/extremeheat/heat_guide.html.
7. Zhao, C., Liu, B., Piao, S., Wang, X., Lobell, D. B., & Asseng, S. (2017). Temperature increase reduces global yields of major crops in four independent estimates. *Proceedings of the National Academy of Sciences*, *114*(35), 9326–9331. https://doi.org/10.1073/pnas.1701762114
8. Estrada, F., Botzen, W. J., & Tol, R. S. (2017). A global economic assessment of city policies to reduce climate change impacts. *Nature Climate Change*, *7*(6), 403–406. https://doi.org/10.1038/nclimate3301
9. Zander, K. K., Botzen, W. J. W., Oppermann, E., Kjellstrom, T. & Garnett, S. T. Heat stress causes substantial labour productivity loss in Australia. Nat. Clim. Change 5, 647–651 (2015).
10. International Labour Office. (2019). Working on a warmer planet: The impact of heat stress on labour productivity and decent work. Geneva: ILO
11. World Meteorological Organization. (2020). *WMO provisional report on the state of the global climate 2020*. Geneva: WMO.
12. Dahlman, R. L. and L. A. (2021, August 12). *Climate change: Global temperature*. Climate Change: Global Temperature | NOAA Climate.gov. Retrieved November 8, 2021, from https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature.
13. Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Beagley, J., Belesova, K., Boykoff, M., Byass, P., Cai, W., Campbell-Lendrum, D., Capstick, S., Chambers, J., Coleman, S., Dalin, C., Daly, M., Dasandi, N., Dasgupta, S., Davies, M., Di Napoli, C., … Costello, A. (2021). The 2020 report of the Lancet

countdown on Health and climate change: Responding to converging crises. *The Lancet*, *397*(10269), 129–170. https://doi.org/10.1016/s0140-6736(20)32290-x

14. Romanello, M., McGushin, A., Di Napoli, C., Drummond, P., Hughes, N., Jamart, L., Kennard, H., Lampard, P., Solano Rodriguez, B., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Cai, W., Campbell-Lendrum, D., Capstick, S., Chambers, J., Chu, L., Ciampi, L., Dalin, C., … Hamilton, I. (2021). The 2021 report of The lancet countdown on health and climate change: Code red for a healthy future. *The Lancet*, *398*(10311), 1619–1662. https://doi.org/10.1016/s0140-6736(21)01787-6
15. United Nations Environment Programme (2021). Beating the Heat: A Sustainable Cooling Handbook for Cities. Nairobi. https://www.unep.org/resources/report/beating-heat-sustainable-cooling-handbook-cities
16. World Meteorological Organization. (2019). *The Global Climate in 2015–2019*. Geneva: WMO
17. US Department of Commerce, N. O. A. A. *Weather related fatality and injury statistics*. National Weather Service. Retrieved November 8, 2021, from https://www.weather.gov/hazstat/.
18. Hifumi, T., Kondo, Y., Shimizu, K., & Miyake, Y. (2018). Heat stroke. *Journal of Intensive Care*, *6*(1). https://doi.org/10.1186/s40560-018-0298-4
19. Global Heat Health Information Network. (2020, November 2). *Heat & Health*. Global Heat Health Information Network. Retrieved November 9, 2021, from https://ghhin.org/heat-and-health/.
20. Province of British Columbia. (2021, July 30). *Heat-related deaths in B.C.* Province of British Columbia. Retrieved November 9, 2021, from https://www2.gov.bc.ca/gov/content/life-events/death/coroners-service/news-and-updates/heat-related.
21. Washington State Department of Health. (2021, August 24). *Heat wave 2021*. Washington State Department of Health. Retrieved November 9, 2021, from https://www.doh.wa.gov/Emergencies/BePreparedBeSafe/SevereWeatherandNaturalDisasters/HotWeatherSafety/HeatWave2021.
22. Popovich, N., & Choi-Schagrin, W. (2021, August 11). Hidden Toll of the Northwest Heatwave: Hundreds of Extra Deaths. *The New York Times*. Retrieved November 9, 2021, from https://www.nytimes.com/interactive/2021/08/11/climate/deaths-pacific-northwest-heat-wave.html.
23. National Oceanic and Atmospheric Administration. (2021, August 13). *It's official: July was Earth's hottest month on record*. It's official: July was Earth's hottest month on record | National Oceanic and Atmospheric Administration. Retrieved November 9, 2021, from https://www.noaa.gov/news/its-official-july-2021-was-earths-hottest-month-on-record.
24. National Oceanic and Atmospheric Administration. (2021, September 13). *Summer 2021 neck and neck with Dust Bowl summer for hottest on record*. Summer 2021 neck and neck with Dust Bowl summer for hottest on record | National Oceanic and Atmospheric Administration. Retrieved November 9, 2021, from https://www.noaa.gov/news/summer-2021-neck-and-neck-with-dust-bowl-summer-for-hottest-on-record.
25. Henson, B. (2021, September 12). *The hottest summer most Americans have ever lived through " Yale climate connections*. Yale Climate Connections. Retrieved November 9, 2021, from https://yaleclimateconnections.org/2021/09/the-hottest-summer-most-americans-have-ever-lived-through/.
26. Adrienne Arsht-Rockefeller Foundation Resilience Center, Atlantic Council. (2021). *#ArshtRockatCOP: A conversation with the first-ever chief heat officers*. Retrieved November 10,

2021, from https://www.atlanticcouncil.org/event/arshtrockatcop-a-conversation-with-the-first-ever-chief-heat-officers/.

27. Sustainable Energy for All (SEforALL). *Tracking global access to cooling in 2021*. Tracking Global Access to Cooling in 2021. Retrieved November 15, 2021, from https://www.seforall.org/chilling-prospects-2021/global-access-to-cooling.
28. Sustainable Energy for All (SEforALL). *Global access to cooling: Regional trends*. Global Access to Cooling: Regional Trends. Retrieved November 15, 2021, from https://www.seforall.org/chilling-prospects-2021/global-access-to-cooling/regional-trends.
29. IEA, *Total CO2 emissions, World 1990-2019*, IEA, Paris. https://www.iea.org/data-and-statistics/data-browser?country=WORLD&fuel=CO2%20emissions&indicator=TotCO2
30. Akbari, H., Menon, S., & Rosenfeld, A. (2008). Global cooling: Increasing world-wide urban albedos to offset CO2. *Climatic Change*, *94*(3-4), 275–286. https://doi.org/10.1007/s10584-008-9515-9
31. Zhao, Q., Guo, Y., Ye, T., Gasparrini, A., Tong, S., Overcenco, A., Urban, A., Schneider, A., Entezari, A., Vicedo-Cabrera, A. M., Zanobetti, A., Analitis, A., Zeka, A., Tobias, A., Nunes, B., Alahmad, B., Armstrong, B., Forsberg, B., Pan, S.-C., … Li, S. (2021). Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: A three-stage modelling study. *The Lancet Planetary Health*, *5*(7). https://doi.org/10.1016/s2542-5196(21)00081-4
32. Center for Disaster Philanthropy. (2020, December 1). *2020 Atlantic Hurricane Season*. Disasterphilanthropy.org. Retrieved November 15, 2021, from https://disasterphilanthropy.org/disaster/2020-atlantic-hurricane-season/.
33. Feyen, L., Ciscar Martinez, J., Gosling, S., Ibarreta Ruiz, D., Soria Ramirez, A., Dosio, A., Naumann, G., Russo, S., Formetta, G., Forzieri, G., Girardello, M., Spinoni, J., Mentaschi, L., Bisselink, B., Bernhard, J., Gelati, E., Adamovic, M., Guenther, S., De Roo, A., Cammalleri, C., Dottori, F., Bianchi, A., Alfieri, L., Vousdoukas, M., Mongelli, I., Hinkel, J., Ward, P., Gomes Da Costa, H., De Rigo, D., Liberta`, G., Durrant, T., San-Miguel-Ayanz, J., Barredo Cano, J., Mauri, A., Caudullo, G., Ceccherini, G., Beck, P., Cescatti, A., Hristov, J., Toreti, A., Perez Dominguez, I., Dentener, F., Fellmann, T., Elleby, C., Ceglar, A., Fumagalli, D., Niemeyer, S., Cerrani, I., Panarello, L., Bratu, M., Després, J., Szewczyk, W., Matei, N., Mulholland, E. and Olariaga-Guardiola, M., Climate change impacts and adaptation in Europe, EUR 30180 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-18123-1, doi:10.2760/171121, JRC119178
34. World Health Organization. (2018, June 1). *Heat and health*. World Health Organization. Retrieved November 18, 2021, from https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health.
35. Kim, J., Lee, A., & Rossin-Slater, M. (2021). What to expect when it gets hotter: The impacts of prenatal exposure to extreme temperature on maternal health. *American Journal of Health Economics*, *7*(3), 281–305. https://doi.org/10.1086/714359
36. Kim, J., Lee, A., & Rossin-Slater, M. (2019). What to expect when it gets hotter: The impacts of prenatal exposure to extreme heat on maternal health. *IZA– Institute of Labor Economics*. https://doi.org/10.3386/w26384
37. Rupa Basu, Brian Malig, Bart Ostro, High Ambient Temperature and the Risk of Preterm Delivery, *American Journal of Epidemiology*, Volume 172, Issue 10, 15 November 2010, Pages 1108-1117, https://doi.org/10.1093/aje/kwq170

38. Brimicombe, C., Porter, J. J., Di Napoli, C., Pappenberger, F., Cornforth, R., Petty, C., & Cloke, H. L. (2021). Heatwaves: An invisible risk in UK policy and Research. *Environmental Science & Policy*, *116*, 1–7. https://doi.org/10.1016/j.envsci.2020.10.021
39. Anderson, M., & McMinn, S. (2019, September 3). *As Rising heat bakes U.S. cities, the poor often feel it most*. NPR. Retrieved November 18, 2021, from https://www.npr.org/2019/09/03/754044732/as-rising-heat-bakes-u-s-cities-the-poor-often-feel-it-most.
40. U.S. Energy Information Administration – EIA. (2015). *One in three U.S. households faced challenges in paying energy bills in 2015*. Residential Energy Consumption Survey (RECS). Retrieved November 18, 2021, from https://www.eia.gov/consumption/residential/reports/2015/energybills/.
41. Human Rights Watch. (2020, October). *Increasing Temperatures Because of the Climate Change Crisis is a Reproductive Justice Issue in the United States*. Human Rights Watch. Retrieved November 18, 2021, from https://www.hrw.org/sites/default/files/media_2020/10/climatecrisis-reproductivejustice-US_1020_web.pdf.
42. Anderson, M. (2020, January 14). *Racist housing practices from the 1930s linked to hotter neighborhoods today*. NPR. Retrieved November 18, 2021, from https://www.npr.org/2020/01/14/795961381/racist-housing-practices-from-the-1930s-linked-to-hotter-neighborhoods-today.
43. Román-Palacios, C., & Wiens, J. J. (2020). Recent responses to climate change reveal the drivers of species extinction and survival. *Proceedings of the National Academy of Sciences*, *117*(8), 4211–4217. https://doi.org/10.1073/pnas.1913007117
44. Ruthrof, K. X., Breshears, D. D., Fontaine, J. B., Froend, R. H., Matusick, G., Kala, J., Miller, B. P., Mitchell, P. J., Wilson, S. K., van Keulen, M., Enright, N. J., Law, D. J., Wernberg, T., & Hardy, G. E. (2018). Subcontinental heat wave triggers terrestrial and marine, multi-taxa responses. *Scientific Reports*, *8*(1). https://doi.org/10.1038/s41598-018-31236-5
45. Park, R.J., Behrer, A.P. & Goodman, J. Learning is inhibited by heat exposure, both internationally and within the United States. *Nat Hum Behav* **5,** 19–27 (2021). https://doi.org/10.1038/s41562-020-00959-9
46. Fischels, J. (2021, August 9). *Dixie, bootleg, Goose. how wildfires get their name*. NPR. Retrieved December 16, 2021, from https://www.npr.org/2021/08/09/1026136978/dixie-bootleg-goose-how-wildfires-get-their-name
47. Hobday, A., Oliver, E., Sen Gupta, A., Benthuysen, J., Burrows, M., Donat, M., Holbrook, N., Moore, P., Thomsen, M., Wernberg, T., & Smale, D. (2018). Categorizing and naming Marine Heatwaves. *Oceanography*, *31*(2), 162–173. https://doi.org/10.5670/oceanog.2018.205
48. Ward, B. (2020, April 17). *Is it time to start naming deadly heatwaves?* Grantham Research Institute on climate change and the environment. Retrieved December 17, 2021, from https://www.lse.ac.uk/granthaminstitute/news/is-it-time-to-start-naming-deadly-heatwaves/
49. Ward, B. (2020, April 17). *Met Office should name Heatwaves to convey their dangers*. Grantham Research Institute on climate change and the environment. Retrieved December 17, 2021, from https://www.lse.ac.uk/granthaminstitute/news/met-office-should-name-heatwaves-to-convey-their-dangers/
50. Knapton, S. (2019, July 23). *Give heatwaves names so people take them more seriously, say experts, as Britain braces for Hottest Day*. The Telegraph. Retrieved December 17, 2021, from

https://www.telegraph.co.uk/news/2019/07/23/heatwaves-deadly-should-named-like-storms-say-experts-britain/?utm_source=pocket_mylist

51. Carr, S. (2021, November 14). *Heatwaves could be named as Met Office looks to use same tactic for storms to grab public attention*. Daily Mail Online. Retrieved December 17, 2021, from https://www.dailymail.co.uk/news/article-10200307/Heatwaves-NAMED-Met-Office-looks-use-tactic-storms-grab-public-attention.html
52. Kotroni, V., Lagouvardos, K., Bezes, A., Dafis, S., Galanaki, E., Giannaros, C., Giannaros, T., Karagiannidis, A., Koletsis, I., Kopania, T., Papagiannaki, K., Papavasileiou, G., Vafeiadis, V., & Vougioulas, E. (2021). Storm naming in the Eastern Mediterranean: Procedures, Events Review and impact on the Citizens Risk Perception and Readiness. *Atmosphere*, *12*(11), 1537. https://doi.org/10.3390/atmos12111537
53. Lin, X., Rainear, A. M., Spence, P. R., & Lachlan, K. A. (2018). Don't sleep on it: An examination of storm naming and potential heuristic effects on Twitter. *Weather, Climate, and Society*, *10*(4), 769–779. https://doi.org/10.1175/wcas-d-18-0008.1
54. Rainear, A. M., Lachlan, K. A., & Lin, C. A. (2017). What's in a #name? an experimental study examining perceived credibility and impact of winter storm names. *Weather, Climate, and Society*, *9*(4), 815–822. https://doi.org/10.1175/wcas-d-16-0037.1
55. *Global Warming of 1.5°C: An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*. IPCC — Intergovernmental Panel on Climate Change, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf.
56. "Using Trees and Vegetation to Reduce Heat Islands." *EPA*, Environmental Protection Agency, https://www.epa.gov/heatislands/using-trees-and-vegetation-reduce-heat-islands.
57. Bernstein, A. S., Sun, S., Weinberger, K. R., Spangler, K. R., Sheffield, P. E., & Wellenius, G. A. (2022). Warm season and emergency department visits to U.S. children's hospitals. *Environmental Health Perspectives*, *130*(1). https://doi.org/10.1289/ehp8083
58. Sun, S., Weinberger, K. R., Nori-Sarma, A., Spangler, K. R., Sun, Y., Dominici, F., & Wellenius, G. A. (2021). Ambient heat and risks of emergency department visits among adults in the United States: Time stratified case crossover study. *BMJ*. https://doi.org/10.1136/bmj-2021-065653
59. Strathearn, M., Osborne, N.J. & Selvey, L.A. Impact of low-intensity heat events on mortality and morbidity in regions with hot, humid summers: a scoping literature review. *Int J Biometeorol* (2022). https://doi.org/10.1007/s00484-022-02243-z
60. Egondi T, Kyobutungi C, Kovats S, Muindi K, Ettarh R, Rocklöv J. Time-series analysis of weather and mortality patterns in Nairobi's informal settlements. Glob Health Action. 2012 Nov 23;5:23-32. doi: 10.3402/gha.v5i0.19065.PMID: 23195509; PMCID: PMC3509073.
61. Bangladesh Red Crescent Society (BDRCS), German Red Cross (GRC), The International Federation of Red Cross and Red Crescent Societies (IFRC), Red Cross Red Crescent Climate Centre (RCCC), & Bangladesh Meteorological Department (BMD). (2021, September 9). *Feasibility Study on Heatwave in Dhaka*. PrepareCenter. Retrieved February 10, 2022, from https://www.anticipation-hub.org/Documents/Feasibility_Study/Feasibility_Study_on_Heatwave_in_Dhaka.pdf
62. IPCC, 2022: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O.

Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press.

63. Watkins, G. (2021, August 16). *Latin America and the Caribbean has an opportunity to avert climate catastrophe*. Inter-American Development Bank. Retrieved March 28, 2022, from https://blogs.iadb.org/sostenibilidad/en/latin-america-and-the-caribbean-has-an-opportunity-to-avert-climate-catastrophe/#:~:text=What%20does%20this%20mean%20for%20our%20region%3F
64. Goering, L. (2020, October 5). *As cities bake on a warming planet, insurers cook up heatwave cover*. Reuters. Retrieved March 29, 2022, from https://www.reuters.com/article/us-heatwave-insurance-climatechange-anal/as-cities-bake-on-a-warming-planet-insurers-cook-up-heatwave-cover-idUSKBN26Q02Y
65. Comberg, E. (2019, July 19). *Philly's heat warning system saved 45 lives last year*. Philadelphia Magazine. https://www.phillymag.com/2019/07/19/heat-warning-system/
66. Spivey, B. (2019, June 11). *What happens when the city declares a heat health emergency: Department of Public Health*. City of Philadelphia. https://www.phila.gov/2019-06-11-what-happens-when-the-city-declares-a-heat-health-emergency/
67. EPA. *Urban Heat Island Basics*. Reducing Urban Heat Islands: Compendium of Strategies. https://19january2021snapshot.epa.gov/sites/static/files/2017-05/documents/reducing_urban_heat_islands_ch_1.pdf
68. Office of Climate Change and Health Equity, NOAA, NIHHIS. *2022 climate and health outlook: Extreme heat*. NOAA. https://www.hhs.gov/sites/default/files/climate-health-outlook-may-2022.pdf
69. Richards, M., Huang, M., Strickland, M.J., Newman, A.J., Warren, J.L., D'Souza, R., Chang, H.H., Darrow, L.A. (2022, June 16). Acute association between heatwaves and stillbirth in six US states. *Environmental Health,* 21(59). https://doi.org/10.1186/s12940-022-00870-y.
70. Bont, J.D., Stafoggia, M., Nakstad, B., Hajat, S., Kovats, S., Part, C., Chersich, M., Luchters, S., Filippi, V., Stephansson, O., Ljungman, P., & Roos, N. (2022). Associations between ambient temperature and risk of preterm birth in Sweden: A comparison of analytical approaches. *Environmental Research*, 213(113586), https://doi.org/10.1016/j.envres.2022.113586.
71. Son, J.Y., Choi, H. M., Miranda, M. L., & Bell, M. L. (2022). Exposure to heat during pregnancy and preterm birth in North Carolina: Main effect and disparities by residential greenness, urbanicity, and socioeconomic status. *Environmental Research*, 204(112315). https://doi.org/10.1016/j.envres.2021.112315.
72. Ward, A., Clark, J., McLeod, J., Woodul, R., Moser, H., & Konrad, C. (2019). The impact of heat exposure on reduced gestational age in pregnant women in North Carolina, 2011–2015. *International Journal of Biometeorology*. https://doi.org/10.1007/s00484-019-01773-3
73. Duff-Brown, B. (2019, October 21). *Global Warming and Extreme Heat Harming Pregnant Women.* Stanford Freeman Spogli Institute for International Studies. Retrieved on July 07, 2022 from https://fsi.stanford.edu/news/global-warming-and-extreme-heat-hurting-pregnant-women.
74. Blom, S., Ortiz-Bobea, A., Hoddinott, J. Heat exposure and child nutrition: Evidence from West Africa. (2022, June). *Journal of Environmental Economics and Management*, 102698. https://doi.org/10.1016/j.jeem.2022.102698
75. Steen, Y.V., Ntarladima, A.M., Grobbee, R., Karssenberg, D., & Vaartjes, I. (2018). Sex differences in mortality after heat waves: Are elderly women at higher risk? International Archives of Occupational and Environmental Health, 92(1), 37–48. https://doi.org/10.1007/s00420-018-1360-1.

76. Wilhelmi, O. V., Howe, P. D., Hayden, M. H., & O'Lenick, C. R. (2021). Compounding hazards and intersecting vulnerabilities: Experiences and responses to extreme heat during COVID-19. Environmental Research Letters, 16(8), 084060. https://doi.org/10.1088/1748-9326/ac1760.
77. Azhar, G.S. (2017, August 28). *As heat rises, women risk death in South Asia.* Thomson Reuters Foundation News. Retrieved on July 07, 2022, https://news.trust.org/item/20170828140743-4pv87
78. Hsu, A., Sheriff, G., Chakraborty, T., Manya, D. (2021, May 25). Disproportionate exposure to urban heat island intensity across major US cities. *Nature Communications,* 12(2721). https://doi.org/10.1038/s41467-021-22799-5
79. Hoffman, J.S., Shandas, V., Pendleton, N. (2020, January 13). The Effects of Historical Housing Policies on Resident Exposure to Intra-Urban Heat: A Study of 108 US Urban Areas. *Climate,* 8(20), https://doi.org/10.3390/cli8010012
80. Ndugga, N. & Aritga, S. (2021, September 08). *Extreme Heat and Racial Health.* Kaiser Family Foundation. Retrieved July 06, 2022 from https://www.kff.org/policy-watch/extreme-heat-racial-health-equity/
81. Abualsaud, R., Ostrovskiy, G., & Mahfoud, Z.R., (2019, January 11) Ethnicity-Based Inequality in Heat-Related Illness on the Rise in California. *Wilderness & Environmental Medicine,* 30(1). https://doi.org/10.1016/j.wem.2018.10.001.
82. Greenfield, N. (2021, November 16). *When Extreme Heat Hits India's Slums, These Women Cool Things Down – And Save Lives.* Natural Resources Defense Council. Retrieved July 07, 2022 from https://www.nrdc.org/stories/when-extreme-heat-hits-indias-slums-these-women-cool-things-down-and-save-lives
83. Dahl, K., & Licker, R. (2021). *Too hot to work: Assessing the threats climate change poses to outdoor workers*. Union of Concerned Scientists. DOI: https://doi.org/10.47923/2021.14236
84. Munday, P., Amiot, M., & Sifon-Arevalo, R. (April 27, 2022). ESG Research Report. *Weather warning: Assessing countries' vulnerability to economic losses from physical climate risks.* https://www.spglobal.com/_assets/documents/ratings/research/101529900.pdf
85. Jarzabkowski, P., K. Chalkias, D. Clarke, E. Iyahen, D. Stadtmueller & A. Zwick. (2019). *Insurance for climate adaptation: Opportunities and limitations.* Rotterdam and Washington, DC. Available online at www.gca.org. https://static1.squarespace.com/static/61542ee0a87a394f7bc17b3a/t/615f0119300af379b686bffb/1633616155359/Insurance%2Bfor%2Bclimate%2Badaptation_Opportunities%2Band%2BLimitations_Web.pdf
86. Jarzabkowski, P., K. Chalkias, E. Cacciatori, R. Bednarek, (2018*). Between state and market: Protection gap entities and catastrophic risk*. Cass Business School, City, University of London, 26th June 2018. https://www.bayes.city.ac.uk/__data/assets/pdf_file/0020/420257/PGE-Report-FINAL.pdf
87. Thom, M., Hougaard, C., Gray, J., Msulwa, B., Rinehart-Smit, K., de Waal, J. (2019). *Insurance for inclusive and sustainable growth: Imperatives for action from a four-country synthesis*. UK Department for International Development (DFID); the Centre for Disaster Protection; World Bank; Financial Sector Deepening Africa (FSD Africa); Cenfri. October, 2019.
88. Tall, A., Lynagh, S., Vecchi., C.B., Bardouille, P., Pino, F.P., Shabahat, E., Stenek, V., Stewart, F., Power, S., Paladines, C., Neves, P., & Kerr, L. (2021). *Enabling private investment in climate adaptation and resilience: Current status, barriers to investment and blueprint for action.* World

Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/35203 License: CC BY 3.0 IGO February, 2021.
89. Ballester, J., Quijal-Zamorano, M., Méndez Turrubiates, R.F. et al. Heat-related mortality in Europe during the summer of 2022. *Nat Med 29*, 1857–1866 (2023). https://doi.org/10.1038/s41591-023-02419-z
90. Romanello, M., Di Napoli, C., Drummond, P., Green, C., Kennard, H., Lampard, P., Scamman, D., Arnell, N., Ayeb-Karlsson, S., Ford, L. B., Belesova, K., Bowen, K., Cai, W., Callaghan, M., Campbell-Lendrum, D., Chambers, J., Van Daalen, K. R., Dalin, C., Dasandi, N., … Costello, A. (2022). The 2022 report of the Lancet Countdown on health and climate change: Health at the mercy of fossil fuels. *The Lancet, 400*(10363), 1619–1654. https://doi.org/10.1016/S0140-6736(22)01540-9
91. Adrienne Arsht-Rockefeller Foundation Resilience Center. (2023, July 26). The scorching divide: How extreme heat inflames gender inequalities in health and income. https://onebillionresilient.org/extreme-heat-inflames-gender-inequalities/
92. Baharav, Y., Nichols, L., Wahal, A., Gow, O., Shickman, K., Edwards, M., & Huffling, K. (2023). The Impact of Extreme Heat Exposure on Pregnant People and Neonates: A State of the Science Review. *Journal of Midwifery & Women's Health, 68*(3), 324–332. https://doi.org/10.1111/jmwh.13502
93. Turner, V. K., French, E. M., Dialesandro, J., Middel, A., M Hondula, D., Weiss, G. B., & Abdellati, H. (2022). How are cities planning for heat? Analysis of United States municipal plans. *Environmental Research Letters, 17*(6), 064054. https://doi.org/10.1088/1748-9326/ac73a9
94. Licker, R., Dahl, K., & Abatzoglou, J. T. (2022). Quantifying the impact of future extreme heat on the outdoor work sector in the United States. *Elementa: Science of the Anthropocene, 10*(1), 00048. https://doi.org/10.1525/elementa.2021.00048
95. McDonald, R., Kroeger, T., Boucher, T., Longzhu, R., Salem, J., Adams, S., et al. (2016). *Planting Healthy Air: A Global Analysis of the Role of Trees in Addressing Particulate Matter Pollution and Extreme Heat.* Arlington, VA: The Nature Conservancy.
96. Stone, B., Gronlund, C. J., Mallen, E., Hondula, D., O'Neill, M. S., Rajput, M., Grijalva, S., Lanza, K., Harlan, S., Larsen, L., Augenbroe, G., Krayenhoff, E. S., Broadbent, A., & Georgescu, M. (2023). How Blackouts during Heat Waves Amplify Mortality and Morbidity Risk. *Environmental Science & Technology, 57*(22), 8245–8255. https://doi.org/10.1021/acs.est.2c09588
97. Sustainable Energy for All. *Chilling Prospects: Global Access to Cooling Gaps 2023.* Retrieved from https://www.seforall.org/chilling-prospects-access-to-cooling-gaps-2023/summaryhttps://www.seforall.org/chilling-prospects-access-to-cooling-gaps-2023/summary.
98. UNICEF. (May 2023) *Protecting Children from Heat Stress: A Technical Note.* Health Environments for Health Children, UNICEF. Retrieved from https://www.unicef.org/documents/protecting-children-heat-stress-technical-note%C2%A0.
99. Copernicus Climate Change Service (C3S). (2023). *European State of the Climate 2022 Summary.* https://doi.org/10.24381/gvaf-h066
100. https://doi.org/10.24381/gvaf-h066World Meteorological Organization. (2023, July 31). *July 2023 is set to be the hottest month on record.* Retrieved from https://public.wmo.int/en/media/press-release/july-2023-set-be-hottest-month-record#:~:text=Published&text=Bonn%20and%20Geneva%2C%2027%2F07,the%20hottest%20month%20on%20record.