REVIEW ARTICLE

FOSSIL-FUEL POLLUTION AND CLIMATE CHANGE
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Climate Change, Extreme Heat, and Health

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Climate change has led to a rise of 1.1°C in mean global temperature since the Industrial Revolution, with projected increases of 2.5 to 2.9°C by the end of the century, in the absence of drastic reductions in greenhouse gas emissions[1] (see Fig. S1 in the Supplementary Appendix, available with the full text of this article at NEJM.org). The chance that the near-surface temperature will be more than 1.5°C above preindustrial levels for at least 1 year between 2023 and 2027 is 66%, with a 98% chance that it will exceed the temperature during the warmest year on record (2016) for at least 1 year during that period.[2] The Intergovernmental Panel on Climate Change (IPCC) concluded unequivocally that human activity, especially the combustion of fossil fuels, is responsible for overall warming of the atmosphere, land, and oceans; that changes in weather extremes driven by climate change are already observed; and that recent extreme heat events are attributable to climate change.[1,3-5]

The frequency, duration, and intensity of heat waves in the United States have increased in recent decades (Fig. 1). The annual number of heat waves is now twice that in the 1980s, and the heat wave season is more than 3 times as long as it was in the 1960s.[6] Although there is variation, overall heat extremes have increased in frequency and duration, whereas cold extremes have decreased.[7] Compound events, such as the co-occurrence of droughts or wildfires with heat waves, have become more common, and the increase in their frequency is expected to continue.[8-10]

A recent study showed that more than one third of heat-related deaths in the period from 1991 through 2018 across 43 countries, including the United States, were attributable to anthropogenic greenhouse gas emissions.[4] Investigations modeling health effects under scenarios characterized by varying degrees of warming predict devastating increases in heat-related mortality and morbidity, with regional variations.[11] A growing literature focuses on identifying policies to reduce risks and increase the resilience of communities to heat exposures, as well as identifying subpopulations at greatest risk.[12-14]

An understanding of the broad range of health effects of extreme heat exposure is critical in order to inform patient care and health care delivery, as well as broader strategies for mitigating and adapting to rising temperatures. Here we summarize the epidemiologic evidence on the health risks from heat, its disproportionate effects on vulnerable populations, and individual- and community-level approaches to providing protection against these risks.

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HEAT EXPOSURE AND HEALTH RISKS

Exposure to heat substantially affects human health, in both the short and long term. Heat also indirectly affects health through associated environmental effects (e.g., reductions in the quality and quantity of crops and the water supply and an

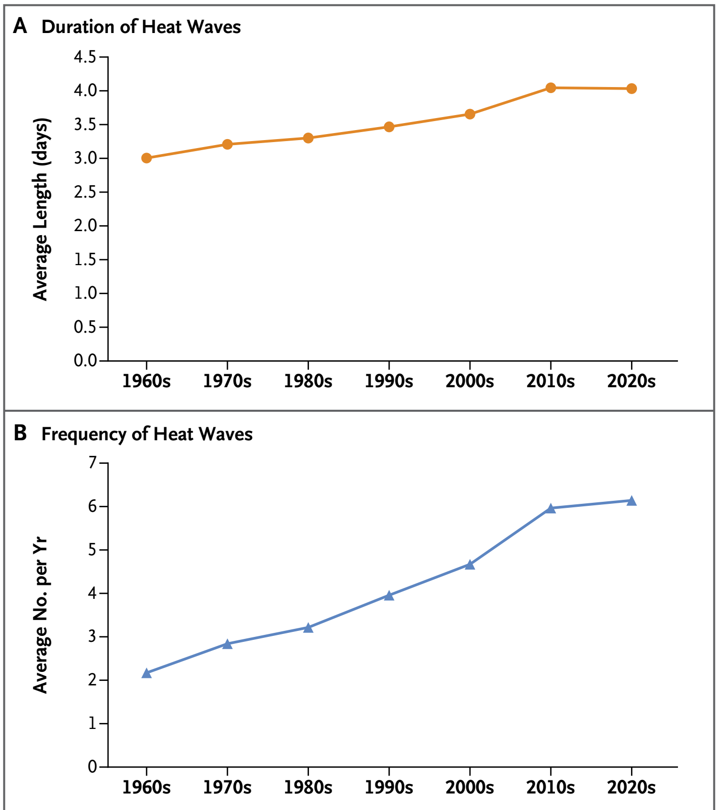

Figure 1. Increase in the Frequency and Duration of Heat Waves over Time in the United States.

Duration and frequency data are based on an analysis of 50 metropolitan areas in the United States. Years included in the 2020s are 2020 and 2021. Data are from the Environmental Protection Agency.

increase in ground-level ozone). The greatest effect of heat on health occurs with extreme heat exposure, but the effects of temperatures that exceed historical norms are also well recognized.

Acute heat-related illnesses have been covered in detail in the *Journal* previously[15] and are mentioned only briefly here. These include heat rash (itchy or painful small blisters, papules, or pustules resulting from blocked eccrine sweat glands), heat cramps (painful involuntary muscle contractions resulting from sweating-induced dehydration and electrolyte imbalances), heat edema, heat syncope (generally associated with prolonged standing or a change to a standing position in hot temperatures and attributed in part to dehydration), heat exhaustion, and heat stroke. Heat exhaustion is typically manifested as fatigue, weakness, dizziness, headache, heavy sweating, muscle cramps, and rapid pulse; the core body temperature may be elevated, but mental status is normal. Heat stroke, in contrast, involves an alteration in central nervous system functioning in association with a core body temperature exceeding 40°C and can progress to multiorgan failure and death.

However, these acute illnesses — along with acute heat effects such as sunburn and severe burns from contact with hot surfaces — represent only a fraction of the overall health burden attributable to heat. Substantial epidemiologic evidence links both extended periods of extreme temperatures (i.e., heat waves) and single days of high temperature with a broad range of adverse health outcomes. Table 1 summarizes key categories of health conditions associated with high temperatures, which are based on large studies, systematic reviews, and meta-analyses reflecting overall effects. The risks of illness and death from cardiovascular events (acute myocardial infarction, arrhythmias, exacerbations of congestive heart failure, and stroke),[16,17] respiratory conditions (e.g., asthma and chronic obstructive pulmonary disease),[19,20] and kidney disease[18] increase with elevated temperatures. The risks are greater with exposure to fine particulate air pollution. Extreme heat is also linked to an increased risk of adverse pregnancy outcomes, including preterm births, stillbirths, low birth weight, and congenital heart defects.[23] Moreover, heat exposure has been linked to increased anxiety and depression, increased suicidality, and aggressive behavior and violence.[21,22]

Associations between extreme heat exposure and increases in emergency room visits and hospitalizations for these and other conditions are well documented. For example, in one large study involving adults across the United States, days in the 95th percentile of local warm-season temperatures were associated with a 7.8% increase in the relative risk of an emergency department visit for any cause (translating to 24 excess visits per 100,000 persons at risk per day), with significant increases in visits for heat-related illness, renal disease, and mental health disorders.[24] An analysis of approximately 50 million summertime hospitalizations showed increased rates of admission (including all-cause admissions and those attributed to coronary vascular disease, respiratory disease, diabetes, fluid and electrolyte disorders, and renal failure) with increases in the daily maximum heat index across

Table 1. Health Conditions Associated with Extreme Heat.*

Category of Health Condition	Representative Conditions Affected by Heat	Examples of Findings
CVD	Acute coronary syndrome with or without myocardial infarction, stroke, congestive heart failure, arrhythmia	A meta-analysis of 60 studies showed that the relative risk of death from CVD was 1.12 (95% CI, 1.09 to 1.14) with heat wave days vs. non–heat wave days; a 1°C increase in temperature was associated with a 21% increase (95% CI, 20 to 23) in the risk of death from CVD; heat-related CVD risks were higher for low-to-middle-income countries.[16] A meta-analysis of 4 studies showed that the relative risk of death from myocardial infarction was 1.64 (95% CI, 1.09 to 2.47) with heat wave days vs. non–heat wave days.[17] A meta-analysis of 13 studies showed that a 1°C increase in temperature was associated with a 16% increase (95% CI, 4 to 28) in the risk of hospital admission for myocardial infarction.[17]
Kidney disease	Acute renal failure, nephrolithiasis, electrolyte abnormalities, rhabdomyolysis with renal insufficiency or failure, urinary tract infections	A meta-analysis of 4 studies showed a relative risk of death from kidney disease of 1.03 (95% CI, 1.02 to 1.04) for a 1°C increase in temperature.[18] A meta-analysis of 32 studies showed that a 1°C increase in temperature was associated with an 11% increase (95% CI, 9 to 13) in kidney failure.[18]
Respiratory disease	Acute respiratory distress, asthma and COPD exacerbations, pulmonary hypertension, increased respiratory infections, pulmonary edema	An epidemiologic analysis of 452 locations in 24 countries showed that respiratory mortality was increased by a factor of 1.34 (95% CI, 1.22 to 1.47) for the 99th percentile warm-season temperature vs. MMT.[19,20]
Mental disorder	Anxiety, symptoms in people with bipolar disorder or depression, suicide attempts, suicide completion, aggressive behavior, mental fatigue	A meta-analysis of 12 studies showed that a 1°C increase in temperature was associated with a 22% increase (95% CI, 15 to 20) in the risk of mental health–related death.[21] An epidemiologic analysis of 341 locations in 12 countries showed that the risk of suicide increased by 33% (95% CI, 30 to 36) with the 93rd percentile of temperature vs. the 1st percentile (the temperatures with the maximum and minimum suicide risks, respectively).[22]
Adverse birth outcomes	Preterm birth, low birth weight, stillbirth, congenital heart defects	A meta-analysis of 6 studies showed that a 1°C increase in temperature increased the risk of preterm birth by 5% (95% CI, 3 to 7); the risk of preterm birth was 16% (95% CI, 20 to 23) higher on heat wave days vs. non–heat wave days.[23] A meta-analysis of 8 studies showed that a 1°C increase in temperature was associated with a 5% (95% CI, 1 to 8) increase in the risk of stillbirth.[23]

* The list of health effects from heat is not comprehensive. CI denotes confidence interval, COPD chronic obstructive pulmonary disease, CVD cardiovascular disease, and MMT minimum mortality temperature (i.e., the temperature associated with the lowest mortality).

regions of the United States.[25] Mortality also increases with heat and heat waves. High temperatures, including multiple heat waves, in Europe between late May and early September 2022 were estimated to account for 61,672 heat-related deaths (95% confidence interval, 37,643 to 86,807).[26]

EPIDEMIOLOGIC DATA LINKING HEAT AND HEALTH OUTCOMES

Traditionally, epidemiologic analyses of heat were based on time-series analyses performed with data aggregated over large areas (e.g., a city) or individual-level investigations using a case-crossover design.[27] More advanced analyses include small-area assessments with finely disaggregated data or individual-level analyses of data from large, population-based cohorts.[28,29] Exposures are often assessed as heat waves (defined by the National Oceanic and Atmospheric Administration as 2 or more continuous days of high heat, outside historical averages for a given area but variably defined across studies) or temperature (e.g., maximum daily temperature or heat index [temperature adjusted for humidity]). Studies have been enhanced by advancements in statistical techniques that allow for the study of complex nonlinear and lagged risk associations.[30]

An important consideration is the possibility of "displacement," with adverse health events after heat exposure occurring mostly in frail people who would have experienced these events soon even without the exposure. A study assessing longer lag times showed evidence of mortality displacement by as much as 30 days[31] but still showed significant risks that were not explained by displacement.[31] Studies assessing long-term effects of heat, using seasonal or multiyear temperature averages, have confirmed the increased risks.[12,32]

Deviations of temperature from historical norms substantially affect the ability to physiologically tolerate and adapt to heat.[33,34] Both a high absolute temperature (e.g., 37°C) and a high relative temperature (e.g., a temperature in the 99th percentile based on historical temperature) drive excess mortality in heat waves. Days that are hot can be harmful even without extreme temperature levels, as evidenced by studies on temperature[35] and temperature variability.[36] A given temperature can have different health effects, depending on the degree of adaptation to that temperature (e.g., when the temperature occurs in a region where that degree of heat is rare or when it occurs earlier or later in the season than historically experienced).[37] Analyses relating heat levels to hospitalizations have shown that the heat index threshold above which the risk of hospitalization increases varies across regions. In colder regions, hospitalization rates increase at heat index levels below those at which heat alerts are issued.[25] Some studies suggest that humidity may affect the relationship between temperature and mortality, although the findings are inconsistent.[38-40]

Even with air conditioning and other factors playing a role in acclimation,[13,41,42] we are approaching the physiological and societal limits of adaptation.[43-46] Tipping points include the capacity of the existing power infrastructure to withstand demands for cooling over prolonged periods and the costs of expanding the infrastructure to meet those demands. This is particularly important when heat waves encompass large areas, as recently experienced. Increases in "heat domes," due to the trapping of hot air over large areas by high pressure aloft, have caused elevated temperatures and heat waves in many regions in recent years. Increasingly prevalent water shortages resulting from prolonged periods of extreme heat — for example, those that have occurred in the southwestern United States — pose additional challenges for the provision of adequate cooling and hydration.

Temperature-related health risks are highly heterogeneous across locations and populations. Large multicountry analyses have identified striking differences in heat risks across the world.[30,47] There is evidence of substantial acclimatization. Temperatures associated with increased health risks are higher in warmer regions, and the risks are attenuated in proportion to average historical temperature patterns.[48] In some countries but not others, the risks associated with extreme heat have decreased markedly over recent decades.[49] This risk reduction is only partly explained by the increased prevalence of air conditioning.[41]

HIGH-RISK POPULATIONS

Both susceptibility, referring to internal factors, and vulnerability, referring to external factors, modify the effects of heat on health. Being a member of a marginalized racial or ethnic group or having low socioeconomic status is a key factor affecting risk (discussed below), but several other factors also increase the risk of adverse health effects, including social isolation, extremes of age, coexisting conditions, and medications.[41,50-53] Patients with cardiac, cerebrovascular, respiratory, or renal disease, those with diabetes mellitus, and those with dementia are at increased risk for heat-related conditions, as are patients taking medications such as diuretics, antihypertensive drugs, other cardiovascular medications, some psychotropic agents, and antihistamines.[54,55] Older persons, whose thermoregulatory systems are often compromised, are more likely than younger persons to have underlying conditions, use medications that interfere with heat dissipation, have mobility issues that may compromise access to hydration or cooling, or live in older housing without air conditioning or windows that readily open.[56]

DISPARITIES ACCORDING TO RACE OR ETHNIC GROUP AND SOCIOECONOMIC STATUS

Communities where members of marginalized racial and ethnic groups and low-income populations live are at particularly high risk for heat-related illness. Disparities in health effects from heat are not fully explained by socioeconomic status or availability of air conditioning.[57,58] These disparities are related to complex, interconnected social, economic, and cultural systems, both current and historical, including structural racism. A notable example is redlining, a discriminatory practice introduced in the 1930s that limited or disallowed mortgages in certain areas, especially communities where many members of racial and ethnic minorities lived.[59] Historically redlined communities, which continue to be characterized by disproportionate numbers of low-income persons and members of marginalized racial or ethnic groups, tend to have more impervious surfaces and less green space than other areas, which results in higher ambient temperatures (i.e., "urban heat islands").[60,61] Low-income urban communities can be as much as 5°C hotter than wealthier communities.[62] The lack of green space also makes it difficult to find relief from extreme heat.

Research suggests that the effects of heat on health differ in relation to many factors of the built environment, such as socioeconomic patterns, amount of green space, and degree of air pollution.[13,53] Heat exposure is also affected by the capacity of individuals and communities to respond to heat, such as the ability to afford and use air conditioning, install cooling roofs, or gain access to cooler environments. Communities of persons from marginalized racial or ethnic groups and low-income communities have increased risks of adverse health outcomes at given ambient temperatures, owing to these and other factors, including more limited access to care,[41,57,63] more frequent occupational exposures (e.g., employment in factories without air conditioning[64] or outdoor labor), and a higher incidence of chronic medical conditions, such as hypertension, diabetes mellitus, and kidney disease.[18,65]

INDIVIDUAL- AND POPULATION-LEVEL INTERVENTIONS

In addition to mitigating climate change by rapidly transitioning away from fossil fuels, there are many protective or adaptive measures that can reduce the burden of illness due heat exposure. Individual protective measures during heat waves include limiting exposure; wearing loose-fitting, light-colored clothing; ensuring adequate hydration; applying sunscreen; and using cooling devices (Fig. 2).[15] Some interventions have negative consequences, such as air conditioning, which is often powered by fossil fuels and releases greenhouse gas emissions and other air pollutants. Health professionals can play an important role by providing their patients with information about preventing or mitigating heat exposure as a component of comprehensive health education. This is especially important for patients at high risk for adverse effects of heat exposure.[15]

A range of population-based interventions can mitigate risks during high temperatures, especially heat waves, including broad public education regarding health risks and strategies for risk reduction.[66] Public health and professional medical organizations have critical roles in educating communities and policymakers about the health dangers of heat and appropriate protective measures. Because of differences in community characteristics (e.g., housing conditions)

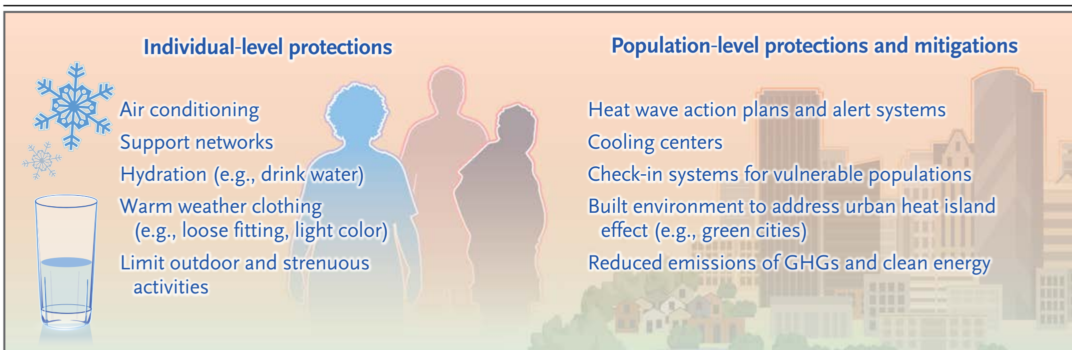

Figure 2. Protective Measures for Heat.
The listed measures are examples; the lists are not exhaustive. GHGs denotes greenhouse gases.

Table 2. Community Interventions That May Reduce Health Effects from Heat.*

Intervention	Description	Examples of Effects
Education[66,67]	Public awareness programs can encourage individual-level actions (e.g., wearing loose-fitting, light-colored clothing and ensuring adequate hydration) to minimize harm from heat.	Heat-related illnesses decreased in at-risk workers after implementation of a heat stress awareness program comprising training, acclimatization, and medical monitoring.[67]
Heat alerts and heat action plans[68-73]	Heat action plans, which can be used for a predicted heat wave or a single day of high temperature, can include heat monitoring systems; predictions of conditions on future days; mobilization of public health, medical, social work, and community organizations; and surveillance.	After implementation of heat action plans in Montreal in 2004, there were an estimated 2.5 (95% CI, −0.3 to 5.4) fewer deaths per hot day, with significant reductions in differences in death rates between older and younger persons and between low- and high-SES neighborhoods.[72]
Cooling centers[74]	A temporary cool space, typically air-conditioned, can provide relief and shelter during extreme heat events; cooling centers can be established in libraries, public housing, parks, community pools, businesses, shopping centers, or other spaces.	A laboratory-based analysis simulating heat conditions and cooling centers showed that participants in the cooling group had a 0.8°C lower core temperature than the control group, although such differences between the groups were not sustained when they returned to heat conditions.[74] A simulation showed that brief exposure to air conditioning limited psychological strain in older adults.[74]
Health checks	Checking in on people at risk can aid early identification of heat-related illness.	Excess heat wave–related mortality was significantly lower in 3 areas of Rome where a program was instituted to reduce social isolation among persons >80 years of age (e.g., phone calls, with home visits as needed) than in areas where this program was not instituted.[75]
Green infrastructure[76,77]	Green infrastructure (e.g., green roofs, green playgrounds, and increased vegetation near roadways) can reduce temperature and address urban heat islands; vegetation can also sequester carbon.	By 2100, under a high GHG emissions scenario, greening could mitigate land warming by 0.71°C, with 83% of the effect driven by carbon sequestration.[77] In New York City, the most vegetated areas were 2°C cooler than the least vegetated areas.[76]
Reflective surfaces	Cool (white) roofs, cool pavements, and other changes affecting surface albedo can lower local temperature.	A United Kingdom regional modeling study estimated that cool roofs could reduce city-center mean daytime temperatures during heat waves by 0.5°C and reduce associated heat wave–related mortality by approximately 25%; installing cool roofs on commercial or industrial buildings was projected to have the greatest benefit.[78]

* Included are interventions for which there are some data supporting a benefit. However, studies of many of these interventions have yielded inconsistent results, and further study of targeted interventions is needed. These interventions are not distinct (e.g., cooling centers and health checks can be part of a heat action plan). The listed effects are descriptive examples and are not comprehensive. GHG denotes greenhouse gas, and SES socioeconomic status.

and in how populations respond to heat, public health policies regarding heat exposure should be tailored to local conditions. Table 2 provides examples of public health strategies for which some supporting evidence exists, including location-specific heat alerts during periods of high heat and humidity; location-specific action plans, such as accessible cooling centers and health checks (especially for socially isolated persons)[66-78]; programs for preidentification of high-risk populations requiring special services during heat waves, such as medical or physical assistance owing to housing conditions or reduced mobility; and infrastructure changes that can reduce temperatures (e.g., use of reflective surfaces on buildings and roads and an increase in trees and other greenery). However, the available data have limitations, including the respective uncertainties from the reliance on observational data, modeling, or simulation and inconsistencies in results across studies.

Adaptive measures should account for compound events, such as simultaneous exposure to extreme heat and high air pollution, drought, and other conditions.[8-10] Collaboration and coordination of multiple systems and organizations, including medical centers, public health agencies, government agencies, and community organizations, are needed to most effectively protect the public from heat.

FUTURE NEEDS AND DIRECTIONS

Further study is warranted to understand the benefits of individual- and community-level interventions for heat, many of which have independent benefits (often called "co-benefits"), such as increased physical activity and improved mental health and social cohesion from parks and other green space. Enhanced standard reporting of heat-related injury and death is needed, including *International Classification of Diseases* (ICD) codes that reflect a recognition of the indirect effects of heat on health, not just the direct effects (i.e., health effects other than those with "heat" in the ICD code). Currently, a generally accepted definition of a heat-related death does not exist. A clear and accurate accounting of heat-related disorders and deaths will aid communities and policymakers in prioritizing programs to address heat-related health burdens. In addition, longitudinal cohort studies are needed to better ascertain differential effects of heat on health according to population characteristics and temporal trends in adaptation across regions and populations.

Multisectoral research is needed to better understand direct and indirect health consequences of a warmer world and to identify effective strategies for improving resilience (e.g., in water and sanitation systems, energy, transportation, agriculture, and urban planning).[79] Particular attention should be paid to the development of effective strategies for adaptation among those at highest risk (e.g., communities of color, low-income populations, and persons at the intersection of at-risk groups).

CONCLUSIONS

Climate change is increasing overall temperatures and the frequency, duration, and intensity of heat waves, resulting in multiple adverse health outcomes. The effects are inequitable, with some individuals and communities disproportionately affected. Intervention strategies and policies targeted to location and population are needed to minimize these diverse health effects.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

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