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Preventing cold-related morbidity and mortality in a changing climate

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Abstract

Winter weather patterns are anticipated to become more variable with increasing average global temperatures. Research shows that excess morbidity and mortality occurs during cold weather periods. We critically reviewed evidence relating temperature variability, health outcomes, and adaptation strategies to cold weather. Health outcomes included cardiovascular-, respiratory-, cerebrovascular-, and all-cause morbidity and mortality. Individual and contextual risk factors were assessed to highlight associations between individual- and neighborhood- level characteristics that contribute to a person's vulnerability to variability in cold weather events. Epidemiologic studies indicate that the populations most vulnerable to variations in cold winter weather are the elderly, rural and, generally, populations living in moderate winter climates. Fortunately, cold-related morbidity and mortality are preventable and strategies exist for protecting populations from these adverse health outcomes. We present a range of adaptation strategies that can be implemented at the individual, building, and neighborhood level to protect vulnerable populations from cold-related morbidity and mortality. The existing research justifies the need for increased outreach to individuals and communities for education on protective adaptations in cold weather. We propose that future climate change adaptation research couple building energy and thermal comfort models with epidemiological data to evaluate and quantify the impacts of adaptation strategies.

Keywords

cold weather; health effects; temperature; adaptation; vulnerability; winter

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1. Introduction

Many studies have provided evidence that morbidity and mortality increase in periods of cold weather. Overall, higher death rates are observed in winter compared to summer (1–3), which may be attributable in part to colder winter temperatures, in addition to higher rates of infectious disease (influenza), and higher air pollution. While cold-related morbidity and mortality do not increase dramatically during extreme cold weather events, as commonly seen during extreme heat events, cold remains a relevant concern for exposed populations. Understanding the complex and multi-factorial relationship between weather and health is increasingly important as climate models indicate that seasonal weather patterns and conditions will continue to vary from current climate conditions as average global temperatures increase.

This article presents an overview of climate models and winter storms, human physiologic responses to cold environments, epidemiologic studies of cold weather and health outcomes, and cold weather adaptation strategies for individuals, communities, and healthcare providers and policymakers. We discuss research needed to better understand and prevent cold weather health impacts, especially in the growing aging population.

2. Climate models and winter storms

Although it may seem counterintuitive, given the overall increasing trend in global temperature, climate change is expected to contribute to an increase in the intensity of winter storms. Climate scientists hypothesize that as average global temperatures increase, evaporation from Earth's surface will increase, adding moisture to the atmosphere and resulting in greater amounts of precipitation. In addition, wind speeds associated with winter storms are expected to increase (4). These factors increase personal-level exposure to low temperatures through skin wetting and increased heat loss, but may also disrupt energy distribution for heating residential and commercial buildings (5) (6).

General circulation models, such as those cited by the Intergovernmental Panel on Climate Change (IPCC) 2007 Assessment Report, build on knowledge of behavior of winter storms in current climate conditions to simulate winter storm behavior when climate conditions include higher concentrations of greenhouse gases (7) (8). Those models have indicated a trend towards more intense winter storms in the Northern Hemisphere, particularly in northwestern Europe and the Upper Midwest and Northeast of the U.S. (4, 9).

3. Physiologic response to cold stress

Exposure to cold temperatures has long been a challenge for human survival. An individual's ability to thermoregulate protects him or her from ambient temperatures by maintaining a core body temperature of about 37°C (98.6°F). Exposure to cold temperatures and impairment of thermoregulation can lead to decreased core temperatures, direct effects such as hypothermia (core temperature below 35°C), and indirect effects such as frostbite, pneumonia, and influenza.

Exposure to cold temperatures initiates a systemic response. First, vasoconstriction occurs in the skin of the extremities to conserve body heat by driving oxygenated blood to support vital organs in the core. As cooling continues and heat is lost in the periphery via radiation, the temperature gradient between the core and the periphery increases, redistributing heat to the periphery and reducing core temperatures. Muscle contractions, shivering, increased heart rates (tachycardia), and rapid breathing (tachypnea) occur, in an effort to generate heat (10–12). Bronchoconstriction also occurs after inhalation of cold air.

Cardiac and cerebrovascular functions are most critically impaired as body temperatures fall below 35°C. Both physical and mental impairment are symptoms of exposure to severe cold (13, 14). Cardiac irritability (e.g., cardiac arrhythmias, ventricular fibrillation, cardiac arrest) and cerebral insults (e.g., reduced cerebral blood flow and oxygen consumption) (12, 15, 16) occur after prolonged exposure to cold. Extreme cold conditions will eventually cause the cardiovascular system to shut down. Loss of consciousness, amnesic episodes, and ischemic stroke occur as a result of decreased oxygen to the brain in extreme cold environments.

Initial respiratory responses to cold weather are an increase in depth and respiration rate (hyperventilation), followed by decrease in respiration (hypoventilation); the respiration rate becomes shallow and erratic between core body temperatures of 25–30°C (12, 16).

Although most people exposed to cold weather will not experience hypothermia or an extreme decrease in body temperature, skin exposure to cold weather may render one susceptible to adverse health outcomes (16). The cooling process can occur within a few minutes in extreme cases (e.g., submersion in cold water) or develop over several weeks (e.g., result of living in substandard conditions). People are regularly exposed to cold temperatures during daily behaviors such as commuting to work and outdoor activities. Whether the cooling experience is acute or chronic, people must protect themselves via physiological and behavioral adaptations.

4. The epidemiology of cold-related morbidity and mortality

4.1. Exposure metrics

Investigations of the relationship between human health and cold weather use a variety of metrics to characterize ambient temperature including daily mean temperature (14, 17), daily maximum temperatures (18), temperatures lower than the 5th percentile (19), combined temperature and relative and/or absolute humidity (20–22), cold surges (23), indoor and outdoor temperatures (14) and a combination of measurements such as temperature, snow and rain precipitation (24). One study concludes that different measures of temperature have roughly the same predictive ability for health outcomes (25), suggesting that measurement types should be determined based on availability and completeness. Often, measurements of temperature and other meteorological parameters used in health studies come from outdoor monitors (e.g., airport monitors) that take hourly readings; the exposures are typically assumed to apply to individuals living in the communities surrounding the monitoring station.

4.2. Cold-related health outcomes

Temperature-related mortality typically demonstrates a U-shaped response, in which mortality rates are highest at the colder and hotter extremes of the spectrum. All-cause mortality is associated with a decrease in ambient temperature (14, 18, 26, 27). The effects of cold temperatures on mortality can last for days, with the greatest association sometimes observed on the same day (28), and lasting up to 24 days after the cold weather. Air pollution (29, 30) can modify the effect of cold weather with increasing associations between cold and mortality with higher pollution.

Cardiovascular-cause mortality is the most commonly identified health outcome associated with cold weather (14, 15, 17, 24, 30–34) and is generally observed shortly after cold weather events. Cold temperatures are associated with increases in blood pressure, cholesterol, fibrinogen and erythrocyte counts (35), which are risk factors for cardiovascular diseases such as myocardial infarction. Cardiovascular diseases account for about 50% of deaths in developed nations, indicating that many people are at risk for cardiovascular events, and, in particular, may be more susceptible to cold weather.

Mortality occurring at the longest lags after a cold wave are associated with respiratory illness (36). Infectious diseases such as pneumonia and influenza are more common in the winter season and also contribute to cold-weather deaths (37–39). Respiratory tract infections are more likely to occur during periods of low temperatures and low humidity (20). Low temperatures can result in bronchoconstriction and suppress immune system responses, which make one more susceptible to respiratory insult (14). Incidence of stroke and cerebrovascular-related deaths is higher in winter than other seasons, possibly due to low ambient temperatures leading to increased blood pressure (13).

While cold-related deaths have been investigated extensively, publications on cold-related morbidity are less common. Recent findings indicate a short-term cold effect on stroke-related hospitalization up to one week after cold weather (40). Additionally, excess winter respiratory morbidity was observed in an older London population. These associations accounted for contextual characteristics, such as housing energy ratings, housing type and fuel poverty, highlighting the relevance of indoor environments to health (41).

4.3. Vulnerability

Both individual and contextual risk factors contribute to a person's susceptibility to cold weather. Elderly populations are considered particularly vulnerable to cold weather as a person's ability to thermoregulate can become impaired with age. Underlying diseases, such as diabetes, and medications can modify blood pressure, circulation, perspiration rates, and some mental capacities such as warmth perception, thus complicating people's ability to identify when they are experiencing cold. Several reports show that counts of excess winter mortality are higher in people over age 65 living in colder climates (1, 42, 43). Women living in colder climates and over age 65 have a higher risk of death than their male counterparts (14, 44, 45). Again, however, the relationship is not consistent; other evidence reports that younger populations (below age 65) have a higher risk of cardiovascular-cause mortality in cold weather (46).

Geographic location strongly contributes to cold weather vulnerability. The effects of exposure vary across and within cities, regions and countries. Research conducted in cities in Europe (18, 19, 22, 36), the United States (43, 47) Brazil (30), Taiwan (48, 49), and Korea (32), reports excess mortality during cold weather periods, highlighting the global relevance of cold weather exposure. Cities with mild winter climates see higher all-cause and cause-specific excess mortality associated with increases in cold (14, 17, 24, 43), suggesting that relative changes in temperature may be a better indicator of mortality than absolute temperatures. City size is also an important marker of vulnerability, as associations between cold and all- and cardiovascular-cause mortality were higher in smaller, rural communities than in larger metropolitan areas (19, 48, 50). Tolerance to cold weather events may be higher in larger communities due to retention of heat in the built environment, which may create urban heat islands that buffer people's exposure to variability in winter temperatures.

Socioeconomic indicators related to morbidity and mortality do not appear to strongly contribute to a person's susceptibility to cold weather (45). However, the role of socioeconomic status is not clear as some evidence implies that income disparities and fuel poverty contribute to cold-related mortality (51). It has been postulated that consistent and regular exposures to cold weather have a protective effect by enhancing a person's resilience (adaptation) to these exposures (27). Yet, some evidence suggests that vulnerability to cold weather has decreased in recent years (3), indicating that a combination of biological or behavioral adaptations is needed for preventing mortality related to cold weather.

5. Adaptation

The Synthesis Report following the IPCC's Fourth Assessment Report concluded that:

> *Responding to climate change involves an iterative risk management process that includes both adaptation and mitigation and takes into account actual and avoided climate change damages, co-benefits, sustainability, equity and attitudes to risk.* (8)

Comprehensive, iterative approaches for protecting human health in a changing environment are increasingly necessary. Adaptation to climate change can have multifaceted benefits and involve strategies that also aid in mitigation of greenhouse gas emissions. Based on the IPCC's definition of a no regrets policy and their definition of resilience, we propose cold weather adaptation measures at the personal, building, and neighborhood scales (Table 1). A no-regrets strategy is a climate adaptation strategy that will generate social and/or economic benefits whether or not climate change occurs (8). A resilient strategy is a climate adaptation strategy that allows a system to absorb disturbances while maintaining its structure and function. (8)

5.1. Individual-level adaptation strategies

Temperature variability poses a threat to human health because humans do not quickly acclimate to weather. Taking protective measures against variable weather is imperative. Layering and selecting appropriate clothing are simple, yet effective ways for the body to conserve heat (10). People living in areas with a warmer wintertime climate were less likely to wear a hat, gloves, an insulated jacket and pants (e.g., women preferred skirts) than populations living in areas with colder winter temperatures (14), leaving them more susceptible to heat loss.

Cold temperatures are often associated with inclement weather that can bring snow and ice. Increased physical activity (e.g., snow shoveling) and decreased immune function contribute to excess morbidity and mortality. Yet, inactivity outdoors during the winter months could cause a reduced tolerance to cold, supporting the notion that some outdoor exercise in cold weather is protective but excess activity is harmful (14). Alcohol and drug use often contribute to deaths due to hypothermia (52) as these substances increase vasoconstriction on the skin, resulting in *feeling* warm, but a reduction in core temperature.

5.2. Built environment adaptation strategies

In the climate change literature, adaptation programs and strategies are described which may have a significant protective influence on human health (8). Adaptive capacity, the ability of a system to adapt to a stress while limiting adverse outcomes, is commonly discussed in both the climate change literature and for describing thermal comfort in indoor environments (53). Notions of how best to combine energy efficiency and human comfort are shifting away from the idea that an indoor environment is a static environment in which temperatures are to be maintained at a constant level through the use of mechanical systems. Building science is increasingly acknowledging the occupant's role in combining strategies such as increased clothing with lower thermostat settings. This shift means that elements of a dwelling unit must permit individual unit heating control and operable manual systems, such as windows that open easily and close tightly. (54)

Buildings that use energy produced from fossil fuel combustion contribute to increasing atmospheric greenhouse gas concentrations. Wilkinson et al (55) discuss the benefits to both the environment and public health through engaging in future planning, construction and building use that are energy efficient. Weatherization programs generally retrofit existing housing stock with energy efficient measures that can improve the health and safety of occupants, reduce energy usage and greenhouse gas emissions, and can translate into significant annual savings. These measures include adding attic and wall insulation, window repairs, pipe insulation, and weather stripping. An assessment of 1,350 households in New Zealand determined that, “insulating existing houses led to a significantly warmer, drier indoor environment and resulted in improved self-rated health, self reported wheezing, days off school and work, and visits to general practitioners as well as a trend for fewer hospital admissions for respiratory conditions” (56). Internal temperatures and structural characteristics of residential and occupational dwellings contribute to a person’s exposure to cold temperatures (41), highlighting areas of focus for adaptation strategies.

5.3. Community engagement

Although the benefits of weatherization seem evident, challenges exist in encouraging participation in retrofit programs, particularly due to concerns about increased maintenance and usage costs (57). Education and outreach to homeowners, building managers, and others can address these concerns and highlight the long-term financial and health benefits.

Local governments and officials can implement programs and strategies to protect residents from cold weather variability. Figure 1 presents this dynamic process. Establishing community cohesion by working closely with local residents, policy makers, and emergency planners, for example, will present adaptation as a community concern with broad impacts, increasingly the likelihood that individuals will participate and support efforts (58, 59). Identifying the most vulnerable building types, neighborhoods, and populations can help target local weatherization efforts. Educational outreach by health care providers and policy makers can encourage vulnerable people to protect themselves adequately. Such strategies could include encouraging use of proper clothing, discouraging use of combustion devices for indoor heating (ovens, hibachis) that can create build up of carbon monoxide indoors, and providing guidance on safe outdoor activity during cold weather.

6. Conclusion

In spite of an overall trend toward increasing global temperatures, climate models forecast more variable weather, which can result in important cold-related health consequences for humans. Increases in winter weather variability have been associated with excess morbidity and mortality across various populations and geographic locations. Innovative use of environmental, epidemiologic, and built environment data can inform and help prepare for health care support during specific weather patterns, especially in the growing aging population. Coupling archived climatologic data with health outcome data has aided researchers (40) in predicting mortality rates. Further epidemiologic studies that incorporate archived climatological and environmental data in an effort to model specific health outcomes in vulnerable populations would advance preparedness strategies.

Adaptation to cold, as well as other climate change related health hazards, can take place through strategies implemented at various scales. Weatherization activities can reduce energy use, and, consequently energy costs and harmful greenhouse gas emissions. However, the co-benefits of adaptation strategies, such as weatherization, have been scarcely investigated in terms of human health. Research that incorporates manipulations of indoor/building environments, energy usage, and human thermal comfort thresholds may validate adaptation strategies that accommodate variation in a changing climate.

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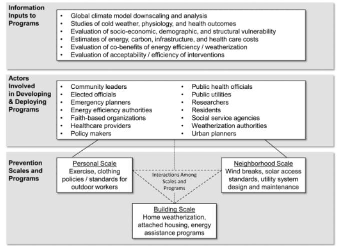

Figure 1.

Contribution of Information and Actors at Prevention and Program Scales for Adaptation Strategies to Cold Weather.

Table 1

Example Adaptation Strategies to Cold Weather at the Individual, Building and Urban Infrastructure Scales based on IPCC "No Regrets Policy" and "Resilience"

	No-Regrets	**Resilience**
Personal Scale	Exercise - improved circulation, increased tolerance to cold.	Clothing policies/standards for outdoor workers
Building Scale	Home weatherization, e.g. increased insulation, reduced infiltration, better windows -produces energy efficiency and carbon reductions in addition to wintertime temperature increases; thermal comfort benefits may also occur in summer Multifamily (attached) housing-reduced heat loss per housing unit	Sidewalk and driveway plowing programs, home energy assistance programs for low Income households, underground energy distribution systems, ice dam resistant construction
Neighborhood Scale	Increased coniferous tree planting in high wind areas, solar envelope standards for passive solar heating District heating and cooling systems to prevent heating/cooling system outages due to local power failure	Undergrounded utilities to prevent ice/storm damage to substations and transmission/ distribution Systems Warming centers