Approaches for Building Community Resilience to Extreme Heat

Peter Berry and Gregory R.A. Richardson

Abstract Climate change is expected to increase the frequency of extreme heat events; observations already confirm this trend in many parts of the world. Extreme heat results in significant increases in morbidity and mortality when individuals and communities are not prepared for it. Vulnerability to the health impacts of extreme heat depends on a number of important individual and community level factors. This chapter presents current knowledge for supporting the development of Heat Alert and Response Systems (HARS) which alert the public and community stakeholders to dangerously hot conditions so that protective measures can be taken that reduce health impacts, particularly on the most vulnerable in society such as older adults, infants and young children, people with chronic illness, and the socially disadvantaged. Information about temperature-mortality associations provide an evidence-based foundation for developing effective measures to protect health. Effective HARS also require engagement with a broad range of community stakeholders to address key vulnerability factors (e.g. role of space and place and socio-economic challenges) and include preventative urban design measures that reduce local heat exposures before they occur. The chapter provides cases studies of Health Canada's collaboration with partners at the provincial and community level aimed at increasing understanding of heat-health impacts, building the capacity to manage growing risks due to climate change and expanding HARS to at risk communities.

Keywords Extreme heat events · Heat Alert and Response Systems · Heat illness · Urban heat island · Climate change adaptation

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S.L. Steinberg and W.A. Sprigg (eds.), *Extreme Weather, Health, and Communities*, Extreme Weather and Society, DOI 10.1007/978-3-319-30626-1_15

1 Introduction

There is widespread evidence of the impacts of climate change around the globe such as increased annual temperatures, changes in precipitation regimes, sea level rise and ocean acidification (IPCC 2013; Patz et al. 2014). Since observations began in 1880, the year 2015 was the hottest on record. It was also the 39th consecutive year that the global temperature was above average (NOAA 2016). Due to the long-lasting nature of greenhouse gases in the atmosphere an additional human-induced warming of 0.7 °C will be realized irrespective of near term reductions in levels of greenhouse gas emissions (McMichael 2013). For the period 1986–2005 to 2081–2100 the increase in average global temperature is projected to be from 0.3 to 4.8 °C, with near-tem warming between 2016 and 2035 expected to be from 0.3 to 0.7 °C (IPCC 2013).

Risks to human health and well-being from climate change are broad. Direct and indirect health impacts are already being observed in both developed and developing countries (McMichael et al. 2006; Costello et al. 2009; Myers and Patz 2009; Berry et al. 2014a; Luber et al. 2014; WHO 2014) and risks are increasing as ecological, social, cultural and economic systems continue to be impacted (McMichael 2009). Knowledge gaps remain concerning attributable disease burdens and projected future impacts. The number, intensity, spatial extent and duration of many extreme weather events such as rain, hail, thunder and lightning, strong winds, and extreme heat events are expected to increase as the climate continues to change (IPCC 2012). For example, a hottest day event in a community that only occurred once every 20 years could likely occur every other year by the end of the 21st century (IPCC 2012). Estimates exist on the projected increase in hot days for a number of cities in Canada (Casati et al. 2013) and in the US. For example, the annual number of 32 °C/90 °F days in New York City could triple by 2050 (from 13 to 39 days) (Patz et al. 2014). Researchers have begun attributing the occurrence of heat wave events, among other extreme weather events, to climate change. Analysis suggests that climate change greatly increased the risk of the record heat waves of 2013 across inland eastern Australia and in Japan (Herring et al. 2014).

A particular concern to human health and vulnerable communities is that mega heat waves are projected to increase in frequency by 5- to 10-fold by the 2050s (Patz et al. 2014). Recent weather events such as the heat waves that affected Europe in 2003 (70,000 deaths) (Robine et al. 2008) and Russia in 2010 (55,000 deaths) (Barriopedro et al. 2011) highlighted the potentially catastrophic consequences of large scale weather disasters on unprepared communities. According to the World Health Organization, in the year 2030, 38,000 additional deaths related to heat exposure are projected to occur globally due to climate change (WHO 2014).

Extreme heat events can also result in significant costs to society. For example, the 2157 excess deaths in the United Kingdom that resulted from the 2003 heat wave are estimated to have cost 2.6 billion pounds. In addition, 1650 excess hospital admissions cost the health system 32 million pounds (Hutton and Menne

2014). Given concern over the growing risks from extreme heat events, health authorities in many countries (e.g., Canada, US, Australia, Spain, France, United Kingdom) and within international health agencies (WHO 2009) have identified heat as a growing public health threat and are developing and implementing adaptation actions to protect people.

Climate change could be the greatest threat to human health of the 21st century (Costello et al. 2009) and actions should be taken by health authorities in all countries to reduce avoidable impacts. This chapter reviews the human health risks from extreme heat events, with a focus on health vulnerabilities and intervention strategies in the Canadian context. It examines current knowledge of adaptation measures that can effectively reduce dangers associated with extreme heat. The chapter discusses consideration of place-based and local context factors for understanding important priority vulnerabilities and designing effective public health interventions. Recent research findings highlight the importance of comprehensive and preventative approaches to preparing communities for extreme heat events—approaches that seek to build the resilience of populations through a wide range of activities—from improved communications about risks and protective behaviours to efforts to mitigate community heat exposure through urban design innovations. To conclude, we draw upon lessons from Health Canada's initiative to increase the resiliency of Canadians to extreme heat events (http://www.hc-sc.gc.ca/ewh-semt/climat/index-eng.php) to provide the reader with practical examples of adaptation planning, stakeholder engagement, and education and outreach activities.

2 Understanding Vulnerability to Extreme Heat

2.1 Health Risks from Extreme Heat

People have the ability to adapt to hot temperatures. However, excess deaths observed in many countries during high temperatures indicates that physiological adaptation is not fully protective (Jendritzky and Tinz 2009). Health is affected by extreme heat when it affects the body's ability to regulate core temperatures; this can lead to skin rashes, cramps, dehydration, syncope (fainting), exhaustion and heat stroke (Health Canada 2011a). Extreme heat events have also been linked to short-term increases in mortality (Bouchama et al. 2007; Kovats and Hajat 2008; Kenny et al. 2010; CIHI 2011; Gamble et al. 2012). People with pre-existing health conditions such as cardiovascular, cerebrovascular, respiratory diseases and neurological disorders are at higher risk (Kenny et al. 2010; Health Canada 2011a). Indirect impacts on health from such events have also been observed. The rate of assaults and domestic violence in Montreal (Quebec) have been linked with hotter weather, particularly when temperatures were above 30 °C/86 °F (Ouimet and Blais 2001).

In the US, between 2006 and 2010 approximately 620 people died each year from exposure to extreme heat, roughly 30 % of all weather-related deaths (Berko et al. 2014). However, because surveillance and monitoring activities based upon the use of disease and heath related problem codes (International Statistical Classification of Disease and Health Related Problem Codes (ICD)) by hospital health coders, coroners, nurse help-lines, and emergency medical service workers do not always identify deaths as being attributable to heat accurately, the actual number of people that die from heat is likely greater (Bassil et al. 2008; Patz et al. 2014). Individual extreme heat events can result in significant loss of life. An extreme heat event in British Columbia, Canada that occurred over an eight day period in the lower mainland area in 2009 resulted in an estimated 156 excess deaths (Kosatsky 2010). In Quebec, Canada an extreme heat event in 2010 resulted in an estimated excess of 280 deaths (Bustinza et al. 2013).

Evidence suggests that in the US the impact of extreme heat on the health of citizens is declining over time. Bobb et al. (2014) found that, among 100 cities, the average reduction in deaths attributable to each 10 °F (5.6 °C) increase in same-day temperature decreased from 51 (per 1000 deaths) in 1987 to 19 in 2005. Similarly, Davis et al. (2002) found statistically significant reductions in hot-weather mortality rates in 3 major northern metropolitan areas (Boston, New York, Philadelphia) over three decades from 1964 to 1994. The findings suggest that Americans are becoming more resilient to extreme heat and this may be due to the success of heat-health warning systems, changes to the built environment (e.g., greening) that are providing more opportunities for cooling during dangerous heat events, improved medical care, increased access to air conditioning, or biophysical adaptations (Bobb et al. 2014; Davis et al. 2002). However, even with these trends, climate change will continue to increase health risks from heat waves (Bobb et al. 2014).

While evidence of increasing resilience to extreme heat suggests progress in efforts to adapt, deaths from these types of events are generally much higher than other types of extreme weather events associated with climate change (Luber and McGeehin 2008; Berry et al. 2014a). There is also strong evidence that an increase in the number of extreme heat events is already being observed in many regions of the world, including Canada and the US, and that they will continue to increase (IPCC 2013). In addition, an ageing population and increased urbanization, with higher exposures from urban heat islands (UHI) will increase the vulnerability of urban dwellers (Luber et al. 2014). Extreme heat may also have less direct, but significant impacts on health through effects on air pollution (Luber et al. 2014; Berry et al. 2014a), mental health (Hansen et al. 2008; Kim et al. 2015), aggression (Anderson 1989) and on critical infrastructure such as power transmission infrastructures (McGregor et al. 2007).

In both the US and Canada extreme heat events are increasing in frequency in many cities (Stone et al. 2010; Luber et al. 2014) and several studies project continued increases in the future due to climate change (IPCC 2013). Figure 1 shows the projected number of hot days and warm nights for a number of Canadian cities such as Winnipeg, Toronto, Montreal and Fredericton. The number of hot days (above 30 °C/86 °F) per year in these cities is expected to double by the end of

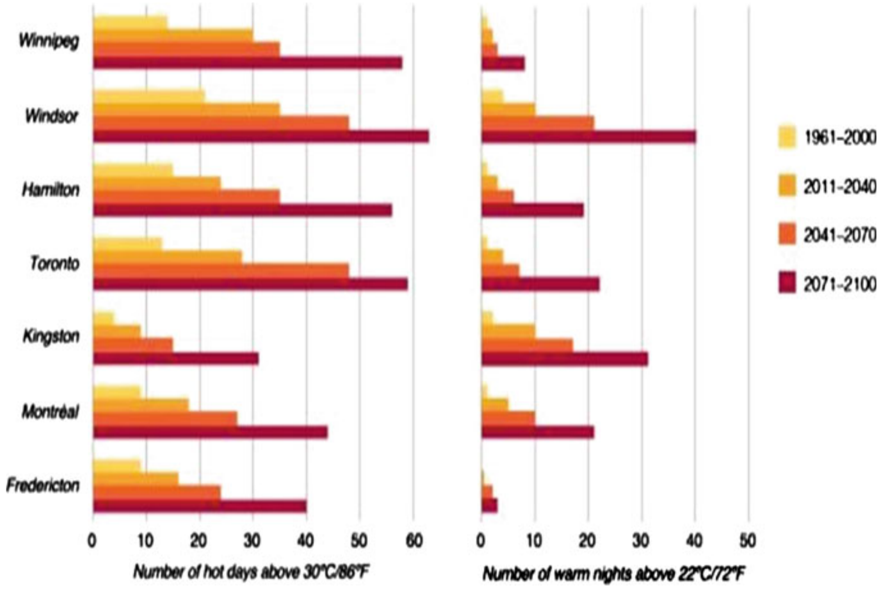

Fig. 1 Projected hot days and warm nights for select Canadian cities. *Source* Casati et al. (2013)

this century, while the number of warm nights for some cities could quadruple (Casati et al. 2013). Warmer nights from rising temperatures and a stronger UHI effect will lead to increase health risks as people may not be able to cool down after hot days (Patz et al. 2005).

With an increase in warmer temperatures and the frequency and severity of extreme heat events, more heat-related illness and deaths in the absence of adaptations are expected (Gosselin et al. 2008; Peng et al. 2011; Martin et al. 2011; Petkova et al. 2013; Benmarhnia et al. 2014; Vardoulakis et al. 2014). For example, a review of 15 Canadian cities suggested that overall, using a 2081–2000 base period, heat-related mortality could triple by 2021–2040, increase five-fold by 2051–2070 and increase by more than eight-fold by 2081–2100 (Martin et al. 2011). In 49 US cities, the EPA (2015) projected that climate change (i.e. more extreme hot days and fewer extreme cold days) could result in a net increase of 2600 deaths annually by 2050 and 13,000 deaths by 2100; greenhouse gas mitigation measures can significantly reduce this health burden (EPA 2015). The City of Chicago, Illinois may experience as many as 2000 excess deaths per year by 2081–2100 due to an increased number of heat waves (Peng et al. 2011). With a 3.5 °C/6.3 °F temperature rise the number of heat deaths in Europe could reach 200,000 per year (Ciscar et al. 2014). Importantly, climate change can exacerbate many factors (e.g. poverty, isolation, dislocation, chronic diseases) that make some populations more vulnerable than others to climate-related hazards such as extreme heat; this may amplify health impacts in the future. Longer-term and higher global temperature increases may mean that people reach the limits of physiological adaptation in some parts of the world (McMichael and Dear 2010).

Knowledge of populations in a community that are at higher risk from heat illness and death allows public health and emergency management officials to disseminate targeted heat-health communications messages and to direct response measures during heat emergencies in the most effective manner. Table 1 provides a list of heat-vulnerable groups and examples of adaptation challenges they face.

Parents need to be particularly careful to not leave children or others requiring assistance in cars during hot weather. On average, 37 children are estimated to die each year in the US from heat in cars Null 2015). Temperatures in cars can rise rapidly (15–30 min) even with relatively cool ambient temperatures. Public awareness and education about how to avoid illnesses and deaths among children in cars can improve child passenger safety (McLaren et al. 2005).

People exposed to heat through a variety of occupations also need to take precautions to avoid serious illness. Occupational heat-related hospitalizations or emergency department visits increased with daily maximum temperature in three different areas of Florida during the summer months (Florida Department of Health 2012 as cited in Adam-Poupart et al. 2014). Similarly, Adam-Poupart et al. (2014) found a strong relationship between occupational heat-related illnesses and exposure to high summer temperatures in the province of Quebec, Canada. Occupational risk factors associated with health impacts from extreme heat included a lack of training and experience, obesity, use of medication, and incomplete knowledge of the main language used in the workplace (Adam-Poupart et al. 2014). Mass gatherings such as festivals, concerts and sporting events can also lead to heat exposure and illness of large numbers of people if precautions are not taken (Feldman et al. 2014).

2.2 Individual and Community Level Factors that Increase Vulnerability

Vulnerability to heat-related illness and death is determined by the physiological sensitivity of a person to heat stress, their exposure to extreme heat and their ability or capacity to take protective measures (Health Canada 2011a). A wide range of individual and community level factors influence vulnerability and whether a person suffers ill effects during a heat event (Fig. 2). These factors often work in combination and in complex ways. For example, seniors who take certain medications that predispose them to health impacts of heat stress, live in housing with no air conditioning and/or on higher floors or have limited social networks are at significantly higher risk from extreme heat events than are many other individuals. In the US, hospital admissions among seniors increase during extreme heat (Gronlund et al. 2014). Of the 14,729 people that died in the August 2003 heatwave in France, almost 80 % were over the age of 75 and the risk of dying was much greater for those living at home than for people in hospitals and clinics (Fouillet et al. 2006). In addition, homeless people are at higher risk of heat illness because

Table 1 Heat-vulnerable groups and examples of challenges they may face in adapting to extreme heat events

Heat-vulnerable groups	Examples of challenges
Older adults	• Physiological characteristics that may contribute to increased vulnerability to heat: – reduced thirst sensation – reduced fitness level – reduced sweating ability – increased susceptibility to chronic dehydration • Visual, cognitive and hearing impairments • Agility and mobility challenges • Differing perceptions of risks and vulnerabilities based on life experiences • Reduced literacy • Social isolation
Infants and young children	• Physiological and behavioural characteristics that may contribute to increased vulnerability to heat: – increased body heat production during physical activity – faster heat gain from the environment if air temperature is greater than skin temperature, due to greater surface-area-to-body weight ratio – inability to increase cardiac output – reduced sweating • Dependence on caregiver to recognize heat impacts and take recommended actions
People with chronic illness or who are physically impaired	• Physiological characteristics that may amplify health risks, such as a failing cardiovascular or respiratory system, psychiatric illnesses, renal illnesses • Taking certain medications that affect heat sensitivity by interfering with the body's cooling functions or water/salt retention (e.g. antihypertensives, antidepressants, antipsychotics, anti-Parkinsonian) • Confined to bed or dependence on caregiver, family or friends for assistance with daily living (e.g. water access) • Communication, sensory, cognitive impairment • Characteristics related to health status or behaviour (e.g. chronic dehydration, does not leave home) • Social isolation
Socially disadvantaged individuals and communities: • Low income • Homeless • Living alone	• Limited financial resources to adequately take protective actions • Reduced access to clean water and cool places • Limited access to health care and social services • More environmental exposures (e.g. homeless, living on higher floors with no air conditioning) • Higher rates of alcohol and drug dependency • Social isolation

(continued)

Table 1 (continued)

Heat-vulnerable groups	Examples of challenges
Newcomers and transient populations such as tourists	• Language and literacy barriers for non-native speakers • Cultural differences, such as food consumption habits, clothing choices, pre-existing social or cultural beliefs • Unique media use patterns • Limited knowledge of local alert systems, health and social service programs
Occupational groups	• Environmental and workplace exposures (e.g. farmers, construction workers, miners, tree planters) • Increased physical strain • Variation in health and safety regulations, codes and standards • Irregular exposure to heat (i.e. lack of acclimatization) for new workers with job-related heat exposures and those faced with early season extreme heat events
The physically active	• Greater environmental exposures (e.g. marathon runners, recreational athletes, people who walk or bike) • Increased physical strain • Reduced perception of risks and heat vulnerabilities • Expectation of usual performance in the heat

Source Health Canada (2011a)

of increased exposure to hot temperatures; they often reside in urban cores that experience the UHI effect, are socially isolated, have fewer hydration options and have less ability to access cooling centres (Health Canada 2012). Public health interventions to protect such people from extreme heat must be formulated in such a way as to address these factors. As an example, the City of Toronto provides transit tokens to homeless people during extreme heat events so that they can get to cooling centres (Health Canada 2012).

2.2.1 Role of Space and Place

Space and place can be a key driver for the impacts of environmental degradation and climate change on human health (Smith et al. 2014). Community design and type can play a major role in predisposing populations in certain geographical areas to greater health impacts from extreme heat (Chow et al. 2012). People living in cities often face higher exposures to air pollution, noise pollution, and UHIs. They may also be subject to other pressures such as reduced opportunities for physical activity and rest, high cost of fresh food, overcrowding, alienation, inequity and high crime rates (Proust et al. 2012), all of which can exacerbate the effects of environmental stressors. In turn, rising temperatures and more extreme weather events associated with climate variability and change may have impacts on the most

Fig. 2 Factors that influence individual and community level vulnerability to extreme heat events. *Source* Health Canada (2011a)

vulnerable populations. One study of health effects of extreme heat events in eight diverse neighborhoods in Phoenix in 2003 showed that marginalized populations such as people with lower socioeconomic status and ethnic minority groups were more likely to reside in neighborhoods with greater exposure to heat stress and to have fewer resources to take protective measures (Harlan et al. 2006). An examination of a range of factors linked with heat-health outcomes in the US found that people living in inner cities were the most vulnerable in urban areas (Reid et al. 2009). Disproportionate impacts of climate change on the health of vulnerable populations (e.g. low income and elderly) means that approaches to address climate change and health impacts would benefit most by linking them with considerations of health equity (Connor et al. 2010).

People living in rural areas can also be at increased risk from extreme heat because of more limited resources to take adaptation actions (e.g. fewer medical facilities), fewer cooling options (e.g. no or limited public transport, fewer air conditioned public spaces), greater challenges identifying health-based alert protocols and difficulty reaching the public with heat alerts (e.g. limited media coverage) (Berry et al. 2014b). An investigation of weather-related deaths in the US from 2006 to 2010 indicated that most heat-related deaths occur in the most urban and the most rural counties (Berko et al. 2014). Another study suggested that over this time period higher rates of presentations to emergency departments for summertime acute heat illness were observed in rural areas (Hess et al. 2014). A study of heat-related mortality in British Columbia, Canada showed that hot weather has a relatively higher impact on health in more sparsely population areas (Henderson et al. 2013).

The impacts of climate change on heat and health could have disproportionate impacts of people living in low and middle-income countries in the tropics which experience very hot seasons. One study that estimated work capacity for selected heat exposure levels and work intensity levels found that it rapidly reduces as the Wet Bulb Globe Temperature (WBGT) exceeds 26–30 °C (Kjellstrom et al. 2009). In South-East Asia, climate change may double the annual work hours lost in heat-exposed jobs by 2050 translating into losses of billions of US dollars (Kjellstrom 2015). Higher temperatures resulting from climate change may pose future challenges to the economic and social development of these countries due to impacts on worker productivity (Kjellstrom et al. 2009).

2.3 Vulnerability Associated with Climate Change, Heat and Air Quality

Climate change may increase health risks from poor air quality through increases in aeroallergens, biological contaminants and pathogens (Greer et al. 2008; Schenck et al. 2010). Wildfires constitute another pathway through which climate change can impact health risks from ambient air quality, particularly increases in particulate matter (PM) across large geographic areas. It may also lead to heat and other meteorologically-related increases in ambient air pollutants such as ground-level ozone (O_3) and PM (Ebi and McGregor 2008; Frumkin et al. 2008; Bambrick et al. 2011).

There is a strong correlation in the US between higher daily summer temperatures and poor air quality (O_3) in many cities (Kenward et al. 2014). One study of 91 urban and non-urban counties in the northeastern US found that populations in non-urban areas are also at risk from high temperatures and air pollution levels (Madrigano et al. 2015).

Under future climate conditions and assuming current population levels and regulatory controls, between 1000 and 4300 additional premature deaths are expected yearly by 2050 in the US from ozone and particulate matter health impacts (Luber et al. 2014). Future projections of health risks from climate induced impacts on ground-level ozone and particulate matter levels in Canada suggest increased

Table 2 Climate change and related drivers for key health risks associated with air quality

Air contaminants	Climate change and related drivers	Health risks
Ground-level ozone	• Increased temperatures	• Premature mortality • Respiratory symptoms, inflammation • Impacts on immunological defences • Cardiac effects • Adverse long-term respiratory impacts
Particulate matter—coarse ($PM_{10\text{-}2.5}$), fine ($PM_{2.5}$) and ultrafine ($PM_{0.1}$)	• Wildfires • Droughts • Renovations to weatherize buildings	• Mortality • Cardiac outcomes • Lung cancer mortality • Restricted activity days • Respiratory symptoms • Bronchitis • Asthma exacerbation
Aeroallergens (e.g., from trees, grasses, weeds, molds, dust mites)	• Warmer temperatures	• Allergic responses in sensitized individuals • Exacerbation of respiratory diseases (e g, asthma and chronic obstructive pulmonary disease)
Fungi (e.g., and infectious bacteria)	• Moisture in buildings from infiltration of rain or flooding • Poorly designed ventilation and air-conditioning systems • Poor building maintenance	• Respiratory disease • Cryptococcal disease (cryptococcosis) which can result in pneumonia or meningitis
Volatile organic compounds (VOCs) and Semi-volatile organic compounds (SVOCs)	• Dampness in buildings	• Asthma • Allergies
Carbon monoxide (CO)	• Use of portable gas-powered or electric generators, oil and gas furnaces, fireplaces, or candles during weather-related emergencies	• Fire-related injuries and death • CO poisoning

Source Adapted from Berry et al. (2014a)

levels of exposure and/or mortality as well (Lamy and Bouchet 2008; Berry et al. 2014a). Table 2 illustrates climate change and related drivers for key health risks associated with air quality.

Understanding the complex relationships between climate change, temperature and air quality is necessary to develop effective public health interventions for these risks and to maximize health co-benefits of adaptive actions. For example, some public health authorities in Canada issue public alerts when dangerously high temperatures are forecasted and when air pollution presents dangers to health. In such cases, the use of alert messages which avoid contradiction in messaging and possible confusion among the public (e.g. cool down to escape the heat / don't use air conditioning to reduce energy use) is important (Rogaeva and Berry 2014). In addition, while future climate conditions could reverse some of the very significant improvements to air quality and public health over the past few decades (Kenward et al. 2014), great potential exists to maximize benefits to human health through innovative urban designs that reduce risks from extreme heat (e.g. expand tree canopy or paved surfaces) while at the same time improve air quality. One study in the New York Metropolitan area suggested that a future land use scenario involving the transformation of forest and agriculture areas to low density urban development would be associated with higher levels of episode-maximum 8-h ozone concentrations, although there is some geographic variation, where a few areas would experience decreases in ozone concentrations (Hogrefe et al. 2004). More generally, greenhouse gas emissions reductions that reduce the combustion of carbon-containing fuels could result in major decreases in mortality (Haines et al. 2014). Many measures to improve air quality, reduce the UHI and alleviate exposure to heat stress, or reduce the rate of climate change, can provide immediate health benefits.

3 Adapting to the Health Impacts of Climate Change

Growing concern about the health impacts of climate change over the last decade has catalyzed public health officials to develop adaptation measures to protect citizens at risk. Health authorities at national, regional and local levels have begun efforts to manage observed health impacts and prepare for future risks (Panic and Ford 2013; IPCC 2014). However, one study in the US revealed that many governmental authorities at the local level do not feel prepared to protect the health of citizens from extreme heat events (O'Neill and Ebi 2009).

Responsibility for implementation of the broadest scope of health adaptations resides with local and regional decision makers. Community involvement in adaptation planning is critical given the necessity to include information about societal, cultural, environmental, political and economic factors that affect the vulnerability of specific individuals and populations (Ebi and Semenza 2008). This includes knowledge of vulnerable populations and factors that increase or mitigate vulnerabilities at the local level, based on demographics and place.

Measures to reduce health impacts from climate variability and change includes integrating information about future risks into early warning systems, public education and awareness campaigns, strengthening of health care and social services, surveillance of new and emerging diseases and actions that support and sustain health through adaptation in related sectors such as water supply and sanitation, agriculture, infrastructure, energy and transportation, ecosystems and land use management (Ebi et al. 2013; IPCC 2014). Public health and emergency managers cannot act alone in protecting citizens from extremes of weather and climate, since pathways for drivers of health impacts are complex and variegated. Climate maladaptation (i.e. unsuccessful adaptation that increases vulnerability) in other sectors such as agriculture, transportation, urban planning can have significant public health consequences by negatively affecting efforts to protect health from extreme heat.

Evidence suggests that adaptation measures—including the reduction of poverty, improvement of water and sanitation conditions and early warning and response systems—can reduce the health consequences of climate change (IPCC 2014). Health adaptation can have immediate knock-on effects including important health co-benefits that increase the resilience of populations to climate impacts (McMichael and Dear 2010; Cheng and Berry 2013). Adaptations to climate that protect health directly or indirectly can also be cost-effective. For example, Ebi et al. (2004) estimated that Philadelphia's heat wave warning system, which costs about $210,000 to run over a three year period, could provide gross benefits in the order of $468 million (117 lives saved times $4 million) over the same timeframe. Studies estimating health-related cost-benefits of adaptation actions are limited and more research is needed in this area (Younger et al. 2008; Toloo et al. 2013).

4 Actions to Protect People from Extreme Heat Events

Heat-related deaths are largely preventable (Luber and McGeehin 2008; Matthies et al. 2008; WHO 2009; McGregor et al. 2015). Public health interventions that increase the accessibility of air conditioning and increase fluid uptake among vulnerable populations can reduce mortality associated with extreme heat events (McGeehin and Mirabelli 2001). Over the last 15 years, local communities and regional and national governments in many developed and some developing countries have begun adopting proactive public health and emergency management interventions to reduce health risks from extreme heat events (Lowe et al. 2011; McGregor et al. 2015). In the community of Ahmedabad, India the Indian Institute of Public Health in partnership with the Natural Resources Defense Council and Emory University have undertaken a heat-health vulnerability assessment to inform the development of an evidence-based heat preparedness plan. It includes early warning measures and recommendations to reduce health risks and protect livelihoods (Knowlton et al. 2014).

Public health officials have focused on the development of tools to support communication and outreach for alerting community stakeholders and the public when heat events are forecast so that measures can be taken to protect the most vulnerable populations (Younger et al. 2008; O'Neill and Ebi 2009; Health Canada 2012). A number of communities in Canada have developed Heat Alert and Response Systems (HARS) that include a proactive community response (e.g. public health visits to vulnerable populations such as older adults living alone or the disabled) and increased access to services that reduce health risks such as cooling centres and shelters (Berry et al. 2014b). While studies that evaluate the effectiveness of HARS are limited, some have suggested that they contribute to the reduction of morbidity and mortality associated with extreme heat events (Kovats and Ebi 2006; Fouillet et al. 2008; Bassil and Cole 2010). For example, implementation of the heat wave and health alert system in France (Système d'alerte canicule et santé) after the very severe extreme heat event of 2003, is thought to have significantly reduced the health impacts of subsequently strong heat events in 2006, 2009 and 2010 (Ministère du Travail, de l'Emploi et de la Santé 2011). Evidence also suggests that the costs of systems can be small compared to costs of negative health outcomes from extreme heat events (Ebi et al. 2004). The cost of setting up and operating the system in France in 2005 was 741,000 euros, which is far less than the estimated health costs of 500 million euros for the 2003 heat wave (Hutton and Menne 2014). However, greater efforts are needed to develop robust measures to provide adequate protection to the most vulnerable populations as many plans neglect low income people and the socially isolated (Bassil and Cole 2010). Development of HARS should be based on anticipatory adaptation planning for extreme heat events that utilizes information on the relationship between temperature, mortality and place-based factors contributing to vulnerability (Fook 2014).

Recent evidence suggests that health impacts from extreme heat may not only be of concern for urban populations; people living in rural and isolated communities can also be at significant risk (Henderson et al. 2013; Madrigano et al. 2015). Heat Alert and Response Systems often differ in scope, types of public health interventions employed, target populations for outreach and communications and the degree and nature of stakeholder involvement due to differences in local meteorological context, extreme heat planning processes and the capacity to undertake response activities. Adaptation efforts in urban and rural communities are most effective when they address unique challenges (e.g. communicating messages to the public, estimating heat-health burdens, assisting vulnerable populations with cooling options) faced by communities in efforts to protect health (Berry et al. 2014b).

4.1 Health Canada's Approach to Increasing Heat-Health Resiliency and Preparing Canadians for Climate Change

Through its national climate change and health vulnerability assessment, Health Canada identified extreme heat as a key health risk to Canadians, both under current climate conditions and with climate change (Health Canada 2008). To help health decision makers and individuals better prepare for these events it launched a multi-year initiative in 2008 to *Develop Heat Resilient Individuals and Communities in Canada*. Under the initiative, Health Canada worked with provincial and local health sector and emergency management officials and community groups to better understand heat-health risks to Canadians, enhance awareness and knowledge of risks among health professionals, develop best practices for adaptation, build the capacity of stakeholders and partners to protect health and expand HARS to at-risk communities across the country. During the first phase of this project (2008–2011), Health Canada engaged four communities (Winnipeg, Manitoba; a rural region in Manitoba, within the former Assiniboine Regional Health Authority; Windsor, Ontario; Fredericton, New Brunswick) to pilot development of new HARS for reducing heat-health risks.

Each community developed its own pilot approach based on local/regional needs and characteristics; common elements included identification of a lead agency, development and approval of a formal HARS plan, development of community outreach activities, and implementation of communication plans and products. To this end, pilot communities learned from table-top extreme heat event simulation exercises and from research in heat-health vulnerability assessments to develop their respective systems. Through such activities they undertook participatory approaches based upon community consultations with local partners and stakeholders (Morris-Oswald 2009).

From the outset the project was guided by a HARS Advisory Committee that included experts with knowledge and professional experience in the development and implementation of HARS, climate and health adaptation, public health and emergency management, the needs of heat vulnerable populations, and occupational health. A Health Professionals Information and Training Advisory Committee was also established to assist Health Canada's development of guidance for health professionals on diagnosing and treating heat-related illness and preparing health facilities for extreme heat events. Both committees included representatives from target audience groups of planned information products to increase access to the people requiring the information and to influence behavioral change.

4.2 Developing Heat Alert and Response Systems to Protect Health

Implementation of measures to protect health from extreme heat have been effective in some cities. Bobb et al. (2014) found that a decrease in mortality from heat events in the US could be due to a range of factors including expansion of heat-health warning systems and public health response programs in US cities since the late 1980s. However, a sole emphasis on expanding air conditioning to reduce vulnerability could lead public health officials to miss key opportunities to most effectively adapt and mitigate the effects of heat. Other evidence suggests that a robust community response to an extreme heat event in Milwaukee in 1999 based upon an implemented heat plan may have helped to significantly reduce the number of deaths resulting from the event. The 1999 heat wave took 10 lives, far less than a similar heat wave in 1995 that resulted in 91 deaths (Patz et al. 2014).

A review of HARS plans along with guidance documents from Europe, Australia, the US, the World Health Organization, and from the experiences of Health Canada's pilot communities highlighted that effective HARS have the following core elements (Health Canada 2012; Berry et al. 2014b):

Community Mobilization and Engagement—A lead agency mobilizes the community and coordinates necessary activities to implement and evaluate the HARS. It works with local stakeholders to identify and develop alert and response measures tailored to the community, recruit partners to support implementation, and develop HARS plans. This agency also leads the performance review of HARS off-season to support the adoption of needed changes or improvements.

Alert Protocol—The alert protocol is developed with knowledge of specific weather conditions (e.g. heat, humidity) that can increase morbidity and mortality in the community or region. Public health officials use the protocol to alert the public, media, government officials and community stakeholders of the level of risk so that predetermined actions may be taken to protect health.

Community Response Plan—The response plan identifies the measures that will be taken to prevent or reduce heat illnesses and deaths when a heat alert is called. It identifies the participating agencies and stakeholders and roles and responsibilities for implementing the measures. A core component of the response plan includes the direct public health measures aimed at protecting vulnerable individuals who may not be able to take health protective measures themselves (e.g. checking on seniors living alone, distributing water to homeless people). Heat adaptations in the community response plan must address the adaptation challenges faced by vulnerable populations.

Communication Plan—The communication plan sets out the communications activities that support the effective implementation of the HARS. Activities generally focus on raising awareness among various audiences (e.g. the public, public health officials, health professionals, the media) of the risks to health from extreme heat, the need to take protective measures when heat events occur and effective adaptations. The plan identifies appropriate communication channels, mechanisms (e.g. media releases, interviews, website information), target audiences, and messages to support HARS implementation.

Evaluation Plan—The evaluation plan provides direction to the HARS lead and participating stakeholders in efforts to evaluate the system including its processes (e.g. timeliness, relevance, effectiveness, ability to meet local priorities) and the actual outcomes (e.g. reduction of heat-related illnesses and deaths). The results are used to improve performance of the HARS through iterative changes to its components.

Evidence suggests that the following principles and actions increase the effectiveness of HARS (Health Canada 2011b, 2012):

- Using the findings of heat-health vulnerability assessments to identify vulnerable populations and geographical areas to inform development of alert protocols, response measures and communications materials
- Tailoring the HARS to meet local needs including addressing barriers to adaptation
- Including key community partners in the HARS that add value to the system
- Calling heat alerts with a trigger or triggers that were developed with information about the relationships between weather variables and health outcomes in the community or region
- Employing response measures that are proven to reduce health risks among the most vulnerable populations
- Implementing communication strategies and messages that raise awareness and educate about heat-health risks and that lead to behavioural change
- Evaluating the HARS at the end of the season and making needed changes to the system
- Preventing and/or reducing heat exposure in communities and regions through preventative public health actions such as mitigation of UHIs.

4.2.1 Supporting Heat-Health Adaptation Through Proactive Communication and Outreach

Communication to the public and community officials of heat-health risks and of measures that can protect health plays a critical role in HARS implementation (Luber and McGeehin 2008; Health Canada 2011c; McGregor et al. 2015). When extreme heat poses health risks, individuals have a primary role to take protective actions or to help their loved ones stay safe. Health communication information delivered in a timely manner supports heat-health adaptation by vulnerable individuals and their caregivers. Public health and emergency management officials implement communication strategies as part of HARS to provide practical and useful information to health service providers, caregivers and the public to help manage health risks from extreme heat events. However, providing information to vulnerable populations does not guarantee the uptake of health protective behaviours during extreme heat events (Wilhelmi and Hayden 2010). Heat-health communication activities face a number of important challenges related to inadequate perceptions of health threat because of the gradual and less dramatic nature of these events and because of high costs of air conditioning which may pose a barrier to use by some vulnerable people (Luber and McGeehin 2008).

Studies have shown mixed results on the effectiveness of HARS communications efforts. A survey of 908 people in four North American cities by Sheridan in 2007 revealed wide spread knowledge of heat warnings. Yet, of the 46 % of people that took protective actions based on the warnings, most adopted only one measure—avoiding the outdoors. In addition, many people could only name one or two of the recommendations made by public health officials through the warnings

(Sheridan 2007). However, recent studies in Toronto, Ontario (Gower et al. 2011) and Montréal, Quebec (Gosselin et al. 2008) have offered more promising findings regarding the success of heat-health communication activities. In Montréal many people that received information from the education campaign “Cet été, soyez cool!” (This summer, be cool!) took a range of protective measures that included using lightweight clothing, avoiding strenuous exercise, taking a shower or bath to cool down, and keeping hydrated. This information is disseminated through electronic media, print media, promotional materials, the health system or personal support networks (Gosselin et al. 2008).

To be effective, communication strategies and materials must be science based, consistent and targeted to the appropriate audiences (Health Canada 2011c). Collaboration with local and provincial health authorities through Health Canada’s heat resiliency initiative revealed the following recommendations for community level heat-health communications activities and approaches (Health Canada 2011c):

- Identify key audiences and their specific communication needs
- Include stakeholders and government partners in communication planning
- Identify clear and realistic communication goals based upon existing resources
- Employ effective communication channels and mechanisms
- Tailor communication products and messages to meet the needs of different audiences
- Develop synergies with existing health promotion campaigns where possible
- Promote through communications activities programs and services that reduce barriers faced by vulnerable populations in taking protective measures
- Consider communication opportunities and challenges faced by different types of communities (rural versus urban)
- Ensure heat-health messages are scientifically sound and do not contradict messages in other health promotion campaigns (e.g. air quality and health, vector-borne diseases, staying active)

Ultimately, HARS need to include proactive communications and outreach activities to identify and provide assistance to vulnerable individuals because simply disseminating heat-health promotion materials will be less effective (Kovats and Ebi 2006). Proactive communication strategies take advantage of multiple dissemination channels (e.g. health networks, interpersonal networks, electronic and print media), are tailored to specific audiences (e.g. use trusted sources and community and group events) and occur over three phases (i.e. before the heat season, during the heat season and during an extreme heat event) (Health Canada 2011c). Communications and outreach activities must be regularly updated based on the latest scientific evidence of heat-health risks. For example, Bobb et al. (2014) found that given recent success in reducing heat-health risks among the eldest segment of the populations (over 75 year of age), future interventions that are broadly targeted to reduce vulnerability over the lifespan should be considered.

Health Canada's Heat-Health Education and Outreach Approach

As part of its initiative to increase the heat resiliency of individuals and communities in Canada, Health Canada has developed a variety of information materials, outreach mechanisms and annual communication strategies to support efforts by individuals and communities to protect people at risk from illness and death associated with extreme heat events. Through consultation with key partners including pilot communities and community organizations (e.g. Canadian Public Health Association, Canadian Medical Association, Canadian Nursing Association, Canadian Red Cross) Health Canada selected target audiences, established communication goals for changing behaviours and developed information products to advance these goals (Table 3).

Case Study—Harmonizing Heat-Health Messaging in Ontario

Ontario is in the process of developing a provincially consistent approach to community management of risks to health from extreme heat. Current measures to protect the public from heat-health risks in Ontario are implemented by a number of public health units and municipalities and range from advanced HARS to very limited activities that simply increase awareness of dangers from heat. This may leave some citizens without resources and assistance during extreme heat events. To facilitate development of a more coordinated approach across public health units, an intergovernmental working group has been established, constituted of public health officials and scientists from the Ontario Ministry of Health and Long-Term Care, Public Health Ontario, local public health units, Health Canada and Environment Canada. The Working Group investigated the status of HARS communication efforts in Ontario to support harmonization of communication approaches and messaging, thereby better protecting public health. In an effort to better understand current heat-health communication practices used in Ontario and identify gaps, two targeted questionnaires were administered in August, 2014. One was sent to 36 Ontario public health units (30 responding) and the other to 390 municipalities (170 responding). The purpose of the questionnaires was to identify how public health units and municipalities are communicating heat alerts (e.g. terminology), what types of heat-health messages are being disseminated to the public, and what population groups are being targeted with these messages.

The findings suggested that a number of public health units and municipalities disseminate heat-health communications to residents while some regions in Ontario do not provide any information on heat-health risks. This gap is prevalent in northern and southern parts of Ontario. Those who do communicate with the public on this issue often communicate in isolation from other jurisdictions, leaving some residents who are exposed to messages from neighbouring jurisdictions struggling to understand alerting terminology and triggers. Analysis of public heat-health messages disseminated by Ontario public health units also revealed broad consistency among messages so that most are unlikely to confuse the public; however,

Table 3 Key elements of Health Canada's heat-health education and outreach approach

Target audience	Communication goals	Information products
Public health officials Emergency management officials Urban planners Non-governmental organizations—for example: • Canadian Public Health Association • YMCA • Canadian Red Cross	• Provide information to support development and implementation of new HARS • Provide information to support efforts to improve existing HARS • Support modification of built environment to mitigate heat • Improve consistency in heat-health messaging across Canada • Build and maintain credibility of Health Canada as a leader on heat-health related issues	Communicating the Health Risks of Extreme Heat Events: Toolkit for Public Health and Emergency Management Officials Heat Alert and Response Systems to Protect Health: Best Practices Guidebook Climate Change and Health: Adaptation Bulletins Adapting to Extreme Heat Events: Guidelines for Assessing Heat Vulnerability Adapting to Extreme Heat Events: Guidelines for Assessing Heat Vulnerability—Workbook
Health professionals—for example: • Dieticians • Respiratory therapists • Occupational therapists • Physiotherapists • Athletic therapists • Personal trainers • Home care providers • Community care workers Non-governmental organizations—for example: • Canadian Medical Association • Canadian Nurses Association	• Increase awareness of heat as a health risk • Increase knowledge of how to diagnose and treat heat-related illness • Increase knowledge of how to prepare health facilities for extreme heat events	Extreme Heat Events Guidelines: Technical Guide for Health Care Workers Extreme Heat Events Guidelines: User Guide for Health Care Workers Factsheets for Health Care Workers
Individual Canadians including vulnerable populations—for example: • Older adults • Parents and caregivers • Children under the age of 4 and their caregivers • Chronically ill persons (e.g. cardiac, respiratory illnesses) • Those who exercise and work outdoors or in hot environments	• Increase awareness of heat as a health risk • Increase knowledge of effective health protection measures	Brochure—It's Way Too Hot! Protect Yourself from Extreme Heat (Seniors) Brochure—You're Active in the Heat. You're at Risk! Protect Yourself from Extreme Heat (Active Canadians) Brochure—Keep Children Cool! Protect Your Child From Extreme Heat (Children) Factsheet—It's Your Health: Extreme Heat Events

some areas for improvement were identified. To achieve better inter-jurisdiction coherence and address information gaps (e.g. symptoms of heat stroke and first response), areas of inconsistencies or inaccuracies in public health messages should be addressed and some messages improved (e.g. include a recommendation to drink liquids before feeling thirsty) (Rogaeva and Berry 2014). As follow-up to the survey, Health Canada reviewed specific messaging from 20 public health units to identify gaps and possibly inconsistent or contradictory messages. Advice on how to strengthen messages based on the scientifically sound heat-messages developed by Health Canada was provided to health officials with the goal of contributing to more harmonized communication efforts in the province.

4.2.2 Testing HARS to Increase Community Preparedness for Extreme Heat Events

Extreme heat events can lead to severe impacts on health when communities and individuals are not prepared for them. Similar to other types of extreme weather events and disasters, extreme heat can affect health due to gaps in knowledge about vulnerable populations, including where they reside, emergency communications, coordination among responding agencies, and resources including surge capacity. Climate variability may change the probability of concurrent events or disasters occurring in a community or region (e.g. severe storm followed by a heat wave). This may significantly raise the possibility of emergency systems and community infrastructures being overwhelmed with adverse impacts on health. Knowledge of existing gaps or weaknesses in emergency plans, partnerships and infrastructures helps to support efforts to increase preparedness for disasters, including extreme heat events.

Table-top exercises that test the community HARS response to extreme heat events bring together partners to discuss a simulated heat event emergency in an informal and safe setting. The exercise often involves decision makers that work through a predefined "simulation" of a heat event in a structured and monitored way to identify gaps and problems with existing response measures and procedures based upon the emergency scenario used (Health Canada 2011d). Extreme heat and health table-top exercises serve to train officials charged with implementing a HARS by focusing on familiarization with procedures and roles and responsibilities as well as to explore the implications of extreme heat during the development of a HARS. Climate change adaptation to the health impacts of extreme heat is supported when table-top exercises are undertaken with one or more scenarios based upon plausible future climate conditions.

Health Canada's Efforts to Support Heat-Health Preparedness Through Table-Top Exercises

The development of HARS to reduce risks from extreme heat is relatively new with the first systems in North America being developed in the late 1990s. Consequently, communities have limited experience using table-top exercises to examine preparedness for extreme heat events and robustness of HARS. In an effort to assist Health Canada's pilot communities (Winnipeg, Manitoba; a rural region in Manitoba, within the former Assiniboine Regional Health Authority; Windsor, Ontario; Fredericton, New Brunswick) test their existing capacity to respond to extreme heat and further the development of their HARS, the department supported one-day table-top simulations in the four communities in 2010. The exercises facilitated discussions among key partners responsible for implementing the HARS plans (e.g. health and social service providers, first responders, emergency response personnel) (Health Canada 2011d). Participants considered a series of worsening extreme heat scenarios (e.g. stresses on the system due to an influx of tourists, power outages and concurrent extreme weather events) for their respective communities in the context of local HARS plans, resources and supporting mechanisms. Communities used results from the simulations about where HARS could be improved to prepare for the next summer heat season. Based on findings from the four simulation exercises, Health Canada published on its website a climate change and health adaptation bulletin "Understanding Community Resilience to Extreme Heat Through Table-top Exercises" to increase awareness of this type of evaluation tool (Health Canada 2011d).

Case Study—Extreme Heat and Health Table-Top Exercise in the City of Winnipeg, Manitoba

As part of efforts to develop a HARS, the City of Winnipeg, with assistance from Health Canada, conducted a table-top simulation exercise at the workshop "Extreme Heat Event Exercise HARS Reality". The exercise was held in Winnipeg on May 26, 2010 and involved 58 stakeholders from a range of governmental and non-governmental organizations (e.g. public health, social services, emergency management, police services, electrical utilities, public transit, first responders, and industry) who have a role in community response to an extreme heat event. The workshop had the following objectives (Health Canada 2010):

- Improve and further develop the HARS and the community's emergency response plan
- Provide a venue through which HARS stakeholders can further understand their roles and responsibilities in an extreme heat event
- Improve communication to stakeholders and the public through enhanced collaboration and coordination

- Identify and further establish critical linkages and partnerships among all stakeholders involved in the HARS

The simulation scenario used by participants was based upon an unseasonably warm and dry summer with a large number of tourists in the area for two large festivals—the 40th Anniversary of Folklorama and Manitoba Homecoming 2010. Once the exercise began, participants were presented with a number of conditions that triggered a response to an extreme heat event including high temperatures, a power outage, shortages of community supplies and large crowds at the festival grounds potentially exposed to high heat conditions. The exercise produced a number of recommendations to enhance the HARS in Winnipeg such as (Health Canada 2010):

Communications—Develop a coordinated strategic communication plan that includes all stakeholders and covers communication activities before, during and after an extreme heat event.
Awareness and Education—Develop and distribute publications that provide information on actions people can take to reduce heat-health risks.
Planning—Organizations participating in the HARS should have a Business Continuity Plan/Emergency Response plan that provides direction in case an extreme heat event occurs and that addresses the needs of vulnerable populations. Plans among stakeholders should be linked to ensure coordinated HARS activities.
Roles and Responsibilities—Increase knowledge of roles and responsibilities among all HARS partners and develop standard operating procedures for the response.
Declaration of Emergency—Develop alert triggers with specific actions for HARS partners associated with each alert level.

Health authorities in Manitoba have used the table-top simulation results to improve efforts to protect populations from extreme heat events.

4.2.3 Preventative Approach to Building Heat Resiliency by Modifying the Built Environment

The design of the built environment—which includes the design of homes, offices, shops, roads, public transit, and parks—can have important impacts on indoor and outdoor thermal conditions in urban areas. The characteristic warming of urban areas, the urban heat island effect, (EPA 2008) is created when impermeable surfaces in cities—such as asphalt roads and parking lots, dark building facades and tar roofs—under the right climate conditions, absorb the sun's radiation and increase both surface and air temperatures. Factors that contribute to UHIs include lack of vegetation, a large area of impermeable surfaces, an urban form (e.g. street canyons) that trap the heat, and anthropogenic heat sources (e.g. factories) (EPA 2008; Dubois 2014). The air temperatures over cities are on average 1–3 °C/1.8–5.4 °F warmer than the surrounding countryside, and up to 12 °C/21.6 °F warmer in places (Oke 1997). During a heat wave, the higher air temperatures in areas characterized by UHIs places added stress on the health of vulnerable people such as seniors and young children (Patz et al. 2005; Harlan et al. 2006; Wilhelmi and Hayden 2010). Increased temperatures in poorly designed outdoor spaces may also discourage people from doing exercise outdoors, thereby having an impact on physical activity levels (Semenzato et al. 2011; Vanos 2015). The more frequent and intense temperatures anticipated because of climate change (Casati et al. 2013; IPCC 2013) could also accentuate urban heat, thereby placing added strain on the health of vulnerable populations.

There is also an important relationship between the design characteristics of buildings and indoor temperatures (Givoni 1992; White-Newsome et al. 2012). Elevated indoor air temperatures are a significant health concern given that North Americans spend a large majority of their time indoors (EPA 1989). Buildings with poorly adapted designs can absorb and trap heat indoors, raising indoor temperatures to levels that are dangerous to the health of residents (Ormandy and Ezratty 2012; White-Newsome et al. 2012). Semenza et al. (1996), in a study investigating causes of death for the 1995 heat wave in Chicago that lead to 700 excess deaths, found that living on the top floor of a building was one of the most important risk factors. In a study of indoor temperatures in 30 different homes in Detroit without air conditioning White-Newsome et al. (2012) found that average maximum indoor temperatures were 13.8 °C/24.8 °F higher than average maximum outdoor temperatures. The authors stated that "indoor exposures to heat in Detroit exceed the comfort range among elderly occupants" and that measures should be taken to retrofit homes to reduce indoor heat exposures (White-Newsome et al. 2012). The higher temperatures found in areas characterized by UHIs can compound indoor overheating that results from design characteristics at the building scale (Mavrogianni et al. 2012).

Measures to reduce UHIs and overheating indoors are complementary. Interventions at the urban scale include increasing vegetation cover by planting trees and shrubs and expanding open spaces, retrofitting buildings to reduce waste heat and improve indoor thermal conditions, and installing cool surface materials such as cool pavements, building facades and roofs (EPA 2008; Rizwan 2008; White-Newsomea et al. 2012; Santamouris and Asimakopoulos 1996). Interventions at the building scale include increasing thermal insulation in the building envelope, maximizing natural ventilation, increasing solar protection (e.g. installing blinds and shutters), and installing energy-efficient appliances (Holmes and Hacker 2007; Santamouris et al. 2011; Coley et al. 2012; Dubois 2014). UHI reduction measures can also have important co-benefits that support community well-being. For example, planting of street trees can help reduce UHIs, as well as reduce energy consumption, improve air quality, enhance biodiversity and reduce stormwater run-off (Tyrväinen et al. 2005). Importantly, actions to reduce UHIs can have significant health benefits. Stone et al. (2014) found that significant reductions in heat-related mortality (40–99 %) could be achieved in Atlanta, Georgia, Philadelphia, Pennsylvania, and Phoenix, Arizona through modifications to the built environment, such as enhanced tree canopies and more reflective, less heat-absorbing surfaces. Improvements in park and playground designs may also contribute to increases in physical activity (McCormack et al. 2010).

Development of Information and Tools at Health Canada to Mitigate the Urban Heat Island

Health Canada has been working with communities since 2009 to help identify the causes of UHIs and support approaches to reduce heat-related illnesses and deaths (Richardson et al. 2015). Health Canada has developed a five pillar approach to its work on heat, health and the built environment. First, stakeholder needs were identified between 2010 and 2011 through a series of workshops across Canada. Subsequently, Health Canada collaborated with communities on pilot projects to develop UHI mitigation strategies, worked with partners in developing UHI-related decision support tools such as heat vulnerability maps and design guidelines, supported research to better understand the health impacts of UHIs, and developed various communication and outreach materials to share best practices with stakeholders.

Since 2012, Health Canada has supported six pilot communities (Windsor, Ottawa, London, York Region and Peel Region in Ontario, and Vancouver, British Columbia) to identify the causes of UHIs and propose and implement intervention strategies. Health Canada encouraged pilot communities to develop multi-stakeholder steering committees that include individuals from municipal departments including public health, urban planning, public works and parks and recreation. These steering committees have been an important tool to prompt interest and support for the projects and advance UHI actions on the ground. The co-benefits of UHI actions have emerged as a key driver for these projects since many of the UHI actions are integrated into plans and policies that address other municipal issues. Reducing UHIs and improving thermal comfort, for example, can be included as a component of a city's urban tree canopy plan or integrated within green building guidelines or standards. Health Canada disseminates results from the community pilot projects to stakeholders across Canada in presentations and case studies with the goal to help raise awareness of these initiatives and spur similar actions by other Canadian communities. In some communities, Health Canada has worked with partners to develop decision-support tools such as UHI maps for evidence-based decision-making. The following Windsor case study is an example of a pilot community project.

Case Study—Measures to Reduce the Urban Heat Island Effect in Windsor, Ontario

The City of Windsor (population 216,000), located directly across the Canada-US border from Detroit, is Canada's southernmost city. Extreme heat is a significant health issue for local residents, particularly for the city's most vulnerable populations. On average, the maximum temperature in the City exceeds 30 °C/86 °F 23 days a year. Climate projections show the number of extreme heat days are expected to almost double over the next 60 years (Casati et al. 2013). The UHI effect, which is pronounced in various parts of Windsor such as the downtown and industrial areas, is expected to exacerbate health risks from heat.

Between 2009 and 2010, the City collaborated with Health Canada to develop a HARS called "Stay Cool Windsor-Essex" (Berry et al. 2011). The HARS identifies when heat becomes a public health concern and activates a communication campaign and an emergency public health response plan aimed to reduce health risks. Windsor and Health Canada have since continued their collaboration, focusing efforts on developing preventative actions that reduce the urban heat island effect and improve outdoor thermal comfort for active living. Between 2010 and 2012, the City developed a comprehensive Climate Change Adaptation Plan (City of Windsor 2012). Among other recommendations, the plan called for the City to complete an urban heat island study. The City has since completed the following steps to help reduce UHIs:

Assessment of urban heat island reduction measures in Windsor (De Carolis 2012)—The City mapped UHIs and then conducted an assessment of UHI reduction measures (such as white roofs, green roofs, street trees). A report was produced with targeted recommendations for action at the local level. Recommendations included installing cool roofs on city-owned buildings, increasing natural area coverage across Windsor, and incorporating thermal comfort considerations in the design of sports fields, playgrounds and parks.

Assessment of thermal comfort in Windsor's parks and playgrounds (Blanchard 2013)—The City conducted an assessment of outdoor thermal comfort conditions in six of Windsor's parks and playgrounds. The report made recommendations about how the City could improve thermal comfort in parks, including planting shade trees, installing built shade structures such as shade sails and gazebos, and installing lighter coloured rubberised mats in playgrounds and sports fields.

Draft Parks Master Plan (2015)—The City prepared a draft "Thermal Comfort" chapter for inclusion in Windsor's updated Parks Master Plan (expected to be published in 2015). The chapter summarizes the scientific literature on thermal comfort and sets out high level design and policy recommendations.

The City used findings from the UHI studies to inform measures to reduce risks from extreme heat. Since 2007, Windsor has installed five green roofs and two reflective roofs on municipal buildings. When roofing materials are ready for replacement, efforts have been made to replace dark shingles with more reflective alternatives. In addition, since Council's approval of the thermal comfort report in 2013, the Parks and Recreation Department has integrated various design features (which include planting trees, installing shade structures such as gazebos, constructing water features such as splash pads, and using lighter coloured artificial mats under playground equipment) into five city parks that were being retrofitted.

Windsor's success in integrating UHI-related considerations into City policy and operations comes down to several factors. First, the UHI projects have had strong local champions and collaboration across departments. The City's Environmental

Coordinator has championed heat resiliency and UHI projects and elected City Councillors and senior managers in departments across the City (including Parks, Engineering, Planning and Forestry) have been receptive to incorporating novel ideas and practices into their work. Another key lesson learned is the importance and utility of UHI maps for engaging key officials such as planners, engineers, and parks staff. These maps have been used as a tool to identify the location of impervious surfaces and to prioritize efforts to both mitigate UHIs and reduce storm water volumes. This case study also demonstrates the importance of leadership within municipal governments in taking adaptation action. In just two years, the City has moved from a study about thermal comfort in parks and playgrounds to having five parks retrofitted with design features such as splash pads, trees, lighter coloured rubberised mats and artificial shade structures.

4.2.4 Multi-sector Collaboration on Heat-Health Adaptation to Achieve Health Co-benefits

Individuals and communities can achieve large health co-benefits through multi-sectoral and integrated approaches to climate change adaptation and greenhouse gas mitigation (Frumkin and McMichael 2008; Haines et al. 2009; Cheng and Berry 2013; Ebi et al. 2013). Significant opportunities to improve health and well-being are forfeited when measures are developed in the absence of such considerations. Taking a preventative approach to climate change and health adaptation by addressing the built environment can have multiple knock-on effects. The second Lancet Commission on Health and Climate Change states that "tackling climate change could be the greatest global health opportunity of the 21st century" (Watts et al. 2015).

Actions that help communities adapt to climate change, reduce fossil fuel use and improve air quality (e.g. designing streets to improve thermal comfort and promote walking and cycling) could have multiple co-benefits including reduced greenhouse gas emissions and lower rates of chronic diseases such as coronary heart disease and obesity. For example, changes in urban design to encourage active transportation can both help increase physical activity levels and build resilience to climate change. Human comfort in outdoor spaces is linked to various climate parameters including air temperature and exposure to sun and wind (Nikolopoulou and Lykoudis 2006). Well-designed outdoor spaces with shade trees, open space and appropriate paving materials can help reduce localized air temperatures and minimize direct human exposure to the sun, both of which increase human comfort on hot summer days and support higher physical activity levels (Brown and Gillespie 1995). The higher rates of physical activity through walking and biking in these spaces in turn helps reduce various health risks such as cardiovascular disease, diabetes mellitus and depression (Younger et al. 2008). Well-designed public spaces (e.g. streets, parks, playgrounds) with trees and vegetation can also help reduce UHIs, which provides additional co-benefits such as reducing greenhouse gas emissions and helping cities adapt to the higher number of extreme days anticipated from climate change (EPA 2008).

A significant concern among health decision makers is that climate change could exacerbate health and socio-economic inequalities due to the projected impacts on more vulnerable populations (Rudolph et al. 2015). However, health focused modifications to the built environment could help mitigate these impacts. For example, maintaining the conditions of buildings (i.e. including homes, offices, and health care facilities) can improve the health of occupants, including people at higher risk to health impacts of extreme heat (e.g. people of low socio-economic status and people with cardiovascular disease). Many conditions associated with substandard housing such as mold, pests, lack of safe drinking water, and inadequate heating or cooling, waste disposal, and ventilation systems can affect health through respiratory illnesses, asthma, infectious diseases, injuries and mental health disorders. Vulnerable populations such as people with low socio-economic status and racial minorities are more likely to have substandard housing and may have underlying health conditions that can exacerbate these health effects (Younger et al. 2008). In addition, changes to the built environment, particularly those that support exercise, can have health benefits for seniors (e.g. lower rates of functional decline and dementia) (Younger et al. 2008), a population group that is highly vulnerable to health impacts from extreme heat.

Case Study—Toolkit for Increasing the Resiliency of Health Care Facilities to Climate Change Impacts Including Extreme Heat Events

Climate variability and change will impact the health care sector and create risks—including risks from extreme heat events—for hospitals and other facilities (Guenther and Balbus 2014; Paterson et al. 2014). Increased admissions to hospital facilities are often observed during extreme heat events (McGregor et al. 2015). During the 1995 heatwave in Chicago 23 hospitals were so overwhelmed by the influx of patients that they had to close the doors of their emergency rooms to new patients (Klinenberg 2002). A more recent heat wave in India in May-June 2015 that caused more than 2500 deaths (Bagcchi 2015) resulted in the government cancelling leave for all doctors in affected areas because hospitals were being overwhelmed with patients suffering from heat-stroke (Bhalla 2015).

Health care facilities play a critical role in treating climate-related illnesses and injuries, caring for patients during and after disasters and participating in community efforts to adapt to and mitigate climate change. Opportunities exist for these facilities to prepare for potential multiple hazards, including extreme heat events, and achieve significant co-benefits by taking simple actions to increase preparedness for climate change (Fig. 3).

Health care facilities, to be resilient, need to assess climate change risks and vulnerabilities in order to be able to adopt adaptive management strategies. A toolkit was developed to do this in Canada. Six health care facilities in three provinces piloted a draft toolkit developed by the Canadian Coalition for Green

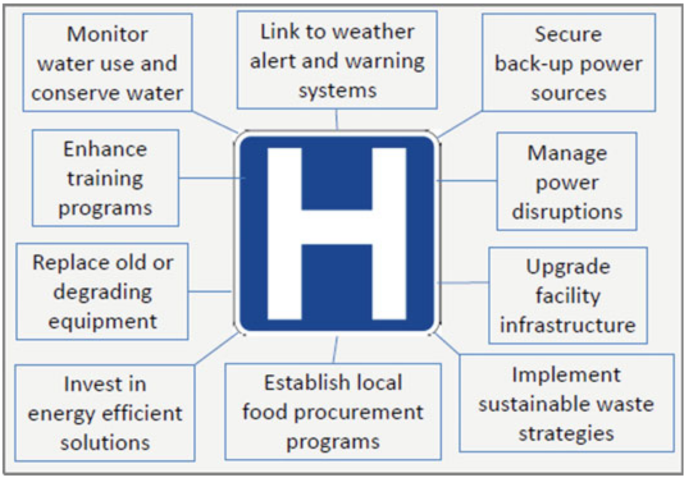

Fig. 3 Examples of climate-resiliency measures for health care facilities. *Source* Paterson et al. (2014)

Health Care (Paterson et al. 2014). The toolkit helps health care facility officials identify gaps in climate change preparedness, direct allocation of adaptation resources and inform strategic planning to increase resiliency to climate variability and change.

The final health care facility resiliency toolkit includes an Assessment Checklist with 82 questions in four areas: general facility information (n = 4), assessing climate-related risks (n = 19), risk management (n = 45), and building capacity to adapt to climate change (n = 14). It includes a Facilitator's Guide with background information on climate change risks to health care facilities and facilitator instructions. A Best Practices Resource Guidebook in the toolkit presents information on effective adaptation measures that may be used to address areas of vulnerability identified through application of the checklist. The toolkit is available for download at: http://greenhealthcare.ca/climateresilienthealthcare/.

5 Lessons for Supporting Heat-Health Adaptation and Building Resiliency to Other Climate Change Impacts

> Collaboration between the research and public health communities is essential for addressing the climate change and human health challenge. We need to ensure that significant research findings are integrated into public health planning, as well as ensure that researchers are addressing the topics of greatest concern. (John Balbus as cited in Kelly 2013)

The urgent challenge posed by climate change for human health represents a problem of enormous complexity (Frumkin and McMichael 2008). Multiple impacts (direct, indirect, cascading, and synergetic) operate through a host of interlinked factors such as population sensitivities, place-based vulnerabilities and the adaptive capacities of associated natural and human systems (Gosselin et al. 2011), all of which need to be taken into account through adaptation. Scientific uncertainty and insufficient information to guide the development, implementation and evaluation of measures to reduce risks to health from climate change are significant barriers to adaptation (Huang et al. 2011). One study in the US identified a lack of knowledge about climate change impacts on health, insufficient expertise to identify adaptation options, and limited human and financial resources as key barriers to taking adaptive actions (Maibach et al. 2008). Significant financial and social costs may arise when adaptation actions are delayed because of such barriers (Snover et al. 2007).

Through its activities with partners to increase the resiliency of Canadians to extreme heat events, Health Canada facilitated development of community level information about vulnerabilities, adaptations and requirements to support and sustain actions by decision makers. Efforts to address climate change impacts on health must recognize the importance and value of local knowledge and of community and regional approaches (Pang et al. 2015). These efforts also need to be based upon meaningful engagement of stakeholders through adaptive management using iterative processes. Such processes support the ability to respond to changes in climatic and non-climatic factors and to advance program goals such as considerations of equity when designing public health interventions (Fook 2014). In addition, broader understanding of socio-economic and cultural characteristics of a population and multi-directional relationships between them is necessary to increase the effectiveness of climate change and health adaptation efforts (Ebi 2011).

Future efforts to adapt to the growing health risks from extreme heat events will benefit from improving knowledge of individual and community level vulnerabilities and of effective adaptation measures within and outside the health sector. Knowledge needs include:

- Climate modeling and projections of future impacts in relevant timescales (Clarke and Berry 2012) for adaptation planning to ensure that communities are prepared for extreme events that may exceed historical trends
- Effectiveness of existing HARS and options to increase their effectiveness
- Application of specific research methods and communication techniques suited to public health decision-making to reduce heat-health risks, such as spatial mapping of vulnerabilities or syndromic surveillance
- Information about how co-benefits can be achieved through cross-disciplinary studies of efforts to reduce greenhouse gases, make communities resilient to climate change impacts (e.g. flood mitigation, UHI mitigation) and adapt to the health impacts of extreme heat (e.g. build social capital)
- Incorporation of land-use patterns into models that project climate impacts related to extreme heat events over time in urban areas (Stone et al. 2010)
- Social and intergenerational equity implications of climate change impacts, resilience actions and cost implications of adaptations

- Nonlinearity and thresholds in climate impacts that could affect health—for example massive tree die-offs due to heat waves
- The impact of increased heat on work productivity (Kjellstrom et al. 2009) and implications for health.

Reducing health risks from extreme heat events requires close collaboration and planning across a number of sectors (Semenza 2011). For example, development of HARS in Health Canada's pilot communities required involvement of representatives from health, meteorology, emergency management, social services, and transportation sectors, among others. Efforts to take a preventative approach and reduce the UHI in a community often must be implemented by other sectors including urban planning, parks, and public works.

5.1 Addressing Vulnerability Factors for Effective Heat-Health Adaptation

Heat-health vulnerability factors—based upon physical, physiological, social and environmental characteristics that predispose populations to heat illness and death—can differ widely among communities. For example, Johnson et al. (2014) found important spatiotemporal variations in health risk to extreme heat events among residents in Chicago, Illinois, Indianapolis, Indiana and Dayton, Ohio between the year 1990 and 2010. Inherent complexity in the understanding and management of heat risks to health requires an interdisciplinary approach to understanding social vulnerability (Wilhelmi and Hayden 2010). Health Canada followed an interdisciplinary approach to support development of heat-health adaptations that were tailored for communities and informed by local knowledge about demographic, decision-making or place-based characteristics that either supported or challenged adaptation efforts.

To develop heat alert protocols and thresholds, pilot communities in Canada used information and data from scientific literature reviews, historical meteorological data, demographic and health outcome data, and information about vulnerability characteristics. The required scientific evidence base to inform early warning systems must therefore be developed through multi-level (federal to local) interdisciplinary collaboration that includes attention to key factors in the community that affect the vulnerability of local populations to extreme heat events (Yardley et al. 2011). Higher level national health authorities can help through consensus definitions of heat-related health outcomes and development of effective surveillance and program evaluation methodologies. Community level public health officials contribute by developing knowledge of local level vulnerabilities and of effective HARS strategies tailored to specific physical and social environments (Yardley et al. 2011).

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