

The Potential Impacts of Climate Variability and Change on Temperature-Related Morbidity and Mortality in the United States

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Heat and heat waves are projected to increase in severity and frequency with increasing global mean temperatures. Studies in urban areas show an association between increases in mortality and increases in heat, measured by maximum or minimum temperature, heat index, and sometimes, other weather conditions. Health effects associated with exposure to extreme and prolonged heat appear to be related to environmental temperatures above those to which the population is accustomed. Models of weather–mortality relationships indicate that populations in northeastern and midwestern U.S. cities are likely to experience the greatest number of illnesses and deaths in response to changes in summer temperature. Physiologic and behavioral adaptations may reduce morbidity and mortality. Within heat-sensitive regions, urban populations are the most vulnerable to adverse heat-related health outcomes. The elderly, young children, the poor, and people who are bedridden or are on certain medications are at particular risk. Heat-related illnesses and deaths are largely preventable through behavioral adaptations, including the use of air conditioning and increased fluid intake. Overall death rates are higher in winter than in summer, and it is possible that milder winters could reduce deaths in winter months. However, the relationship between winter weather and mortality is difficult to interpret. Other adaptation measures include heat emergency plans, warning systems, and illness management plans. Research is needed to identify critical weather parameters, the associations between heat and nonfatal illnesses, the evaluation of implemented heat response plans, and the effectiveness of urban design in reducing heat retention. *Key words:* climate change, cold weather, global warming, heat waves. — *Environ Health Perspect* 109(suppl 2):185–189 (2001). <http://ehpnet1.niehs.nih.gov/docs/2001/suppl-2/185-189mcgeehin/abstract.html>

The relationship between human health and stressful weather is a complex medical, social, and environmental issue (Figure 1). Future-climate scenarios suggest that higher global mean temperatures could result in marked changes in the frequency of temperature extremes (1). Software developed by the National Oceanic and Atmospheric Administration (2) can be used to estimate changes in the probability that a given extreme temperature will occur for a specified duration under a defined climate scenario.

Heat-Related Health Risks

Heat waves are sporadic but recurrent. Elevated temperatures during summer months are associated with excess morbidity and mortality. Conservative estimates are that, on average, 240 heat-related deaths occur annually in the United States; in a 1980 heat wave, there were 1,700 deaths (3). Following a 5-day heat wave in 1995 in which maximum temperatures in Chicago, Illinois, ranged from 93 to 104°F, the number of deaths reported increased by 85%, and the number of hospital admissions increased by 11% compared with numbers recorded during the same period in the preceding year (4–6). During this period at least 700 excess deaths (i.e., deaths beyond those expected for that period in that population) in Chicago were recorded, most of which were directly attributed to heat (4–6).

Exposure to extreme and prolonged heat is associated with heat cramps, heat syncope (fainting), heat exhaustion, and heatstroke (7). The initial human physiologic response to heat entails increasing surface blood circulation, thereby promoting heat loss through radiation, convection, perspiration, and increased rates of evaporative cooling (8). The ability to respond to heat stress is limited by the capacity to increase the maximum cardiac output required for cutaneous blood flow. The cardiac output, in turn, is a function of maximal heart rate, intravascular volume, and sustainable renal and splanchnic vasoconstriction. Under mild heat stress, heat acclimatization can increase the body's tolerance to heat stress. However, under extreme or chronic heat stress, the body loses its ability to maintain temperature balance and death may occur.

The most common cause of death and the most acute illness directly attributable to heat is heatstroke, a condition characterized by a body temperature of 105.0°F (40.6°C) or higher and altered mental status (9). Other causes of death observed to increase following heat waves include ischemic heart disease, diabetes, stroke, respiratory diseases, accidents, violence, suicide, and homicide (10,11). Even when appropriate, medical examiners do not routinely record these causes of death as heat related.

As observed following a 1980 heat wave in Kansas City, Missouri, heatstroke victims showed few symptoms of illness prior to the onset of heat stroke (12). The onset of heatstroke occurs rapidly through progressively serious symptoms, including lethargy, confusion, disorientation, delirium, and coma (4,13). Survivors of heatstroke often experience persisting organ dysfunction that is predictive of 1-year mortality (i.e., death within 1 year of an event) (14). Heat stroke mortality and heat-related mortality from all causes appear to peak with a 1- to 2-day lag following high temperatures (6,15,16). One epidemiologic study of deaths during and following a heat wave indicated that a rise in the heat index (HI) is followed by an increase in the number of deaths due to heat (Figure 2) (6).

The impact of heat on morbidity is less certain than the heat–mortality association (17,18). A 5% increase in hospital admissions was observed during the 1980 heat wave in Kansas City (12). During periods of excessive heat, emergency rooms report an overall increase in visits, specifically for fainting, nausea, dizziness, and heat cramps (16,19). A detailed analysis of all inpatient hospital admissions during the 1995 heat wave in Chicago found that individuals with a wide range of underlying medical conditions were at increased risk for hospitalization. These underlying medical conditions included cardiovascular and respiratory diseases, diabetes, renal diseases, nervous system disorders,

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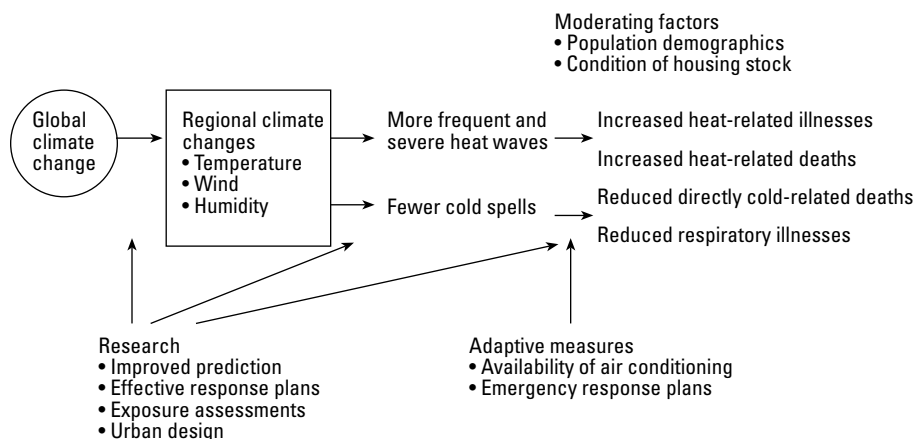


Figure 1. Projecting the influence of weather and climate change on temperature-related illnesses.

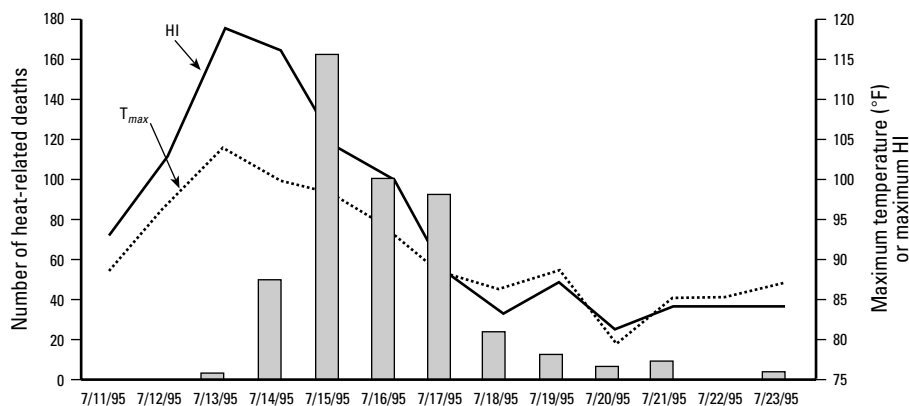


Figure 2. Relationship of HI to heat-related deaths, showing probable cause and effect and a lag time of approximately 2 days, Chicago, 11–23 July 1995. Data from the National Oceanic and Atmospheric Administration (47).

emphysema, and epilepsy (5,20). Increases in hospital visits for cardiovascular diseases (11,16) and increases in deaths due to cardiovascular and respiratory diseases (21) also have been documented during heat waves, suggesting that heat exacerbates these conditions. Dehydration and volume depletion limit the cardiovascular response necessary to increase the cutaneous circulation during heat stress. Consequently, patients with underlying diseases or the elderly may not have the physiologic capability to adequately respond to heat exposure.

Meteorologic Conditions and Associated Health Conditions

A scientific question currently being investigated pertains to the meteorologic air masses present during heat waves and how they can predict adverse effects. In a recent study Kalkstein and Greene (22) used a new air mass-based synoptic procedure to evaluate historical weather–mortality relationships and to illustrate how climate change scenarios might alter these relationships. Data from 44 large U.S. cities were analyzed for air masses identified in each city, and for each air mass the weather–mortality relationship was estimated.

Climate change scenarios were then applied to each weather–mortality relationship to estimate the potential changes in the relationship by 2020 and 2050. Using three unique models and accounting for possible acclimatization, Kalkstein and Greene concluded that, under the proposed climate scenarios, summer mortality will increase markedly, whereas winter mortality will decrease slightly.

Rates of morbidity and mortality due to heat-related illnesses can rise during and immediately after a heat wave. However, the magnitude of these health effects is difficult to predict and depends on a variety of factors such as suddenness of heat onset, city planning for heat emergencies, regional heat tolerance, heat duration, and macroclimate adaptability. The sudden onset and magnitude of a heat wave early in summer in a city with no prior experience with extreme weather conditions, and thus no detailed heat emergency plans, can pose serious health risks.

In the United States, there does not appear to be a single universal threshold temperature above which rates of heat-related morbidity and mortality rise sharply. Instead, tolerance of excess heat varies regionally according to the population and

its preparedness for heat and according to the local average temperatures and frequency of extreme temperatures (23). In temperate regions, severe but infrequent temperature fluctuations, such as very hot episodes during periods of generally milder weather conditions, are associated with increases in weather-related mortality. In tropical regions, summer temperatures are higher for a longer period of time and are less variable. As a result, elevated temperatures in these regions do not appear to have a significant impact on weather-related mortality.

Models of the weather–mortality relationship indicate that populations in northeastern and midwestern U.S. cities may experience the greatest number of heat-related illnesses and deaths in response to changes in summer temperature, and that the most sensitive regions are those where extremely high temperatures occur infrequently or irregularly (24), including Philadelphia, Pennsylvania (25); New York, New York (11); Chicago, Illinois (4); Milwaukee, Wisconsin (13); and St. Louis, Missouri (17), where past heat waves resulted in large numbers of heat-related deaths. In some heat waves, daily mortality levels are more than double baseline levels (26). The most severe conditions, resulting in the highest heat-related mortality rates, are often characterized by successive days of high temperatures coupled with high overnight temperatures (27). Furthermore, the duration of the heat, including overnight heat, and the microclimate of non-air-conditioned automobiles, apartments, and other dwellings appear particularly critical to the heat–mortality relationship (18).

Risk Factors for Heat-Related Illnesses

Major risk factors for heat-related morbidity and mortality include urban living, age, and socioeconomic factors, as well as preventive behaviors.

Urban Living

Urban living is an important risk factor. Populations residing on the top floor of apartment buildings (6,28), in urban areas (12), and without access to air-conditioned environments (6,28) experience higher rates of heat-related morbidity and mortality, suggesting that the living conditions of susceptible populations are important.

The “urban heat island effect” describes the elevated temperatures observed in urban areas. Observational studies indicate that the HI and heat-related mortality rates are higher in the urban core than in surrounding areas (29). Buechley et al. (30) attributed the elevation in heat-related deaths in urban areas to the high population density. Clarke suggested that urban areas retain heat throughout the

nighttime more efficiently than the outlying suburban and rural areas (31). The overnight heat may create a critical thermal stress (i.e., no nighttime relief from heat) to urban inhabitants, resulting in excessive heat-related deaths.

The importance of living environments in the weather–health relationship is supported by recent analyses (32,33). The findings of an analysis of hot weather-related mortality across the United States indicate that household conditions in urban and metropolitan areas, including central air conditioning and other indicators of housing quality, may have an important impact on heat-related health outcomes (32). During a heat wave in St. Louis, higher mortality rates were recorded predominantly in the business and urban core areas than in other, cooler sections of the city (33). According to the U.S. Bureau of the Census, 29% of the occupied housing units in the United States in 1995 were located in the central cities, 35% in the suburbs, 20% in nonmetropolitan areas, and 13% in rural areas (34,35). Jones et al. (12) examined mortality following a July 1980 heat wave and found that deaths from all causes increased by 57 and 64% in the major metropolitan areas of St. Louis and Kansas City, respectively, but only by 10% in predominantly rural areas in the remainder of Missouri.

Age

Another risk factor is age. Epidemiologic studies of heat-related morbidity and mortality during and following heat waves suggest that the elderly and young children are particularly vulnerable (9,12,36,37). Regardless of race or gender, individuals 65 years of age or older are more susceptible to the adverse effects of heat than are younger adults (5,9,27,38). The risk for heat-related death increases sharply with age, as those 85 years of age or older are most at risk for heat-related mortality (9). Like the elderly, young children are at high risk for heat-related illnesses (9). Young children with certain predisposing illnesses such as diarrhea, respiratory tract infections, and neurologic defects are at especially increased risk for hyperthermia during extreme heat (12). Both the very old and the very young tend to have reduced heat-regulating mechanisms (9). In addition, each of these populations experiences restricted mobility, resulting in diminished control of their environments, including access to fluids (9).

Socioeconomic Factors, Ethnicity, and Race

Other risk factors include poverty, social isolation, inadequate English language skills, residence in high-crime areas, certain medications associated with aging, and lack of access to media (such as television and newspapers),

and thus reduced awareness both of the potential dangers from heat exposure and of the ways to reduce risk. Populations uniquely vulnerable to the impacts of excessive heat exposure include the poor (16,39) and the socially isolated (6). Populations of lower socioeconomic status may not have access to air-conditioned places because of the cost of an air-conditioning unit or utility bills (6,16). Although opening windows and using fans for ventilation may help reduce stagnant and hot indoor air conditions, the effectiveness of electric fans in reducing the risk of heat-related mortality has not been substantiated (6). Individuals confined to bed or unable to care for themselves are at increased risk (6,28), whereas those living with others are at decreased risk and are more likely to increase their fluid intake during heat waves. Non-English-speaking or -reading populations, who exemplify the group of individuals lacking access to heat-relieving conditions, are quite vulnerable. Furthermore, because of neighborhood crime or violence, urban residents, including the elderly, report a reluctance to leave windows open (16,40). Finally, patients taking medications or drugs that modify thermoregulatory capacity are at increased risk also (28,41,42). The urban elderly experience the highest rates of heat-related morbidity and mortality because of both their declining thermoregulatory abilities and the extreme heat conditions in urban areas (16).

Data on the 1995 heat wave in Chicago indicate that mortality among African Americans was 50% higher than among whites (38). The disparity likely reflects residence in inner-city neighborhoods, poverty, housing conditions, and medical conditions (12,16,28). Similar findings emerged following heat waves in Texas (36), Memphis, Tennessee (16), St. Louis, and Kansas City (12).

Current Protections

Air Conditioning

Air conditioning is often recommended and used to mitigate many of the factors that increase the risk of heat-related illness and death (3,4,13). Over 70% of residences in the United States are now equipped with air conditioning: 46% are equipped with central air conditioning, and 27% are equipped with room air-conditioning units. The proportion of housing units with central and/or room air conditioning varies regionally and ranges from 27% in the Northeast to 88% in the South. In central cities the proportion of residences with air conditioning is nearly identical to that of residences in the entire United States; 71% reported air conditioning equipment (34,35). The use of air-conditioning systems in homes, workplaces, and vehicles has increased steadily

over the past 30 years and is projected to become nearly universally available in the United States by 2050 (34,35).

Behavioral Changes

Peer-reviewed literature contains extensive evidence that heat-related illnesses are largely preventable through behavioral adaptations, including the use of air conditioning (3) and increased fluid intake (28) in high-risk populations, although the magnitude of mortality reduction cannot be predicted.

Community-Wide Planning and Warning Systems

For decades, investigators have asserted the benefits of community-wide heat emergency plans (4,14,43,44), improved heat warning systems (11,45), and better management plans for heat-related illnesses (11,46). The ability to adapt to chronic heat stress may hinge upon development of these systems, rather than on changes in thermoregulatory functions. Adaptation and, ultimately, prevention of increases in heat-related morbidity and mortality may be determined by the ability to caution and educate populations and to prepare for heat emergencies, taking into account risk factors (e.g., medications, age, or residence location) and populations at risk (e.g., elderly, young, or chronically ill).

Future Adaptations

Heat Emergency Response Plans

Chicago, St. Louis, and several other U.S. cities maintain comprehensive heat emergency response plans involving key components: *a*) preparations prior to the onset of excessive heat, *b*) meteorology-based warning systems, *c*) rapid and coordinated actions during the heat wave, *d*) criteria and procedures for deactivating the plan, and *e*) evaluation following the response activities and outcomes. Preparations include strategies to encourage organizations participating in the heat response activities to review their emergency plans, update a database of at-risk individuals and populations, ensure the availability of resources, and activate record-keeping procedures at all affected agencies. Following the 1995 Chicago heat wave, existing state and community intervention strategies were identified. Assessment of these strategies resulted in the recommendation that a model response plan involving multiple and diverse agencies be developed and disseminated (47). A comprehensive response plan should use information on risk factors with meteorologic variables, prevention strategies, and outcome measurements to monitor and attenuate the impact of excessive heat. This proactive approach to reducing heat-related morbidity and mortality appears

to be an effective government-sponsored adaptation to extreme heat that might serve as a model for other communities.

Use of Risk Factors

Extensive epidemiologic research into the risk factors associated with heat-related mortality demonstrates that the relationship between health and temperature is multifactorial. Future use of risk factors to identify the most vulnerable populations is an important strategy to avoid heat-related mortality.

Environmental and Behavioral Measures

Because some degree of projected elevation in worldwide temperatures over the next several decades cannot be prevented, environmental and behavioral changes may be the most effective means of reducing the severe impact of heat. Monitoring the hydration status of the elderly, very young, and medically at-risk populations may indicate when these populations are in danger of dehydration and other, more severe, heat-related illnesses. Organized programs to check on the elderly are frequently arranged by community, volunteer, and religious organizations. Visiting the elderly who live alone or who are socially isolated ensures that they are aware of the dangers of extreme heat and are taking sufficient precautionary measures. Opening air-conditioned shopping malls, community centers and recreation facilities, and extending the hours of public swimming pools increase the availability of cool environments. Providing transportation to the facilities may be necessary to ensure that the isolated and at-risk populations use these environments. These and other measures, such as limiting strenuous activities during peak daytime hours and increasing fluid intake, exemplify environmental and behavioral measures likely to be effective in reducing the impact of heat in high-risk populations (5,6).

Cold Weather Mortality

An increase in mean global temperatures could result not only in warmer average summer temperatures but also in slightly warmer average winter temperatures. Overall mortality is generally higher in winter than in summer, but there is little convincing evidence that weather patterns are solely responsible. The adverse health effects of cold weather include direct effects, such as hypothermia, and indirect effects, such as increased rates of pneumonia, influenza, and other respiratory illnesses (22). Cold weather-related deaths directly attributable to cold exposure are prevalent in northern and mountainous regions of the United States, but they also occur in the milder climates of the Southern States (48). Hypothermia deaths are reported

to have occurred on days with minimum temperatures above 32°F (0°C). Often, alcohol and drug use contribute to hypothermia deaths (48). The impact of an increase in global mean temperature on cold temperature-related morbidity and mortality has not been quantified; however, because hypothermia deaths occur even in Southern States and at temperatures above freezing, a significant reduction in mortality from the direct effects of cold seems unlikely.

Colder regions of the United States experience more frequent cold spells, lower temperatures, and higher levels of snowfall. The lower temperature and/or higher snowfall is often followed by an increased number of deaths due to ischemic heart disease, cerebrovascular disease, and respiratory disease (49). These indirect effects of cold temperature appear to be more severe when accompanied by strong winds (50).

An increase in average winter temperatures could result in a reduction in deaths during winter months, particularly in areas with relatively colder climates. However, many winter-time deaths are due to infectious diseases such as influenza and pneumonia (51). If increases in worldwide mean temperatures encourage people to spend more time outdoors or to increase indoor ventilation, infectious disease transmission may be reduced. European studies indicate an association between mortality and cold temperature, controlling for influenza. This finding suggests that influenza contributes to, but does not fully explain, the association between winter temperature and mortality (50,52).

An analysis of weather and mortality data in 44 U.S. cities found a weak association between winter weather and mortality (22). The authors used models to estimate climate change for 2020 and 2050 and concluded that winter mortality will decrease slightly but will not offset the larger projected increases in summer mortality. Additional research is needed to understand the relationship between temperature and the predominant causes of death in winter.

Research Needs and Data Gaps

More information is needed about which weather parameters are important in the relationship between weather and health. Maximum temperature, minimum temperature, relative humidity, HI, and duration of exposure are currently used to estimate exposure to heat. Further research into determining the importance of each of these factors will improve estimation of the relationship between heat and health and facilitate precautionary measures as the thresholds of the key parameters are reached.

More information is also needed about the association between heat and morbidity.

Most susceptible are patients with certain chronic medical conditions, such as cardiovascular and cerebrovascular diseases, diabetes, respiratory and renal diseases, Parkinson's disease, Alzheimer's disease, and epilepsy (5,20). These conditions predispose patients to dehydration, heat exhaustion, and heat stroke. Increased awareness among healthcare providers that individuals with these conditions are at higher risk allows for guided intervention. The effectiveness of such tailored prevention efforts should be closely monitored. Surveillance of morbidity during the onset of extreme heat may assist in identifying other susceptible populations. Rydman et al. (19) proposed using computerized data from emergency departments to analyze hospital admissions in real time. However, whether this information can be used to predict heat-related morbidity and mortality has been questioned (53).

Individuals who lack social networks pose a particular challenge for prevention efforts (6). The feasibility and effectiveness of specialized health education efforts aimed at reaching these populations should be evaluated.

To improve the comparability of data collected during and following periods of extreme heat, methods of recording heat-related health outcomes should be standardized. After the 1995 heat wave in Chicago, the Centers for Disease Control and Prevention (3) recommended the use of uniform criteria for the diagnosis of heat-related deaths. Since that recommendation, Donoghue et al. (54) published diagnostic guidelines and criteria for use by medical examiners.

Extensive epidemiologic research of risk factors for heat-related morbidity and mortality offers numerous possibilities for the development of effective interventions. In many cities and regions of the United States, interventions have been established to attenuate health impacts of heat; few, if any, of these interventions have been used during a heat wave or evaluated following their use. Evaluation of existing and implemented heat response plans could determine the cost-effectiveness and health impact of these plans, as well as highlight areas where improvements are necessary.

To assist the efforts of municipalities in their heat wave response plans, we need a greater understanding of the importance of urban design to heat. Although some types of buildings (e.g., brownstones, tall apartment buildings) retain heat efficiently, other urban characteristics (e.g., tree cover and light-colored roofs) may facilitate wind, shade, and other heat-relieving conditions. Research and subsequent incorporation of these infrastructure characteristics into urban areas may contribute to a reduction of the urban heat island effect and its associated health effects.

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