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Climate change and temperature extremes: a review of heat- and cold-related morbidity and mortality concerns of municipalities

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Abstract

Cold and hot weather are associated with mortality and morbidity. Although the burden of temperature-associated mortality may shift towards high temperatures in the future, cold temperatures may represent a greater current-day problem in temperate cities. Hot and cold temperature vulnerabilities may coincide across several personal and neighborhood characteristics, suggesting opportunities for increasing present and future resilience to extreme temperatures. We present a narrative literature review encompassing the epidemiology of cold- and heat-related mortality and morbidity, related physiologic and environmental mechanisms, and municipal responses for hot and cold weather, illustrated by Detroit, Michigan, USA, a financially-burdened city in an economically diverse metropolitan area. The Detroit area experiences sharp increases in mortality and hospitalizations with extreme heat, while cold temperatures are associated with more gradual increases in mortality, with no clear threshold. Interventions, such as heating and cooling centers, may reduce but not eliminate temperature-associated health problems. Furthermore, direct hemodynamic responses to cold, sudden exertion, indoor air quality and respiratory epidemics likely contribute to cold-related mortality. Short- and long-term interventions to enhance energy and housing security and housing quality may reduce temperature-related health problems. Extreme temperatures can increase morbidity and mortality in municipalities like Detroit that experience both extreme heat and prolonged cold seasons amidst large socioeconomic disparities. The similarities in physiological and built environment vulnerabilities to both hot and cold weather suggest prioritization of strategies that address both present-day cold and near-future heat concerns.

Keywords

climate change; weather; adaptation; housing; neighborhoods

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1. Introduction

Cold and hot weather are associated with distinct patterns of mortality and morbidity, particularly among older individuals, and can create municipal-level health burdens, which may be exacerbated by climate change. Evidence-based guidance to help city and state planners develop synergistic interventions to reduce temperature-related health effects is needed. Vulnerability to heat- and cold- morbidity and mortality has been reviewed elsewhere.[1–3] Our narrative literature review builds on this information by highlighting commonalities between heat- and cold-related vulnerabilities and co-beneficial interventions. We focus on vulnerabilities specific to Detroit, Michigan, USA and the tri-county region (Wayne, Oakland and Macomb Counties)--a region with broad economic disparities. For example, in 2016, in cities in the tri-county area, household median incomes ranged from $28,000 (Detroit—1st percentile of median household income nationally) to $96,000 (Troy—91st percentile nationally).[4] Our findings may therefore be applicable to other cities in temperate-to-cold climates which must contend with a wide range of weather events, where residents may lack options for adequate housing and face hardships in paying for heating and cooling ("energy poverty"), and where future climate will likely be more hot and humid.[5] We reviewed literature concerning the epidemiology of temperature-related mortality and morbidity, related physiologic and environmental mechanisms, housing quality and energy use, and municipal planning for hot and cold weather.

2. Methods

We conducted a narrative rather than a systematic review, describing the current state of knowledge from a contextual perspective rather than more systematically identifying literature. We searched the "Web Of Science" citation indexing service in February, 2018 using search terms such as "temperature," "heat," "cold," "thermoregulation," "physiolog*," "homeless*," and "housing," identifying relevant works from all years, particularly reviews and articles studying Detroit or cities in similar climates.

3. Results

3.1. Epidemiology of temperature vulnerability

In the Detroit tri-county area from 2002–2016, approximately 2–3 deaths per year were classified specifically as due to hyperthermia and 16 deaths per year to hypothermia.[6] However, heat and cold likely lead to health events that are not identified as hyper- or hypothermia in medical records.

3.1.1. Temperature-associated mortality exposure-responses—Several multi-city studies have examined the associations between heat and/or cold and natural-cause mortality in the Detroit area. Associations between mortality and temperature typically take a U-shape, such that mortality risk increases both below and above a minimum mortality temperature. However, cold temperature effects increase gradually below the minimum mortality temperature without a clear threshold while heat effects increase more abruptly.[7–9] Increased heat-associated mortality risk is highest in the first 0–3 days following heat exposure [9] and may increase with more intense or longer-lasting heat waves.[7] From

1985–2012, hot temperatures were estimated to account for approximately 0.4% of deaths annually in the Detroit area (Table 1).[8] However, as average ambient temperatures and heat waves increase, the burden of heat-associated health effects may increase substantially in many U.S. regions, including the Detroit area.[10]

Cold temperatures were estimated to account for more deaths than heat−−7% annually in the Detroit area (Table 1).[8] In contrast to heat, mortality associated with cold temperatures is highest 2–3 weeks after exposure,[7] suggesting a less direct mechanism of action including cardiorespiratory diseases.[7, 11] Consecutive, as opposed to single, days of sustained cold temperatures do not increase mortality risk in the U.S., although both cold and heat effects are greater earlier in their respective seasons, perhaps due to lack of acclimation.[12]

3.1.2. Temperature-associated morbidity exposure-responses—Among Detroit area older adults, hospitalizations for heat-related (e.g., heat exhaustion/stroke), renal, and respiratory diseases were found to increase in association with hot temperatures.[13, 14] In 2014, emergency department visit rates for heat- and cold-related causes in the Midwest were 16/100,000 persons and 22/100,000 persons, respectively.[15] Although less well studied, in climates similar to Michigan's, fall-related injuries may increase on days with snow and ice.[11]

For both morbidity and mortality, cities with cooler climates tend to be more sensitive to warm effects and vice versa, suggesting that populations acclimatize to the local climate.[16, 17]

3.2. Physiology of thermoregulation and temperature susceptibility

Humans have sophisticated physiologic mechanisms for coping with extreme heat and cold, and the health severity of extreme temperatures varies by individual and context.

3.2.1. Normal physiologic responses—A healthy body copes with both moderately high and low temperatures first by sensing changing skin and core temperatures. For heat, this triggers blood vessel widening (vasodilation), a pronounced increase in the rate at which blood is pumped (cardiac output), and sweating. This brings heat to the body's surface to dissipate, in part by sweat evaporation. In general, as a result of vasodilation and dehydration, blood pressure drops in warm temperatures.[18] However, hot temperatures may interfere with sleep, and one Detroit study found increases in blood pressure in the mornings following hot nights.[19] The drop in blood pressure from vasodilation and sweating-induced dehydration can lead to headaches, dizziness, nausea, vomiting, muscle weakness, and even loss of consciousness.[20] Heat stroke occurs when body temperature exceeds 39–40 °C (103–104 °F), often resulting in death or permanent neurologic damage.[20]

On exposure to cold temperatures, blood vessels narrow (vasoconstriction), slowing the transfer of heat to the body's surface.[21] When behavioral adaptations, such as moving to warm locations or wearing more clothing, have failed and core temperature drops, shivering initiates to generate heat.[21] As core temperature drops further, hypothermia occurs and may involve confusion and drowsiness.[20] Besides short-term increases in blood pressure as a result of vasoconstriction, longer-term increases have been observed in blood viscosity, cholesterol, and platelets during the cold-season, potentially increasing the risk of myocardial infarction or stroke.[22]

3.2.2. Susceptibilities—Enhancements or impairments to any of the organ systems involved in thermoregulation—the nervous, endocrine, renal, cardiovascular, or integumentary (skin) systems—alter susceptibility to both hot and cold temperatures. Older individuals, even in the absence of obvious heart disease, and individuals with heart failure, have reductions in the amount of blood pumped per heartbeat (stroke volume) and decreased capacity for both vasodilation and vasoconstriction.[23, 24] Loss of muscle mass with age also leads to decreased internal heat production, although increased fat stores retain heat.[25] Additionally, older individuals have been found to produce less sweat, have a blunted shivering response, and have diminished neurologic responses to heat and cold,[21, 25] as do individuals with diabetes.[23] Individuals with coronary artery disease may be at particular risk for acute myocardial infarction during physical exertion in cold weather.[26] Cold temperatures are also associated with exacerbation of respiratory conditions, including chronic obstructive pulmonary disease and asthma.[11]

Medications and alcohol can also affect temperature susceptibility. Many of the drugs used to treat diseases of the nervous, endocrine, renal, or cardiovascular systems—such as anticholinergic, antihypertensive, and antipsychotic drugs—may impair thermoregulation. These drugs may reduce the ability of an individual to sense heat or cold or may inhibit other thermoregulatory responses, such as sweating.[9] Given that 27.5% of Detroiters reported being in fair or poor health in 2016, and Detroit rates of self-reported coronary heart disease, stroke, and diabetes were similar to or higher than the tri-county, state and national rates (Table 1), Detroit residents may be particularly physiologically susceptible to extreme temperatures.

3.2.3. Physiologic adaptation—Physical conditioning and controlled exposures to warm and cool temperatures can improve physiological responses to heat and cold. Individuals with better cardiovascular fitness are better able to tolerate heat.[27] Furthermore, exercise training in warm environments can promote heat acclimation, causing skin blood flow and sweating to occur earlier and in greater volume.[23] As seen in cold-water and cold-weather athletes, cold-weather exercise can induce acclimation to prolonged cold temperatures, as well.[21]

3.3. Social and environmental vulnerability to extreme temperatures

Occupational and built environment characteristics, including housing characteristics, may directly increase extreme temperature exposures, thereby triggering the physiologic responses described above. These extreme temperature exposures may be harmful in many circumstances, particularly when the exposed individual has limited capacity to access more thermally comfortable spaces. Additionally, increasing time indoors due to extreme outdoor conditions may have indirect adverse health effects.

3.3.1. Occupational exposure—Among Detroit workers, 26.3% have jobs that may involve outdoor labor compared to 21% in the tri-county area (Table 1). High summer temperatures have been identified as being particularly hazardous to outdoor workers, increasing the risk of exertional heat stroke and accidents resulting from reduced or lost consciousness.[28] Heat and cold risks to workers are well understood, and the U.S. Occupational Safety and Health Administration provides specific recommendations for protecting outdoor workers when temperatures exceed 32.8 °C (91 °F), including frequent rests, increased hydration, and acclimation periods.[28]

3.3.2. Neighborhood characteristics—Neighborhood characteristics related to heat vulnerability include urban heat islands, whereby heat-retaining surfaces and heat from air conditioners and other machines raise urban temperatures above those in rural areas. In Wayne County, MI (which includes Detroit), air temperature varied spatially by 4.0 °C (7.2 °F) on average in August, 2008, with generally higher temperatures in areas with more heat-retaining surfaces.[29] Other neighborhood characteristics affecting heat vulnerability, identified in research in Detroit and other cities, include crime, transportation, and public access to cool and warm spaces.[3, 30] We did not identify studies of variation in cold temperature vulnerability according to neighborhood characteristics. However, it seems plausible that improving neighborhoods to increase walkability and access to public indoor spaces could decrease vulnerability to both hot and cold temperatures by reducing extreme temperature exposure and increasing opportunities for physical activity. Increased physical activity would then also reduce cold and heat susceptibility factors such as cardiovascular disease, social isolation, and mental illness.[1] Detroit neighborhoods on average are “somewhat walkable,” although many lack green space and crime rates are high (Table 1), suggesting a role for neighborhood-wide approaches to increasing temperature resilience.

3.3.3. Housing characteristics--heating, cooling, and weatherization—Housing conditions also affect vulnerability to both heat and cold. Europe and New Zealand studies of cold indoor temperatures and interventions to weatherize homes and increase indoor heating have found that such interventions do decrease the cardiovascular risks associated with cold temperatures and improve thermal comfort.[2, 31] Detroit housing quality lags behind the U.S. on average. Among the Detroit participants of the 2015 American Housing Survey, 18% reported having no air conditioning, vs. 10% in the tri-county area and 11% nationally, and 18% reported their home being uncomfortably cold for 24 hours or longer, vs. 14% in the tri-county area and 8% nationally (Table 1). In a 2012–2015 housing survey of 500 Detroit residents, discomfort from cold was the highest (47%) serious complaint, while discomfort from heat was the third-highest (9%).[32]

3.3.4. Homelessness—In 2016, 4/1,000 and 2/1,000 persons in Detroit and nationally, respectively, were homeless on a given day, compared to the slightly lower rate of 1/1,000 persons in the tri-county area (Table 1). By definition, the homeless are particularly vulnerable to heat and cold due to inadequate shelter. This population’s vulnerability is increased by high rates of uncontrolled chronic illness, alcohol and substance abuse, and mental illness.[33, 34] Studies have found a higher risk of hypothermia, hyperthermia, and mortality among the homeless vs. non-homeless during periods of extreme heat or cold.[35–37] In Phoenix, 15% of hyperthermia deaths from 2000–2008 were among the homeless.[35] However, to our knowledge, no U.S. research has been conducted estimating the fraction of cold- or heat-attributable deaths, besides hypo- and hyperthermia, that are specifically among the homeless.

3.3.5. Energy poverty—Researchers worldwide have modeled energy usage intensity (EUI, energy/housing unit area/yr) as a function of building characteristics and demographic and cultural factors using various techniques.[38] A recent study of Wayne County, MI (in which Detroit is located) examined disparities in EUI by modeling heating EUI and then comparing EUI with demographics data. Census block groups with lower median household incomes and higher percentages of African American or Hispanic households tended to have higher modeled household heating EUI (as high as 1100 $MJ/m^2/yr$), suggesting that these areas had less energy efficient homes than those with higher household incomes and percentage of white residents (as low as 280 $MJ//m^2/yr$).[39]

In terms of cooling homes in the summer, qualitative research in Detroit corroborated findings from qualitative and survey research in other cities that cost concerns are a substantial barrier to air conditioning use.[3, 30] Given the high summer and winter costs of maintaining thermal comfort and the four-fold difference in EUI across Wayne County, energy efficiency upgrades in Detroit housing warrant prioritization.

3.3.6. Indirect indoor housing effects—During extremely hot or cold weather, individuals often spend more time indoors in non-naturally ventilated spaces, thereby increasing exposure to indoor health hazards. These include carbon monoxide, molds and other potential allergens, respiratory pathogens, combustion products from cooking, smoking, and candle use, and volatile organic compounds from furnishings and carpet.[40] Some of the cold-weather mortality burden may be indirectly due to this increased exposure to indoor health hazards, including respiratory disease.[41] In light of these concerns, a holistic approach to indoor air quality in the context of climate change has been proposed, addressing 1) reducing contaminants at the source, 2) providing adequate indoor ventilation, and 3) if necessary, purifying indoor air.[42] Additionally, awareness of the potential health impacts of building and home infrastructure design, construction, and materials is important to ensure that energy efficiency measures do not inadvertently cause health problems.[40]

3.4. Warming and cooling center interventions

The U.S. Centers for Disease Control and Prevention (CDC) developed a comprehensive guidance document including a literature review on the utilization and implementation of cooling centers and suggested steps for implementation and potential barriers.[43] The same guidance is not available for warming centers, although some cooling centers can be used as warming centers during the cold months.[43] From qualitative research in Detroit and other cities, many respondents spoke of specific barriers to the use of warming centers, including transportation, the belief that such facilities are only available to the homeless, and concerns about boredom, culturally inappropriate food or activities, or questions regarding immigration status.[30] These barriers to cooling and warming center use suggest a role for improved advertisement and strategies to increase activities and appeal.

Given their knowledge and perceived trust, community and faith-based organizations can be useful partners in emergency preparedness[44] and already provide a number of facilities as warming centers in Detroit.[45] Faith-based organizations can also help develop city-wide operational protocols for warming centers.[46]

4. Discussion

The above literature highlights opportunities to ameliorate cold-related morbidity and mortality while simultaneously increasing adaptation to near-future increases in extreme heat events. Our findings are applicable to Detroit and regions with similar climates and/or similar challenges in health, housing adequacy, walkability, or crime.

4.1. Short-term recommendations

Interventions which could result in immediate reductions in temperature-associated morbidity and mortality should target individuals with impaired physiological responses to extreme temperatures, especially the aged, and individuals in inadequate housing. Improvements in emergency response planning are also warranted. The CDC’s cooling center guidance[43] can serve as a foundation for Detroit to develop a cooling center protocol as a portion of their larger extreme heat response plan, and some of the resources available for cooling center implementation can be used to inform the implementation of warming centers. Toronto’s extreme cold and heat response plans are detailed and publicly available and can also serve as templates for extreme cold and heat response plans.[47] Other potential short-term interventions include a) increasing the number of cooling and warming centers with emergency power generators to provide short-term temperature relief but also shelter in other natural disasters or civil emergencies; b) promoting increased training among residents in emergency preparedness through programs such as the Federal Emergency Management Agency’s Community Emergency Response Team (CERT); c) enhance transportation options on extremely hot or cold days such as by shuttling vulnerable groups to cooling centers on school buses during the summer; and d) involving programs like Meals-On-Wheels, CERT, and Detroit youth programs in checking on seniors, particularly those who might have cognitive or mobility impairments, on hot and cold days.

4.2. Long-term recommendations

Many interventions already being considered or pursued in Detroit have temperature-health co-benefits. These include improving neighborhood safety and walkability and public transit options, which could increase physical activity as well as access to cooler spaces, and increasing and improving green spaces and indoor public spaces. Increasing roof repairs, insulation, and weather stripping and assessing thermal comfort and health before and after upgrades to provide and evaluate long-term cold and heat resilience should also be prioritized. Many temperature-susceptible residents might benefit from air conditioning installation in their homes, but given the increases in air pollution (from fossil-fueled power plants) and waste heat, wide-scale air conditioning installation may not be advisable without considerations for offsetting air-pollutant emissions by other means. Considering the U.S. Centers for Disease Control and Prevention’s “Healthy People 2020” goal to reduce not only disease rates but also health disparities, decreasing housing and built environment disparities in both a region and a nation of economically disparate cities should be prioritized.

5. Conclusions

This review highlights the robust knowledge base available on the health consequences of extremely hot and cold weather, which disproportionately impacts certain populations defined by their individual, built environment, and community characteristics. Additionally, we discuss various municipal response strategies to reduce the health impacts of these exposures. The clinical implications of this work are that extreme temperatures continue to be a population health concern and social justice issue, and health care providers can provide clear and concrete guidance for patients to take to reduce their exposure and risk. Additionally, deploying community interventions and resources and careful planning for the design and operation of buildings, homes, and surrounding areas can provide important preventive value beyond direct clinical intervention. Additional research evaluating the efficacy of various approaches in reducing the burden of temperature-related health effects on the population will aid development of municipality-specific strategies. However, sufficient information is available to guide multiple strategies at the local level that benefit both human health and environmental quality.

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Abbreviations:

EUI	energy use intensity
HHWS	heat-health warning system

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Highlights

- Both heat and cold have measurable health effects, particularly among the aged.
- In a future climate, heat-associated health effects may outweigh cold effects.
- Characteristics of physiological heat susceptibility and cold are likely similar.
- Built environment characteristics of heat vulnerability and cold may be similar.
- Interventions that target both cold- and heat-vulnerability warrant prioritization.

Table 1.

Characteristics related to temperature vulnerability.

Characteristic	Unit	Detroit	Tri-County Area[a]	Michigan	U.S.
Population, 2016[4]	Persons	673,000	3,861,000	9,933,000	323,400,000
Heat-attributable deaths[8]	Percent of total annual deaths	ND	0.4%	0.4%[b]	0.3%
Cold-attributable deaths[8]	Percent of total annual deaths	ND	6.9%	7.0%[b]	5.5%
Fair or poor health[48][a]	Percent of residents	27.5%	17.5%	17.5%	17.9%[49]
Angina or coronary heart disease[48]	Percent of residents	4.6%	4.8%	5.0%	4.3%[49]
Ever had stroke	Percent of residents	6.0%	3.6%	3.4%	3.2%[49]
Diabetes[48]	Percent of residents	13.1%	10.5%	10.8%	10.8%[49]
Occupation with outdoor exposure[4][c]	Percent of residents in the labor force	26.3%	20.6%	23.7%	21.0%
Household median income[4]	Income in the past 12 months	$28,000	$57,000	$52,000	$58,000
Non-green space[50][d]	Population-weighted average percent in a ZIP code	ND	92.8%	34.2%	ND
Violent crime in cities with 500,000–999,000 residents[51]	Annual rate per 100,000 residents	1,989	NA	NA	864
Walkability[52]	WalkScore™ walkability index on a scale of 0–100	55 (Somewhat walkable)	43 (Car-dependent)	40[e] (Car-dependent)	ND
Homeless, 2016[53]	Rate per 1,000 persons[4]	3.5	0.9	1.0	1.7
No air conditioning[54]	Percent of homes	18%	10%[a]	ND	11%
Uncomfortably cold home[54]	Percent of homes	18%	14%	ND	8%

ND = Data not available. NA = not applicable.

[a]Seven-county Metropolitan Statistical Area, including Livingston, Monroe, St. Clair and Washtenaw Counties in addition to the tri-county area of Wayne, Oakland and Macomb Counties.

[b]Death-weighted averages of Detroit, Flint, Grand Rapids, Lansing, and Saginaw metro areas.

[c]Natural resources, construction, maintenance, production, transportation, and material moving occupations.

[d]Cells (30 m resolution) classified as “developed, medium or high intensity.”

[e]Average WalkScore™ across 65 Michigan cities.