Rapid Synthesis

Identifying Adaptation Interventions in Built Environments that Reduce the Risks to Human Health Due to Climate Change

23 September 2022

McMaster University | HEALTH FORUM

EVIDENCE >> INSIGHT >> ACTION

Rapid Synthesis:
Identifying Adaptation Interventions in Built Environments that Reduce the Risks to Human Health Due to Climate Change
30-day response

23 September 2022

McMaster Health Forum

The McMaster Health Forum's goal is to generate action on the pressing health-system issues of our time, based on the best available research evidence and systematically elicited citizen values and stakeholder insights. We aim to strengthen health systems – locally, nationally, and internationally – and get the right programs, services and drugs to the people who need them.

Authors

Marcela Vélez, PhD, Senior Lead, Innovative Evidence Products and Spanish Outreach, McMaster Health Forum

Téjia Bain, M.Sc., Co-lead, Evidence Synthesis, McMaster Health Forum

Aunima R. Bhuiya, M.Sc., Co-lead, Evidence Synthesis, McMaster Health Forum

Safa Al-Khateeb, MPH, Engagement Coordinator, McMaster Health Forum

Michael G. Wilson, PhD, Assistant Director, McMaster Health Forum, and Assistant Professor, McMaster University

Timeline

Rapid syntheses can be requested in a three-, 10-, 30-, 60- or 90-business-day timeframe. This synthesis was prepared over a 60-business-day timeframe. An overview of what can be provided and what cannot be provided in each of the different timelines is provided on McMaster Health Forum's Rapid Response program webpage (www.mcmasterforum.org/find-evidence/rapid-response).

Funding

The preparation of this rapid synthesis was funded by the British Columbia Ministry of Health. The McMaster Health Forum receives both financial and in-kind support from McMaster University. The views expressed in the rapid synthesis are the views of the authors and should not be taken to represent the views of the British Columbia Ministry of Health or McMaster University.

Conflict of interest

The authors declare that they have no professional or commercial interests relevant to the rapid synthesis. The funder played no role in the identification, selection, assessment, synthesis or presentation of the research evidence profiled in the rapid synthesis.

Merit review

The rapid synthesis was reviewed by a small number of policymakers, stakeholders and researchers in order to ensure its scientific rigour and system relevance.

Citation

Vélez M, Bain T, Bhuiya AR, Al-Khateeb, Wilson MG. Rapid synthesis: Identifying adaptation interventions in built environments that reduce the risks to human health due to climate change. Hamilton: McMaster Health Forum, 23 September 2022.

Product registration numbers

ISSN 2292-7999 (online)

KEY MESSAGES

Question

- What does the evidence say about adaptation interventions in built environments that reduce health risks due to climate change?

Why the issue is important

- Climate change is greatly influencing the lives of all Canadians by increasing the health risks of populations and vulnerabilities of built environments.
- Built environments include infrastructures that are part of the everyday physical surroundings of people, such as buildings, parks, houses, and road systems, and therefore can play an important role in reducing health risks from climate change.
- The federal government and some provincial and territorial governments have released climate resilience plans that include adaptation interventions in built environments that reduce the risks of climate change on human health.
- To inform these and any future efforts, there is a need to identify research evidence and experiences on adaptation interventions in built environments that can reduce health risks due to climate change.

What we found

- We identified 34 relevant documents, which included 10 systematic reviews, two non-systematic reviews, and 22 single studies that provided data analytics (n=8), qualitative insights (n=6), modelling (n=5), implementation/behavioural insights (n=1), evaluations (n=1) and technology assessment/cost-effectiveness assessment (n=1).
- We assessed each for relevance and categorized them as high (n=15), medium (n=14), or low (n=5) relevance to the question.
- According to a modelling study, a combination of adaptation strategies (green walls, sidewalk greenways, increased-albedo sidewalks, and street trees) could reduce the number of extreme heat days and the average mean of radiant temperatures by the 2050s in a scenario of governmental commitment with other climate adaptations, but in a "business as usual" scenario and no interventions to mitigate climate change, green walls, sidewalk greenways, and reduced-albedo sidewalks could not provide adequate adaptation effects by the 2050s, and only street trees offered sufficient reductions in the impacts of climate.
- Cooling centres have the potential to provide relief for the public during extreme heat events, principally for the most vulnerable populations, but their use has been found to be inconsistent, and residents have faced access barriers including safe and affordable transportation, easy identification of the location, concerns about health and safety, hygiene, culturally appropriate food, and stigma.
- Five studies also found that cool roofs that include new materials and reflective surfaces are effective as a single intervention in reducing outdoor and indoor temperatures, but the benefit depends on the house's characteristics (principally the number of stories and the height of the roof).
- One low-quality systematic review and two single studies found that green roofs/walls are beneficial for reducing indoor and outdoor temperatures, but their use is limited by high initial costs and a lack of awareness about the long-term benefits.
- One medium-quality systematic review focused on the U.K. and two studies conducted in the U.S. found that installing and using air conditioners is an effective intervention to increase indoor thermal comfort and reduce heat-related morbidity and mortality; however, studies identified racial and socio-economic disparities (e.g., one study found that given financial barriers, 28% of New Yorkers did not have access to a functioning air conditioning (AC) or used it less than half the time or not during sweltering weather).
- Some studies indicated that air conditioners might not be an eco-friendly solution given the increased consumption of electrical or fossil energy associated with their use, and that the outdoor temperatures of neighbourhoods with high use of AC are commonly higher than neighbourhoods with less use of AC.
- One medium-quality systematic review found that households struggle to build long-term adaptive capacity (e.g., tiling floors, relocating electrical fittings, and removing impermeable surfaces), adoption of such measures are only expected to be adopted if government or insurers offer financial incentives, and in

the interim that flood-proofing measures can be rolled out quickly and temporarily (e.g., door guards, toilet plugs, and airbrick covers).

- We only identified one single study addressing adaptations to wildfires, which found that in eight locations affected by destructive wildfires, authorities did not change the tools and actions used for wildfire mitigation and planning, and local and state governments declined to take more significant action on land-use planning or building standards in response to these wildfires.
- We also conducted a scan of select jurisdictions (Australia, New Zealand, Germany, France, United Kingdom, United States – California, Massachusetts, Oregon, Minnesota, New York) and all Canadian provinces and territories to identify real-world approaches to adaptation interventions in built environments that aim to reduce the risks to human health due to climate change.
- Some jurisdictions described approaches to improve healthier neighbourhood designs such as land-use planning policies and guidance (France, United Kingdom) and educational programs for the public (Ontario).
- Many jurisdictions are providing homeowner incentives to support energy-efficient initiatives and tools for communities to assess risk to environmental hazards (Minnesota, Massachusetts, New York, California, British Columbia, Nova Scotia).
- There are efforts to reduce transportation emissions by some jurisdictions such as New Zealand, France, and Canada, specifically around the development of zero-emission transit options and sustainable transportation infrastructure.
- Related to improving natural environments, New Zealand has adopted a Green Star Accreditation system for public buildings, and New York and Canada have programs that promote green infrastructure and reforestation
- We identified limited information about improving food systems through the jurisdictions' climate change and healthy city plans.

QUESTION

What does the evidence say about adaptation interventions in built environments that reduce health risks due to climate change?

WHY THE ISSUE IS IMPORTANT

Climate change is greatly influencing the lives of all Canadians by increasing the health risks of populations and vulnerabilities of built environments. Specifically, there is an increasing number of reports of climate-related hazards such as flooding, heat events (e.g., heat domes and wildfire), poor air quality, and other extreme weather events.

Built environments include infrastructures that are part of the everyday physical surroundings of people such as buildings, parks, houses, and road systems. According to the 2021 Report on Health and Planning in Canada, there has been growing awareness from health and community planners of the impact of the built environment on health and on climate change.(1) The federal government and some provincial and territorial governments have released climate resilience plans that include adaptation interventions in built environments that reduce the risks of climate change on human health. Recently, the Government of Canada announced funds for climate resilient infrastructure initiatives through the Climate Resilient Built Environment initiative.(2)

In British Columbia (B.C.) (where this rapid synthesis was requested from), the Healthy Built Environment Linkages Toolkit outlines five core features of a healthy built environment from a recently updated scoping review: 1) neighbourhood design; 2) housing; 3) transportation networks; 4) natural environments; and 5) food systems. According to the toolkit, healthy neighbourhood design involves land-use decisions that focus on building compact communities with mixed land use and increased opportunities for connectivity with efficient and safe networks. Housing refers to the design, quality, and affordability of options that promote health and well-being. This could include different housing forms and tenure types, specialized housing for equity-deserving populations, and approaches to minimize exposure to environmental hazards. Approaches to transportation systems involve the design of networks that prioritize safe, accessible, and active transportation.(3) Natural environments include community planning that aims to preserve and connect environmentally sensitive areas, maximize accessibility for everyone, and reduce urban air pollution.(3) Food systems relate to the affordability and accessibility of healthy foods through the protection of agricultural land, community-based food programs, and land-use planning and design.(3)

Given the importance of the issue, there is a need to identify research evidence and experiences on adaptation interventions in built environments that reduce the risks to human health due to climate change.

Box 1: Background to the rapid synthesis

This rapid synthesis mobilizes both global and local research evidence about a question submitted to the McMaster Health Forum's Rapid Response program. Whenever possible, the rapid synthesis summarizes research evidence drawn from systematic reviews of the research literature and occasionally from single research studies. A systematic review is a summary of studies addressing a clearly formulated question that uses systematic and explicit methods to identify, select and appraise research studies, and to synthesize data from the included studies. The rapid synthesis does not contain recommendations, which would have required the authors to make judgments based on their personal values and preferences.

Rapid syntheses can be requested in a three-, 10-, 30-, 60- or 90-business-day timeframe. An overview of what can be provided and what cannot be provided in each of these timelines is provided on the McMaster Health Forum's Rapid Response program webpage (www.mcmasterforum.org/find-evidence/rapid-response)

This rapid synthesis was prepared over a 30-business-day timeframe and involved three steps:

1) submission of a question from a policymaker or stakeholder (in this case, the British Columbia Ministry of Health);
2) identifying, selecting, appraising and synthesizing relevant research evidence about the question; and
3) drafting the rapid synthesis in such a way as to present concisely and in accessible language the research evidence.

WHAT WE FOUND

From our searches (see Box 2 for our search strategy), we identified 34 relevant documents, which included 10 systematic reviews, two non-systematic reviews, and 22 single studies that provide data analytics (n=8), qualitative insights (n=6), modelling (n=5), implementation/behavioural insights (n=1), evaluations (n=1) and technology assessment/cost-effectiveness (n=1). We assessed each for relevance and categorized them as high (n=15), medium (n=14), or low (n=5) relevance to the question.

We also conducted a jurisdictional scan of select jurisdictions (Australia, New Zealand, Germany, France, United Kingdom, United States – California, Massachusetts, Oregon, Minnesota, New York) and all Canadian provinces and territories to identify real-world adaptation interventions in built environments that reduce health risks due to climate change within each of these jurisdictions. Within each country, we reviewed national and sub-national documents that were publicly available. Additional details are provided in Tables 2 and 3.

Key findings from the research evidence

We identified 34 relevant documents, which were categorized according to the following framework:

- Healthier neighbourhood design
  - Urban vegetation, street trees and green canopy
  - Cools roofs, green roofs and green walls
  - Cool pavements and increased-albedo sidewalks
  - Cooling centres
  - Superblocks
- Housing
  - Air conditioning units
  - Cool and/or reflective roofs
  - Green roofs and walls
- Transportation systems
- Natural environments
- Food systems

Box 2: Identification, selection and synthesis of research evidence

We identified research evidence (systematic reviews, other types of reviews, and primary studies) by searching (in August 2022) Social Systems Evidence, and PubMed. In Social Systems Evidence we searched for adapt* AND health combined with all the topics included under the program and services filter for climate action, and those related to recycling, waste, environmental resilience and environmental-threats management under the program and services filter for environmental conservation. In PubMed, we searched for meta-analyses, reviews and systematic reviews published within the last 10 years using the following combination of terms: climate change AND (resilien* OR adapt*) AND build AND (floods OR wildfires OR heat waves).

We supplemented these searchers with hand searches of government resources from select jurisdictions and the provinces and territories in Canada.

The results from the searches were assessed by one reviewer for inclusion. A document was included if it fit within the scope of the questions posed for the rapid synthesis.

For each systematic review we included in the synthesis, we documented the focus of the review, key findings, last year the literature was searched (as an indicator of how recently it was conducted), methodological quality using the AMSTAR quality appraisal tool (see the Appendix for more detail), and the proportion of the included studies that were conducted in Canada. For primary research (if included), we documented the focus of the study, methods used, a description of the sample, the jurisdiction(s) studied, key features of the intervention, and key findings. We then used this extracted information to develop a synthesis of the key findings from the included reviews and primary studies.

Findings from the included evidence documents are organized using this framework in Table 1 in relation to the three threats/hazards that pose the largest risk to population health (flooding, heat-dome events and wildfires).

Most of the evidence found in this rapid synthesis focused on heat-dome events (nine systematic reviews, two non-systematic reviews, and 20 single studies), some of the studies addressed flooding (two systematic reviews and two single studies), and only one single study focused on wildfires. We present findings below in relation to those that provide general insights about adapting the built environment to reduce health risks from climate change, followed by findings specific to adapting built environments for heat-dome events, flooding and wildfires.

General findings about adapting the built environment to reduce health risks from climate change

A low-quality systematic review mentioned that many actions to combat climate change (e.g., appropriate mitigation strategies in transport, household energy, food and agriculture, and power generation) could bring substantial health co-benefits.(4) Moreover, a non-systematic review with a global focus assessed the state of public-health adaptation in 401 urban areas with more than 1 million people.(5) The authors found that only 10% of the sampled urban areas reported public-health adaptation initiatives. Those initiatives most frequently address risks posed by extreme weather events and involve immediate changes in management or behaviour rather than capacity building, research, or long-term investments in infrastructure. The authors highlighted that a large majority of municipalities sampled (90%) were not reporting any public-health adaptation initiative implementation. Several cities reported risk from extreme heat (88 cities) and more frequent storms (43 cities), but did not have an adaptation plan, suggesting a time lag between cities' self-reported recognition of risk and the formation of existing programs.

One medium-quality systematic review reported health co-benefits of seven categories of urban climate change adaptation measures.(6) Authors found various solutions ranging from the individual building scale (e.g., green roofs), to neighbourhood scale (e.g., neighbourhood parks, bicycle lanes), to city-wide networks of green and blue spaces. Urban planning and design measures that promote walkability and ensure outdoor thermal comfort can provide multiple benefits by enhancing physical activity, improving air quality, and creating environments conducive to mental health and well-being. Early warning systems for climate change events can improve well-being and reduce mortality, disease risk, or adverse health impacts. Another low-quality systematic review found minimal research available to offer assessments of different urban-scale morphologies and urban-scale adaptation planning.(7) The authors suggested that building codes and guidelines could facilitate climate-responsive buildings that have the potential to change user behaviour during extreme weather events. However, it was noted that retrofitting existing buildings is expensive, and therefore governments must be cautious to avoid potential negative impacts on social equity.(7)

Some studies emphasized that some strategies might not benefit the most vulnerable populations. For instance, a multiple case study in the United States found that emergency preparedness plans, heat-health warning systems, and related interventions may not be reaching or supporting behaviour change among those most vulnerable to heat events.(8) A cross-sectional study also reported that countries with solid institutional frameworks for environmental governance and/or incentive structures are likely to be higher adoptors to climate change.(9) The study determined that GDP is significantly related to health adaptation. Still, at the same time, weaker performance among some of the world's wealthiest countries indicates that resource availability alone may be insufficient to provoke high levels of adaptation in the absence of policy commitments. It was suggested that barriers to adaptation exist within high-income countries that limit how much adaptive capacity translates into health adaptation action.(9)

Adapting built environments for heat-dome events

We identified eight systematic reviews, two non-systematic reviews, and 20 single studies related to adapting built environments for heat-dome events.

Healthier neighbourhood design

One low-quality systematic review examined how national-level public-health adaptation to climate change occurs in OECD countries.(10) The authors found 175 discrete health-adaptation initiatives, with Canada contributing 28 of those. The findings of the review suggest that national governments are primarily addressing infectious disease and heat-related risks posed by climate change, typically emphasizing capacity building or information-based groundwork initiatives. However, in this review, only Belgium reported adaptations on construction and infrastructure, that specifically focused on regulations for transforming facilities to ensure thermal comfort of the buildings and their occupants (thermal insulation, solar protection shutters, ventilation).(10)

One study reported on a survey of planning professionals from diverse cities across the United States and found that numerous strategies have been proposed to enhance resilience to extreme heat. However, no clear evidence of effectiveness was found.(11) The analyzed were grouped by a focus on heat mitigation or heat management. Heat-mitigation strategies refer to design and planning interventions to reduce the contribution of the built environment to extreme heat (e.g., land-use policies, urban design, urban greening, and waste heat). In contrast, heat-management strategies include efforts to prepare for and respond to extreme heat (e.g., strategies related to energy, personal exposure, public health, and emergency preparedness).

Regarding heat-mitigation strategies, the authors of the study found that urban-design strategies contribute with site-level elements that mitigate heat, such as building and street orientation to maximize shade, constructed shade structures, and using "cool" or more reflective pavements. Moreover, it was found that urban-forestry strategies like green stormwater infrastructure, green roofs or parks, and increasing vegetation are commonly cited as heat-resilience strategies. In addition, heat management strategies include energy-related strategies, such as enhancing energy-grid resilience to avoid power outages during heat events and policies to make energy and cooling more accessible and affordable. Other public-health interventions essential to adapt and mitigate the effects of heat-dome events include public education and information campaigns, emergency-preparedness strategies focused on warning systems for extreme heat, and planning and coordinating responses to heat emergencies.(11)

One qualitative study in the Netherlands explored potential governance arrangements between public and private actors for mitigating heat-dome events by analyzing the perceived responsibilities of different stakeholders.(12) The authors interviewed various stakeholders and explored their perceived responsibilities, concluding that "cool" governance implies extensive public responsibilities throughout the policy process. It was also noted that policy implementation needs public-private networks tailored to these differentiated approaches. The authors suggest that some of the public sector's responsibilities include installing or subsidizing air conditioners for low-income, vulnerable older adults, and turning public buildings into cooling centres during a heat wave in districts with high concentrations of vulnerable citizens.

A documentary study focused on five Mediterranean-type climate cities (Adelaide, Barcelona, Cape Town, Los Angeles and Santiago) identified three types of policy tools to adapt to heat-related threats to public health.(13) The study identified three types of policies that can be considered for inclusion in urban design, which focus on policies for: improving surface cover to increase reflectivity; increasing urban tree canopy and generating air movement through urban corridors; heatwave management; and reducing emissions.

We also identified evidence in relation to the five specific adaptation interventions for healthier neighbourhood design outlined in the organizing framework above, which relate to: urban vegetation, street trees or green canopy; cool roofs, green roofs, and green walls; cool pavements or reduced-albedo sidewalks; cooling centres; and superblocks.

Urban vegetation, street trees and green canopy

This intervention refers to expanding urban vegetation and trees, including measures such as urban nature protection, increasing the share of urban greenery (e.g., urban trees, parks, and gardens), and creating connected networks of parks and green spaces. Four evidence syntheses and two single studies addressed urban vegetation as an efficient intervention for healthier neighbourhood designs. One medium-quality systematic review found that many interventions have health and well-being co-benefits. Some of these benefits include thermal comfort that minimizes health issues caused by heat stress (principally for vulnerable social groups such as the elderly), and mental/physical health benefits.(6) The authors emphasized the benefits of mitigating the urban heat island (UHI) effect, and found that areas with a higher level of green coverage exhibit lower temperatures, with urban green coverage having the most significant mitigation effect on reducing heat-related mortality. One low-quality systematic review also suggested that the only building

intervention able to sustain benefits for people and the environment is to increase regular vegetation and trees in general.(7)

A non-systematic review assessed public-health adaptations in 401 urban areas with more than one million people worldwide, and found that most heat-related initiatives aim to reduce the long-term effects of the UHI through green-infrastructure projects.(5) Such projects included expanding the urban tree canopy and converting rooftops into vegetable gardens. A documentary study focused on five Mediterranean-type climate cities (Adelaide, Barcelona, Cape Town, Los Angeles and Santiago) reported that Adelaide and Los Angeles emphasized increasing vegetation and tree canopy that provides shade and cooling temperatures and reduces the UHI effect.(13)

A modelling study, aimed to determine the effect of adaptation strategies to reduce the mortality risk under two climate-change mitigation scenarios: RCP2.6 (Representative Concentration Pathways representing the closest pathway to 1.5◦C climate-change mitigation pathway described in the Intergovernmental Panel on Climate Change -IPCC- special report) and RCP8.5 (Representative Concentration Pathways representing a business-as-usual scenario with no mitigation efforts, and an increase in temperature over 3◦C).(14) The study found that green walls, sidewalk greenways, reduced-albedo sidewalks and street trees could alleviate the increase in extreme heat under RCP2.6 to reduce the number of extreme heat days (EHDs) to below 10 and the Average Mean Radiant Temperature (AMRT) to below 55.88◦C by the 2050s. However, under RCP8.5, green walls, sidewalk greenways, and reduced-albedo sidewalks could not provide adequate adaptation effects by the 2050s, and only street trees offered sufficient reductions in the impacts for the entire investigated timespan.

One low-quality systematic review about the effects of climate change in urban spaces in Chile found that it is necessary to increase green areas to mitigate the impact of heat waves.(15) In comparison, a low-quality systematic review found that exposure to green space also benefits fundamental components of mental health, including overall mood and feelings of stress and anxiety.(16)

Cool roofs, green roofs, and green walls

We found two systematic reviews (6; 7) and three single studies (14; 17; 18) addressing cool roofs, green roofs, and green walls, alone or in combination with other building adaptations. A cool roof is designed to reflect more sunlight than a conventional one (cooler materials or clear colours), absorbing less solar energy. A green roof, garden roof or living roof is the roof of a building partially or totally covered with vegetation, either in soil or in an appropriate growing medium, with an impermeable membrane. A green wall or cultivation wall is a vertical installation covered with plants of various species cultivated in a special structure that gives the appearance of being a garden, but vertical; hence it is also known as a vertical garden.

In the medium-quality systematic review, green roofs, green walls, bioswales, and green bike lines, were found to contribute in the same way as urban vegetation and tree canopy to climate-change adaptation by regulating stormwater runoff and urban microclimate.(6) The low-quality systematic review suggested that the relative efficiency of cool roofs compared with green roofs is variable, given that white roofs have similar potential to reduce the urban heat island.(7) However, they can quickly turn grey due to dust and air pollution, which diminishes their effectiveness. These effects are now well studied, and newer performance standards should account for aging and soiling effects on reflectivity. The review also found that the cooling performance of green roofs is highly variable and depends on the actual water content of the green-roof substrate, with dry vegetation performing poorly in terms of cooling.(7)

A modelling study showed that under RCP2.6, green walls, sidewalk greenways, reduced-albedo sidewalks and street trees could reduce the number of EHD and the AMRT by the 2050s. However, under RCP8.5, green walls, sidewalk greenways, and reduced-albedo sidewalks could not provide adequate adaptation effects by the 2050s.(14)

A case study performed in Rome examined different mitigation strategies for the urban microclimate by considering the campus of the Sapienza University of Rome. The study found that combining cool roofs, urban vegetation and cool pavement leads to a decrease in an outdoor comfort index compared to the present configuration of the site, with a mean reduction of the air temperature of 1.49◦C.(17) The authors also found that only the cool roofs make a small contribution to the benefits, which, if used as a unique mitigation strategy, can lead to a decrease in the mean of the outdoor comfort index. However, the height of the buildings characterizing the site must be considered, principally, the distancing of roof tops from the human height level, which affects the benefits of the cool roofs.

One survey conducted in the U.S. (n=70 respondents) found that many U.S. communities are not adequately prepared to prevent the effects of hot weather on the health of residents. The study also found that reflecting paving materials and vegetated roofs were common heat-mitigation strategies.(18)

Cool pavements and increased-albedo sidewalks

Cool pavements or increased-albedo sidewalks refer to pavements with higher albedo, typically absorbing less solar energy, resulting in cooler pavement temperatures. This intervention was mentioned in two systematic reviews and three different single studies, always in combination with other strategies such as cool roofs or increased urban vegetation. One medium-quality systematic review found that reductions in city-wide albedo produced moderate to significant decreases in air temperature ranging from 1 to 3.5° C. Increasing albedo and vegetation may also reduce ground-level ozone and lower energy costs associated with air conditioning use.(6) One low-quality systematic review suggested that the aging of 'cool pavements' is complex, which makes their long-term performance less reliable to predict.(7)

As described earlier, one study found that cool pavements can alleviate the increase in extreme heat by the 2050s under RCP2.6, but not under RCP8.5.(14) Another study showed that combined with cool roofs and urban vegetation, cool pavements can lead to an improvement in outdoor comfort. Moreover, if only asphalt was used and all the vegetation was removed, it would result in an increase in the outdoor temperature, and the thermal balance of the pedestrians would increase in some places of about 40◦C.(17) In a single study in the U.S., combining cool pavements and urban vegetation was a common heat-mitigation strategy identified by different urban planners.(18)

Cooling centres

A cooling centre is an air-conditioned public space set up by local authorities to temporarily mitigate the health effects of a heat wave. Cooling centres are intended to prevent hyperthermia caused by heat, humidity, and poor air quality. We identified one systematic review (6) and four single studies (of which two were conducted in the U.S., one in the U.K., and one in the Netherlands) addressing this intervention.

One mixed-methods study evaluated the capacity of cooling centres to provide relief for the public during extreme heat events in a region of Arizona that experiences temperatures of more than 108F from May through October (on average, temperatures reach a maximum of 108F, 26 days a year).(19) The study estimated that up to 2,000 individuals used the cooling centres daily, reaching some of the region's most vulnerable populations. Many visitors were unemployed, lacked a permanent residence, had no reliable access to home air conditioning, and/or had a chronic medical condition. One qualitative study in the Netherlands explored potential governance arrangements between public and private actors.(12) The study concluded that some of the public sector's responsibilities are for installing or subsidizing air conditioners for low-income, vulnerable older adults, and turning public buildings into cooling centres during a heat wave in districts with high concentrations of vulnerable citizens.

In contrast, a multiple case study in four cities of the U.S. with documented racial/ethnic and socio-economic disparities and diverse heat-preparedness strategies, showed that usage of cooling centres was inconsistent.(8) Access barriers included concerns about culturally appropriate food, accommodations or care for pets, safe

and affordable transportation to and from the centres, and distrust in the entities offering services or transportation to them. The same study investigators conducted another study and interviewed government leaders in the same four cities, and found that cooling centres are possibly the most used heat-preparedness strategy in cities across the nation for protecting health during heat events.(20) However, many barriers were identified, including stigma, hygiene, health and safety, access, and difficulty evacuating one's home. Some interviewees spoke of the misconception that cooling centres are only for seniors or homeless individuals, which was viewed as deterring people from accessing them. In addition, one medium-quality systematic review found that cooling centres may provide air conditioning more efficiently and reach a more significant number of people unable to afford air conditioning in their own homes.(6) However, as a heat-mitigation strategy, cooling centres require that individuals have transportation to them and recognize when they need to go to the centres.

Three single studies suggested some activities to improve the use of cooling centres. These included planning paratransit or public transportation in a direct route to cooling centres;(8) improving signs or making them more visible to attract potential visitors;(19) improving the information and accurate maps of cooling centre locations;(19) and adapting different locations that citizens use to visit to avoid the stigma of places for seniors or homeless individuals.(20)

Superblocks

A superblock is a projected neighbourhood laid out in an orthogonal grid pattern, usually covering approximately 400 metres × 400 metres. Within Superblocks, there will be pacified interior roads providing a local road network that is accessible primarily to active transport (i.e., walking and cycling) and secondarily to residential traffic with a maximum speed of 20 km/h. Besides accommodating cars/motorcycles, the primary road network will contain segregated cycling and pedestrian infrastructures and bus lanes for rapid transit. For optimal access, bus stops will be placed every 400 m at the main intersections of the Superblocks, and buses will circulate at a high frequency, making public transport an attractive alternative.

Only one study assessed this innovative model's projected health impact in urban and transport planning; this model reframes the current mobility paradigm and places people and well-being at the centre.(21) The study found that 503 superblocks designed in Barcelona will reclaim public space for people, reduce motorized transport, promote sustainable mobility and active lifestyles, provide urban greening, and mitigate the effects of climate change. The study estimated that 667 premature deaths could be prevented annually in Barcelona, translating into a substantial economic impact of 1.7 billion euros and considerable average gains in life expectancy of almost 200 days due to reductions in harmful environmental exposures. The most significant number of preventable deaths could be attributed to cuts in NO_2 (n=291), followed by noise (n=163), heat (n=117), and green space development (n=60). The study also identified an increase in physical activity for an estimated 65,000 persons shifting car/motorcycle trips to public and active transport, which resulted in 36 preventable deaths. The authors also found that superblocks promote physical activity in children, facilitating safe and independent play.

Housing

We identified four systematic reviews and seven single studies addressing housing. One low-quality systematic review aimed to identify actions that can be taken on the local scale to mitigate heat.(22) The review found that indoor temperature can reach levels 50% higher than the outdoor temperature, which highlights the importance of assessment and remediation of indoor-heat levels. Most heat-health warning systems (HHWS) based on the outdoor climate only, can lead to a misleading interpretation of the health effects and associated solutions. Given this, the review suggested that integrating innovative phase change materials (PCM) into facades, roofs, floors, and windows can be a promising alternative once no adverse health and environmental effects of PCM can be ensured.(22)

One modelling study from Melbourne, Australia assessed the impact of building energy efficiency in mitigating the risks of experiencing heat stress by the occupants of different energy-rated dwellings.(23) In Australia, the energy rating is measured on a scale of 0–10 stars, with the higher the energy star rating, the lower the requirement for artificial heating and cooling to maintain occupant thermal comfort. The study found that residents of 0.9 energy star-rated houses are approximately 50% more vulnerable to experiencing heat stress during a heatwave compared to the residents of 5.4 energy star-rated houses. It was revealed that upgrading the energy efficiency of existing dwellings could be one of the most effective heatwave-mitigation measures. If the entire lower energy-rated houses can be upgraded to a 5.4 star, the percentage of people at risk of exposure to extreme heat-stress conditions for six hours could be reduced from 50% to only 4%.

The housing-adaptation interventions commonly addressed in the studies reviewed included cool roofs, green roofs/walls, and air conditioner installation and use. All those interventions aimed to improve indoor comfort and reduce morbidity and mortality associated with extreme heat. Besides those infrastructure interventions, one study validated an index of various behavioural adaptations to heat in the most deprived areas in nine cities of Quebec.(24) The study found that using a balcony and/or backyard to cool off in the evening and frequenting places other than home for air conditioning to cool off were the two main behaviours related to infrastructure to reduce heat health effects.(24) A medium-quality systematic review (6) found that depending on weather conditions, some passive design measures, like installing external shutters, may decrease mortality associated with heat stress by 30-60%. Other wide-ranging passive measures include natural ventilation, application of phase-change materials, solar shading, night cooling, optimal orientation, nocturnal radiation, and thermal insulation. These interventions can be used to improve indoor thermal comfort and enhance indoor air quality, which is essential to mitigate the risk of respiratory and cardiovascular diseases. Such measures are particularly beneficial to vulnerable groups such as the urban poor, those with underlying chronic diseases, or the elderly who may not be able to afford mechanical cooling and/or be more susceptible to heat stress.(6) A low-quality systematic review also mentioned that buildings can be adapted to the negative consequences of climate change by altering their characteristics, such as by increasing the insulation and natural ventilation (preferably during the night) and solar orientation of bedroom windows; applying high-albedo materials for the building envelope; and altering the thermal mass.(7) Moreover, the review suggested that the most promising adaptation measures are a combination of solar shading with increased levels of insulation and ample possibilities to apply natural ventilation to cool down a building.(7)

Cool roofs

One modelling study estimated the impact of reflective cool roofs in reducing health risks due to UHI in West Midlands (U.K.) and found that the UHI contributes up to 40% of heat-related mortality over the summer period.(25) If cool roofs were implemented across the whole city, it could potentially offset 18% of seasonal heat-related mortality associated with the UHI (corresponding to 7% of total heat-related mortality). Cool roofs reduced average UHI intensity by approximately 23% and reduced heat-related mortality related to the UHI by approximately 25% during a heatwave. These roofs were most effective at reducing peak temperatures during the daytime and therefore have the potential to limit dangerous extreme temperatures during heatwaves. The most significant effect on air temperatures appears when used on buildings one to two storeys high. For cool roofs, the adjacent top-floor rooms will benefit the most, which is also where the most significant hazard exists. The study also reported that targeting only commercial and industrial buildings contributed more than half of the reduction for heatwave periods. This modelling suggested that half of all industrial/commercial urban buildings could have the same impact as modifying all high-intensity residential buildings in the West Midlands. In contrast, one medium-quality systematic review of adaptative capacity to climate change in the U.K. found that few households had taken expensive adaptation decisions such as installing reflective roofs, given the lack of public funds available to support these.(26)

A study conducted in India evaluated the efficiency of cool roof technologies for reducing the indoor temperature of households and improving heat resilience.(27) The results revealed that selected cool roof technologies, including Thermocol insulation, solar reflective white paint on the outer surface of the roof, and Modroof, effectively reduce the indoor temperature compared to non-intervention roofing.

Green roofs/walls

One low-quality systematic review evaluated the impact of photovoltaic (PV)-green roofs, a new development integrating the PV system with a green roof, which aims to provide additional benefits for renewable electricity production compared to the green roof.(28) The review found that the PV-green roof is an effective strategy for producing clean energy on the building scale. Various challenges still hinder the large-scale implementation of PV-green roofs, including high initial costs, limited experimental data, and a lack of awareness about the long-term benefits.

A modelling study from Chicago outlined strategies to identify vulnerable neighbourhoods where green roofs could achieve multiple goals to mitigate urban heat-related challenges.(29) The findings suggest that even though green roofs generally reduce temperatures, they will have a limited effect on temperatures in the most vulnerable neighbourhoods. Moreover, AC consumption showed an inverse relationship with vulnerability and a positive relationship with roof surface temperatures. In addition, the authors highlighted common challenges with siting green roofs, including the competing objectives of reducing electricity consumption or addressing heat vulnerability.

In Portugal, a study evaluated the willingness to pay of owners/tenants for green roofs/walls in residential buildings.(30) The results show a relatively low willingness to pay for green roofs/walls. The average willingness-to-pay reported by respondents is similar for green roofs and walls, at 3% and 2.13%, respectively. Authors also found that greater knowledge about the benefits of green roofs/walls leads to greater willingness-to-pay values, and that the amount that users are willing to invest increases with increasing monthly incomes. Summary statistics indicate that the benefit of recreation is at the forefront of individuals' concerns, even more than esthetics.

Air conditioner units

We identified three systematic reviews and two single studies addressing air conditioners as an adaptation intervention to heat. One medium-quality systematic review found that increasing the use of air conditioning by individuals might reduce heat-related mortality and illness.(6) For instance, cities in the U.S. with higher air-conditioning prevalence have lower or no heat-related mortality. One medium-quality systematic review in the U.K. found that few households had taken expensive adaptation decisions (e.g., installing air-conditioning units, interior redesign, and reflective roofs), despite the lack of public funds available to support these interventions.(26)

A single study surveyed New York City habitants to explore the drivers of socio-economic disparities in heat-related vulnerability (31) and found that 28% of New Yorkers did not have access to a functioning AC or used it less than half the time or not at all during sweltering weather. Authors suggested that racial and socio-economic disparities in heat illness and death are partially explained by AC access. Moreover, the study showed that non-Hispanic blacks and individuals with a household income of less than $30,000 per year were less likely to possess AC than those of other races/ethnicities and those with higher household incomes. In socio-economically deprived neighbourhoods, the most frequently reported reasons for lack of AC or lack of AC use were financial barriers expressed as a desire to avoid high utility bills.(8; 31) Despite the extended use of air conditioners, two systematic reviews found that air conditioners are not a viable heat adaptation strategy. Three reasons for this conclusion are: 1) they cannot be used during power outages; 2) they emit heat during use and therefore increase the local urban heat island, and the choice of refrigerant has a significant impact on global warming potential, raising the ambient temperature; and 3) the associated increase in the use of fossil fuel burning power plants.(6; 7)

Transportation

We only identified one study addressing transportation. The modelling study about Superblocks in Barcelona, found that this urban design could increase physical activity for an estimated 65,000 persons when

incentivized to shift car/motorcycle trips to public and active transport, which would result in 36 preventable deaths.(21)

Natural environment

One modelling study in Portugal found a stronger association between elderly mortality and a 1°C increase in universal thermal climate index (UTCI) in areas with low vegetation than for regions in the highest quartile of vegetation. In areas > 4 km from a water body, a 1°C increase in UTCI was associated with a 7.1% increase in mortality. In areas ≤ 4 km from water, the estimated increase in mortality was only 2.1%.(32) The authors concluded that urban green and blue appeared to have a mitigating effect on heat-related mortality in the elderly population in Lisbon, and that increasing the amount of vegetation may be an excellent strategy to counteract the adverse effects of heat in urban areas.

Food systems

No evidence was identified related to food systems.

Flooding

Despite floods being the most common natural disaster, we only identified four documents (two systematic reviews and two single studies) addressing adaptation intervention for flooding disasters. From 1996 to 2005 floods accounted for 42% of all natural disasters. During that decade, 1.3 billion people were affected by floods, and over 90,000 died. That decade also saw floods cause more damage than any other natural disaster, accounting for one-third of all disaster-related costs. The public-health impacts of flooding include damage to homes and consequent displacement of occupants, compromised personal hygiene, contamination of water sources, disruption of sewage service and solid-waste collection, injuries sustained during the cleanup, stress-related mental health, substance-use issues, and deaths (mainly from drowning).(33)

Healthier neighbourhood design

A low-quality systematic review considered evidence linking green-building strategies in the Leadership in Energy and Environmental Design® (LEED) Rating System with the potential to reduce adverse health outcomes following exposure to urban flooding events.(34) The review found opportunities to strengthen the LEED Rating Systems, including the LEED pilot credits on resilient design, which provide the opportunity for project teams to:

- perform a hazard assessment to identify the three natural hazards that pose the highest risk for the site;
- incorporate design elements to protect building occupants from those hazards; and
- integrate design elements that will allow the building to continue functioning in the event of a disruption to critical utilities (i.e., design for passive survivability).

The Building Resilience Task Force of New York City recommended reducing the risk of wind damage and raising the first floor of occupied space and building equipment above the 100-year flood plain.(34) Code recommendations also encourage on-site backup power using renewable sources such as cogeneration and solar panels. The Building Resilience Task Force also urges passive survivability or strategies that allow occupants to continue to use a building when the power and water are disconnected. For instance, operable windows, water fixtures that can function when the power is out, and emergency lighting that works for an extended period without electrical power.(34)

A documentary study focused on five Mediterranean-type climate cities (Adelaide, Barcelona, Cape Town, Los Angeles and Santiago) reported different adaptation measures for floods (as a result of intense rainfall or sea waves during storms) and rising sea levels.(13) Considering infrastructure, Adelaide emphasized green infrastructure, protection from sea-level rise and storm-discharge management. Santiago emphasized blue

infrastructure, namely revitalizing existing water-flow networks, while Barcelona chose to start with mapping flood risks, developing an action plan for flood zones and monitoring. Cape Town details flood management as well as adaptation to the risk of sea-level rise, including risk assessment, economic modelling and regulation of a coastal protection zone by-law.

One study presented the development of a system dynamics simulation model to assess the resilience of the participating cities (Manila, Bangkok, Lagos and Vancouver) in the multidisciplinary project the Coastal Cities at Risk (CCaR).(35) The final maps indicated that the Richmond and Delta regions of Metro Vancouver are more vulnerable to climate change caused by sea-level rise and flooding compared to other municipalities. The authors suggested that this is a "stand-alone" product for assessing and developing mitigation and adaptive strategies for coastal cities.

Housing

One medium-quality systematic review focused on the U.K.'s adaptative capacity to climate change found that households struggle to build long-term adaptive capacity and rely on traditional reactive coping responses.(26) Authors found that flood-proofing measures rolled out quickly and temporarily (e.g., door guards, toilet plugs, and airbrick covers). More permanent measures (e.g., tiling floors, relocating electrical fittings, and removing impermeable surfaces) are only expected to be adopted if government or insurers offer financial incentives. Those at risk of flooding tend to defer responsibility to the government, believe the insurance safety net will save them, and cite unfamiliarity with flood-proofing products as reasons for not acting.

Transportation

A low-quality systematic review considered evidence of green building strategies with the potential to reduce adverse health outcomes following exposure to urban-flooding events.(34) One of the key findings of the literature review is the link between flooding vulnerability and access to transportation to evacuate vulnerable areas before, during, and after flooding events. The authors suggested considering transportation as part of flooding emergency-response plans.

Food systems

We did not identify documents addressing the natural environment and food systems.

Wildfires

We identified a case study addressing healthier neighbourhood design, with none of the evidence documents addressing the other categories in the organizing framework.

The case study identified examined how destructive wildfire affected progress toward becoming fire adapted in eight locations in the United States.(36) The study found that nearly all sites reported changes in wildfire suppression, emergency response, and hazard-planning documents. Half of the places identified expansion in voluntary education and outreach programs to increase defensible space. Land-use planning and regulations remained essentially unchanged across diverse settings. Moreover, the study found that destructive fires did not change the tools and actions typically used for wildfire mitigation and planning. Local and state governments declined to take more significant action on land-use planning or building standards in response to these wildfires. Across various sites, the most common response to wildfire experience (typically garnering community support) was to invest in suppression and emergency response. For example, the authors described that residents in rural Oklahoma (Loco-Healdton, OK) passed a public safety tax to improve firefighter resources. Another commonly used tool to reduce wildfires was increasing investment in vegetation mitigation on public lands.

Key findings from the jurisdictional scan

Key findings from the jurisdiction scan are summarized below according to real-world approaches to adaptation interventions in built environments that aim to reduce the risks to human health due to climate change. Our scans focused on identifying examples from the country and/or provincial/territorial level. More detailed findings from our scan of select jurisdictions (Australia, New Zealand, Germany, France, United Kingdom, United States – California, Massachusetts, Oregon, Minnesota, New York) are presented in Table 2 and findings from our scan of all Canadian provinces and territories are presented in Table 3.

Healthier neighbourhood design

Some jurisdictions described approaches to improve healthier neighbourhood designs such as land-use planning policies and guidance, and educational programs. France published a guide for local communities to promote healthy urbanism based on nine determinants of health including living environments. As part of The National Adaptation Programme and the Third Strategy for Climate Adaptation Reporting, the U.K. is altering land-use planning policy, and working with developers to minimize new building in areas at high flood and erosion risk now and in the future, while working to improve protection for 300,000 existing households and investing in sustainable drainage systems. In terms of educational programs, The Grey and Bruce Health Unit in Ontario outlines key strategies such as promoting the "Know your Neighbour" campaign to build community resiliency during extreme weather events and surveillance. Also, through Ontario's Green Investment Fund, 40 Indigenous communities are collecting traditional ecological knowledge, leading the assessment of their communities' vulnerabilities to climate change.

Housing

Many jurisdictions are providing homeowner incentives to support energy-efficient initiatives. Some examples in the U.S. include Massachusetts' Mass Save Heat and Commercial PACE programs and Minnesota's energy-efficiency rebates and programs for homeowners. In Canada, the federal government provides incentives such as $5,000 in grants to Canadian households to make energy-efficiency and climate-resilience improvements to their home, and interest-free loans to help landlords and homeowners with energy retrofits to existing homes and new builds. Similar energy-efficient home programs are available across the provinces and territories in Canada. Related to equity-deserving populations, the province of Nova Scotia is investing in energy-efficiency assessments free of charge for low-income homes and conducting a pilot program to provide energy-efficiency upgrades to 100 homes in all 13 Mi'kmaw communities across the province.

Additionally, some jurisdictions developed tools for communities to assess risk to environmental hazards. In the U.S., the New York City Climate and Health Program (NYC CHP) developed the NYC Heat Vulnerability Index, which provides an assessment of how the risk of dying during a heat emergency varies across neighbourhoods. The CalEnviroScreen is a screening tool that can be used to help identify California communities that are disproportionately burdened by multiple sources of pollution. Further, the CalBRACE Project produced the Climate Change and Health Vulnerability Assessment Framework to identify where a person's or neighbourhood's susceptibilities to injury or disease exist relative to their distance and sensitivity to climate-related environmental exposures or hazards. Similarly in Canada, the British Columbia Interior Health produced 'Community Health and Climate Change' maps, which can inform decision-making to improve the quality of infrastructure in communities such as housing.

Transportation systems

Many jurisdictions released targets and actions related to reducing transport emissions. New Zealand aims to implement a sustainable aviation fuel mandate to support the uptake of low-carbon liquid fuels, supporting initiatives that promote walking and cycling, requiring only zero-emissions public-transit buses, and incentivizing zero-emissions vehicles. Similarly, France participates in the Transport, Health and Environment Pan-European Programme (THE PEP), which brings together members of the United Nations

Economic Commission for Europe and WHO Europe to address the health and environmental impacts of transportation.

In Canada, some provinces are investing in the development of zero-emission transit options in some provinces. The government of Québec is undergoing a major electrification of public transportation, subsidies for electric vehicles (e.g., prohibition of gasoline-powered light-duty vehicles), expansion of charging infrastructure, and other modes of transportation. The government of Prince Edward Island has invested $25 million over five years to support sustainable transportation infrastructure such as urban and rural transit, vehicles and transportation, active transportation, and community design and infrastructure (e.g., new walking and bike paths, installing or widening paved shoulders, connecting existing trails, and other innovative ideas).

Natural environments

Some jurisdictions have developed innovative approaches to improve natural environments. For example, New Zealand has adopted a Green Star Accreditation system that verifies that commercial buildings, including schools, office buildings and hospitals, meet best-practice benchmarks of sustainable design. New York is increasing the use of cooling centres and supports outreach through the Be-a-Buddy Program to promote green infrastructure and reforestation to moderate the urban heat island effect and reduce the severity and frequency of future projected extreme heat events. In Canada, the federal government created The Natural Climate Solutions Fund (NCSF), which aims to provide $4 billion over 10 years towards planting two billion trees and restoring and conserving Canada's natural and managed ecosystems. In Toronto, the "A Commitment to Double the Tree Canopy", provides shade and lessens the urban heat island effect, and "Building Green Roofs" is a bylaw that requires the construction of a green roof on all new developments in order to reduce the negative effects on the urban heat island effect of large flat roofs.

Food systems

Few jurisdictions reported detailed approaches to improving food systems through their climate change and healthy city plans. The Agricultural Clean Technology Program was launched to provide farmers and agri-business with $165.7 million in funding so that they can develop and adopt clean technologies to reduce greenhouse emissions and enhance competitiveness.

Table 1: Key findings from included evidence documents

Components of built environment		Heat-dome events	Flooding	Wildfires
Healthier neighbourhood design	General findings	• One medium-quality systematic review reported health co-benefits of different adaptation measures,(6) and authors found that: o Urban planning and design measures that promote walkability and ensure outdoor thermal comfort can provide multiple benefits through enhancing physical activity, improving air quality, and creating environments conducive to mental health and well-being o Early warning systems for climate change events can improve well-being and reduce mortality, risk of disease or adverse health impacts • A non-systematic review assessed the state of public-health adaptation in 401 urban areas globally with more than 1 million people,(5) which found that a large majority of municipalities sampled (90%) are not reporting implementation of any public-health adaptation initiatives o Several cities reported a time lag between cities' self-reported recognition of risk and the formation of actual plans • In one single study,(11) authors surveyed planning professionals from diverse cities across the United States, finding that numerous strategies have been proposed for enhancing resilience to extreme heat, but there is no clear evidence of effectiveness • One low-quality systematic review examined how national-level public health adaptation to climate change is occurring in OECD countries; authors found 175 discrete health-adaptation initiatives, but only Belgium reported adaptations on building and infrastructure to ensure thermal comfort such as thermal insulation, solar protection shutters, and ventilation (5)	• A low-quality systematic review considered evidence linking green building strategies with the potential to reduce adverse health outcomes following exposure to urban flooding events,(34) and authors suggest: o Performing a hazard assessment to identify the three natural hazards that pose the highest risk for the site o Incorporating design elements to protect building occupants from those hazards o Incorporating design elements that will allow the building to continue functioning in the event of a disruption to critical utilities (i.e., design for passive survivability) • The Building Resilience Task Force recommendations encouraged passive survivability (i.e., strategies that allow occupants to continue to use a building when the power and water are disconnected; for example, operable windows,	• One case study examined how destructive wildfire affected progress toward becoming fire adapted in eight locations in the United States,(36) and authors found that: o Nearly all sites reported changes in wildfire suppression, emergency response, and hazard planning documents o Destructive fires did not change the tools and actions typically used for wildfire mitigation and planning, and local and state governments alike declined to take more significant action on land-use planning or building standards in response to these wildfires o Across diverse sites, the most common response to wildfire experience (typically garnering community support) was to invest in suppression and emergency response
	Urban vegetation Street trees Green canopy	• One medium-quality systematic review (6) found that areas with a higher level of green coverage exhibit lower temperatures, and urban green coverage has the most significant mitigation effect on heat-related mortality • One low-quality systematic review suggested that the only building intervention able to sustain benefits for people and the environment is to increase regular vegetation and trees in general (7) • A non-systematic review assessed the state of public-health adaptation in 401 urban areas globally, with more than one million people, finding that most of the heat-related initiatives imply green infrastructure projects, expanding the urban tree canopy (5)		

		• In a modelling study,(14) authors aimed to determine the effect of adaptation strategies to reduce the mortality risk under two climate-change mitigation scenarios RCP2.6 and RCP8.5 (explanations in the body of the manuscript); authors found that under RCP8.5, green walls, sidewalk greenways, and reduced-albedo sidewalks could not provide any adequate adaptation effects by the 2050s, and only street trees offered sufficient reductions in the impacts for the entire investigated timespan o A low-quality systematic review found that exposure to green space also has benefits for fundamental components of mental health, including overall mood and feelings of stress and anxiety (16)	water fixtures that can function when the power is out, and emergency lighting that functions for an extended period without electrical power • A documentary study reported different adaptation measures to flooding (as a result of intense rainfall or sea waves during storms) and rising sea levels (13) o Adelaide city emphasized green infrastructure, protection from sea-level rise and storm discharge management o Santiago emphasized blue infrastructure, namely revitalizing existing water-flow networks o Barcelona chose to start with mapping flood risks, developing an action plan for flood zones and monitoring	
	Cool roofs Green roofs Green walls	• A medium-quality systematic review suggested that green roofs, green walls, bioswales, and green bike lines contribute in the same way as urban vegetation and tree canopy to climate change adaptation by regulating stormwater runoff and urban microclimate (6) • A modelling study showed that under RCP2.6, green walls, sidewalk greenways, reduced-albedo sidewalks and street trees can reduce the number of extreme heat days to below 10 and the mean radiant temperature to below 55.88°C by the 2050s; however, under RCP8.5, green walls, sidewalk greenways, and reduced-albedo sidewalks could not provide any adequate adaptation effects by the 2050s (14) • A case study performed in Rome found that combining cool roofs, urban vegetation and cool pavement leads to a decrease in an outdoor temperature of 1.49°C (17), and that only the cool roofs could have a negligible effect on reducing outdoor temperatures • One low-quality systematic review (7) suggested that the relative efficiency of cool roofs compared with green roofs is variable because while white roofs have similar potential to reduce the urban heat island, they can quickly turn grey due to dust and air pollution, losing their effectiveness, although these effects are now well studied and newer performance standards should account for aging and soiling effects on reflectivity o Authors also found that the cooling performance of green roofs is highly variable and depends on the actual water content of the green roof substrate, with dry vegetation performing poorly in terms of cooling (7)		
	Cool pavements	• One medium-quality systematic review found that cool pavements produce modest, though significant, reductions in air temperature of 1C to3.5°C, increasing albedo and vegetation may also reduce ground-		

	Increased-albedo sidewalks	level ozone and lower energy costs associated with air conditioning use (6) • One low-quality systematic review suggested that the aging of 'cool pavements' is complex, which makes their long-term performance less reliable to predict (7) • One single study found that cool pavements contribute to alleviating the increase in extreme heat by the 2050s under RCP2.6, but not under RCP8.5 (14) • Another single study showed that combined with cool roofs and urban vegetation, cool pavements lead to an improvement in outdoor comfort, and that if only asphalt was used and all the vegetation was removed, it would be an increase in the outdoor temperature and the thermal balance of the pedestrians will increase in some points of about 40ºC (17)		
	Cooling centres	• One mixed methods study evaluated the capacity of cooling centres to provide relief for the public during extreme-heat events in a region of Arizona (19); authors estimated that up to 2,000 individuals used the cooling centres each day, reaching some of the region's most vulnerable populations • In contrast, a multiple case study in four cities of the U.S. with documented racial/ethnic and socio-economic disparities,(8) showed that usage of cooling centres was inconsistent, and residents faced barriers including safe and affordable transportation to and from the centres • One medium-quality systematic review (6) found that cooling centres may provide air conditioning more efficiently and reach a more significant number of people unable to afford air conditioning in their own homes; however, cooling centres as a heat-mitigation strategy require that individuals have transportation to and recognize when they need to go to the centres • Three single studies suggested some activities that improve the use of cooling centres, for instance, planning paratransit or public transportation in a direct route to cooling centres,(8) improving signs or making them more visible to attract potential visitors,(19) enhance the information and accurate maps of cooling centre locations,(19) and adapting different sites that citizens use to visit to avoid the stigma of places for seniors or homeless individuals (20)		
	Superblocks	• Only one single study assessed the projected health impact of this innovative model in urban and transport planning (21); authors found that 503 superblocks designed in Barcelona will prevent 667 premature		

		deaths annually in Barcelona, translating into a substantial economic impact of 1.7 billion euros and considerable average gains in life expectancy of almost 200 days		
Housing	General findings	• One low-quality systematic review (22) found that the indoor temperature can reach levels 50% higher than the outdoor temperature, which highlights the importance of assessment and remediation of heat indoors • One single study validated an index of various behavioural adaptations to heat in the most deprived areas in nine cities of Quebec; authors found two behaviours related to infrastructure that reduce heat health effects, using the balcony and the backyard to cool off in the evening and frequenting places other than home for air conditioning to cool off (24) • A medium-quality systematic review (6) found that depending on weather conditions, some passive design measures like installing external shutters may decrease mortality associated with heat stress by 30-60% o Other wide range of passive measures include natural ventilation, application of phase change materials, solar shading, night cooling, optimal orientation, nocturnal radiation, and thermal insulation o Such measures are particularly beneficial to vulnerable groups such as the urban poor, those with underlying chronic diseases, or the elderly who may not be able to afford mechanical cooling and/or be more susceptible to heat stress (6) • A low-quality systematic review (7) suggested that the most promising adaptation measures are a combination of solar shading with increased levels of insulation and ample possibilities to apply natural ventilation to cool down a building	• One medium-quality systematic review focused on adaptative capacity to climate change in the U.K. found that households struggle to build long-term adaptive capacity and are reliant upon traditional reactive coping responses (26) o Flood-proofing measures rolled out quickly and temporarily – door guards, toilet plugs, and airbrick covers – have also been implemented o More permanent measures – tiling floors, relocating electrical fittings, and removing impermeable surfaces – are only expected to be adopted if financial incentives are offered by the government or insurers	No documents identified
	Air conditioner units	• One medium-quality systematic review (6) found that increasing the use of air conditioning by individuals might reduce heat-related mortality and illness; for instance, cities in the U.S. with higher air conditioning prevalence have lower or no heat-related mortality • Two single studies in the U.S. explored socio-economic disparities in heat-related vulnerability; and authors found that 28% of New Yorkers did not have access to a functioning AC or used it less than half the time or not at all during sweltering weather,(31) and that in socio-economically deprived neighbourhoods, the most frequently reported reasons for lack of AC or lack of AC use were financial barriers (8)		

		• However, with the extended use of air conditioners, two systematic reviews found that air conditioners are not a viable heat adaptation strategy because: o They cannot be used during power outages (6) o They emit heat during use and therefore increase the local urban heat island, and the choice of refrigerant has a significant impact on global warming potential, raising the ambient temperature (6; 7) o They use electricity generated by fossil fuel burning power plants (6; 7)		
	Cool roofs (reflective roofs)	• One modelling study estimated the impact of reflective cool roofs in reducing health risks due to Urban Heat Island (UHI) in West Midlands (UK);(25) authors found that cool roofs implemented across the whole city could potentially offset 18% of seasonal heat-related mortality associated with the UHI (corresponding to 7% of total heat-related mortality) o Cool roofs reduced average UHI intensity by ~23%, and reduced heat-related mortality associated with the UHI by ~25% during a heatwave o The most significant effect on mean near-surface air temperatures appears when used on buildings one to two storeys high o The adjacent top floor rooms will benefit the most, which is also where the greatest hazard is • One medium-quality systematic review of adaptative capacity to climate change in the U.K. found that few households had taken expensive adaptation decisions such as installing reflective roofs, given the lack of public funds available to support these (26) • A study in India evaluated the efficiency of cool roof technologies,(27) and the results revealed that selected cool roof technologies, including Thermocol insulation, solar reflective white paint on the outer surface of the roof, and Modroof are effectively reducing the indoor temperature as compared to the non-intervention roofing		
	Green roofs/walls	• One low-quality systematic review evaluated the impact of Photovoltaic (PV)-green roofs;(28) authors found that the PV-green roof is an effective strategy for producing clean energy on the building scale • A modelling study in Chicago discussed strategies to identify vulnerable neighborhoods where green roofs could achieve multiple goals to mitigate urban heat-related challenges,(29) and authors suggest that even though green roofs reduce temperatures in general, they will have		

		a limited effect on temperatures in the most vulnerable neighbourhoods • In Portugal, a study evaluated the willingness-to-pay of owners/tenants for green roofs/walls in residential buildings;(30) the results show that willingness-to-pay for green roofs/walls is relatively low and that greater knowledge about the benefits of green roofs/walls leads to greater willingness-to-pay values		
Transportation systems		• One study assessed the health impact of Superblocks,(21) finding that this model would increase physical activity for an estimated 65,000 persons, who will shift car/motorcycle trips to public and active transport, which would result in 36 preventable deaths	• A very low-quality systematic review (34) found that there is a link between flooding vulnerability and access to transportation to evacuate vulnerable areas before, during, and after flooding events	No documents identified
Natural environments		• One modelling study in Portugal found an association between elderly mortality and a 1°C increase in universal thermal climate index (UTCI) more vital for areas with low vegetation than for regions in the highest quartile of vegetation (32)	No documents identified	No documents identified
Food systems		No documents identified	No documents identified	No documents identified

Table 2: Experiences in selected jurisdictions on adaptation interventions in built environments that reduce the risks to human health due to climate change (note that many of the points in this table are extracted from a complementary rapid evidence profile about the capacity of public-health systems to address climate change)

Country	Summary of experiences
Australia	• *None identified*
New Zealand	• New Zealand has adopted a Green Star Accreditation system that verifies that commercial buildings, including schools, office buildings and hospitals, meet best-practice benchmarks of sustainable design o Green Star certification of a building involves a third-party assessor rating a building's performance and environmental impact using a holistic tool that awards points across a combination of credits • A national adaptation plan is currently being developed by the New Zealand government that will outline what needs to be done to respond to the risks of climate change identified in the country's first national climate change risk assessment o The government has consulted with the public on the draft adaptation plan in April and May 2022 • The costs of pollution will be directly recycled back into projects that reduce emissions through the $4.5 billion Climate Emergency Response Fund (CERF), which receives funding from the Emissions Trading Scheme revenue o The CERF provides financial security over the long term to ensure that climate objectives remain a priority in future budgets

	• In May 2022, the Ministry for the Environment released the first Emissions Reduction Plan that contains targets and actions for the country to reduce its transport emissions by 41% by 2035, including: o Improving the reach, frequency, and quality of public transport, and requiring only zero-emissions public transport buses o Supporting initiatives that promote walking and cycling o Implementing a sustainable aviation fuel mandate in order to support the uptake of low-carbon liquid fuels o Improving EV-charging infrastructure across the country o Continuing to incentivize the uptake of low and zero-emissions vehicles and increasing access to these for low-income households
Germany	• Germany has a health heat warning system which calculates the heat load for regions and counties countrywide and issues heat health warnings when high levels of heat are forecasted for at least two consecutive days o When a heat warning has been issued, local authorities, health clinics, and care homes initiate adaptation measures via specific communication channels based on the level of the heat warning issued
France	• Santé Publique France and the Paris Region Institute conducted a study to investigate the influence of urban characteristics on the relationship between temperature and mortality and found that more vegetations, more trees, and more natural soils contribute to lower heat-related mortality o This study also notes that within Paris there are significant differences in the risk of heat-related mortality across the city and that interventions related to vegetation and soils have the potential to mitigate the health risks of heat • The French Ministry of Health has published a guide about promoting healthy urbanism that outlines the links between urban environments and health, describes mechanisms (such as environmental assessments and health-impact assessments) that factor health into urban zone planning, and provides a methodological framework that regional health agencies can use to issue health opinions about urban zone planning projects o The framework for assessing projects includes considerations for nine determinants of health: air quality; water quality and management; quality and usage of soils and subsoils; noise; waste management; non-ionizing radiation; climate change adaptation; mobility, transport and accessibility; and living environments • An adaptation of the above guide was produced to assist regional health agencies in providing health-impact opinions regarding local urbanization plans o The guides includes a methodological tool with 10 health determinants to consider when providing advice: air quality; water quality and management; soils; noise; waste management; non-ionizing radiation; climate change adaptation and the energy transition; mobility and accessibility; living spaces and landscapes; and economic dynamism • France participates in the Transport, Health and Environment Pan-European Programme (THE PEP), which brings together members of the United Nations Economic Commission for Europe and WHO Europe to address the health and environmental impacts of transportation o In France, the objectives of this collaboration have been incorporated into national environmental health plans
United Kingdom	• The U.K. is committed to advancing green finance, which aims to mobilize private investment in environmental and sustainable projects and infrastructure (e.g., built environment), to help meet its domestic and international climate change commitments • The U.K. has a range of schemes, grants and benefits to help with home energy-efficiency projects

	• As part of The National Adaptation Programme and the Third Strategy for Climate Adaptation Reporting, the U.K. is altering land-use planning policy and working with developers to minimize new building in areas at high flood and erosion risk now and in the future, while working to improve protection for 300,000 existing households and investing in sustainable drainage systems o The programme also aims to support the installation of flood gates or air brick covers, or more substantial changes such as fitting a pump, having solid floors or raising electrics in building to prevent damage • The National Adaptation Programme and the Third Strategy for Climate Adaptation Reporting aims to address overheating in buildings through green infrastructure for homes, hospitals and care homes, schools, and prisons

California – US	• The California Department of Public Health (CDPH) Climate Change and Health Equity Section (CCHES) developed climate change and health indicators, narratives, and data to provide local health departments and partners with tools to better understand the people and places in their jurisdictions that are more susceptible to adverse health impacts associated with climate change
	  o The assessment data can be used to screen and prioritize where to focus deeper analysis and plan for public health actions to increase resilience
	• The CalBRACE Project produced Climate Change and Health Vulnerability Assessment Framework to help to identify where a person's or neighbourhood's susceptibilities to injury or disease exist relative to their distance and sensitivity to climate-related environmental exposures or hazards
	• CalEnviroScreen is a screening tool that can be used to help identify California communities that are disproportionately burdened by multiple sources of pollution
	  o The screening tool maps indicators such as pesticide use, drinking water quality, and toxic exposures (e.g., ozone levels) that will likely be exacerbated by higher temperatures associated with climate change
	• CDPH will continue to conduct Community Assessments for Public Health Emergency Response (CASPER), a rapid community-needs assessment method developed by the Centers for Disease Control and Prevention (CDC), for extreme events
	  o This tool is used to assess local jurisdictions' preparedness for Zika, wildfire, earthquakes and drought, as well as to assess mental health impacts after such events
	• CDPH also supports many research efforts focused on climate, including epidemiologic studies on heat, the health impacts of wildfire smoke exposure, and the life cycle assessment and co-benefits of cool pavements
	• The PULSE system has been activated during recent years' wildfires to provide specified volunteer healthcare workers to patients' personal health information in the short term
	  o PULSE connects multiple local data sources from health-information organizations and systems during a disaster
	• The California Health and Human Services Agency is required to create a data exchange framework to facilitate the sharing of health and social services information across healthcare entities and government agencies
	  o This effort will enable sharing of real-time health information during climate-driven emergencies
	• CDPH, in collaboration with the Governor's Office of Planning and Research and Strategic Growth Council, provide technical assistance and monitoring of progress by state agencies toward protecting climate-vulnerable communities while accounting for climate change in all infrastructure and investment plans

	• California Environmental Protection Agency (CalEPA) Environmental Justice Small Grants Program offers funding opportunities to assist eligible non-profit organizations and federally recognized Tribal governments in addressing environmental justice issues in areas disproportionately affected by environmental pollution and hazards • Governor Gavin Newsom signed a US$15-billion package last year to address the climate change risks faced in California, and signed 24 bills in July 2021 focused on climate and clean energy, drought, and wildfire preparedness o The package includes a US$3.7 Billion Climate Resilience Package focusing on vulnerable front-line communities, US$4.6 billion for drought and water resilience activities, and US$988 million to address wildfire and forest resilience • California's Emergency Medical Services Authority (EMSA) has been allocated $36 million of funding in the 2021-22 state budget to increase the authority's capacity to surge medical staff, store and maintain equipment, and respond to regional disasters and to plan and develop a statewide emergency-services data-resources system • CDPH's Emergency Preparedness Office coordinates emergency planning and preparedness by operating and managing California's health alert network, planning for public-health disasters, and providing resources for counties, local healthcare facilities, and state entities to prepare for catastrophic health threats • The CDPH Licensing and Certification Program ensures the safety and continuity of care for patients/residents at the facilities it licenses during heat-related emergencies
Massachusetts – US	• Massachusetts' Mass Save Heat and Commercial PACE programs provide loans and financial incentives for residents and commercial property owners, respectively, to support energy-efficiency initiatives in the built environment • Massachusetts 2050 Decarbonization Roadmap outlines strategies for reducing on-site combustion of fossil fuels in residential and commercial buildings, such as by swapping out heating, ventilation, and air conditioning equipment for efficient electric equipment in existing buildings and modifying residential buildings, as well as implementing high-performance code for new constructions • Zero Net Energy Building (ZNE Building) aims to ensure that buildings produce as much energy as they use through a year, with cities in Massachusetts such as Cambridge and Amherst developing ZNE plans
Oregon – US	• A comprehensive climate change and health-impact assessment report and a complementary data-visualization tool for the Portland metropolitan region was developed by a regional collaborate of Clackamas County Public Health, Oregon and multiple neighbouring counties • The State of Oregon issued a 2021 State Agency Climate Change Adaptation Framework to plan for and respond to climate change impacts in a coordinated and efficient manner that minimizes redundant effort o Part Three of the Framework describes adaptation strategies and approaches within six themes, one of which is public health • Oregon Health Authority (OHA) is in the process of developing an updated State Health Improvement Plan and a new Environmental Public Health Modernization Plan, both of which prioritize integration of climate change, equity, and social justice into public-health programming and policy o OHA also contracted climate equity consultants to provide climate equity training for participants of their Climate Equity Workgroup within the Climate Change Adaptation Framework (CCAF) interagency

	• The Oregon Public Health Division (OPHD) has provided training on the health impacts of climate change, health equity, and strategies for reducing health impacts and building resilience to trained public-health and emergency-response personnel, as well as to community health workers, partner state agencies, and the general public. o In addition to training, the OPHD has provided funding and technical assistance to five local health jurisdictions to understand and prioritize the health effects of a changing climate in their communities and to develop and implement strategies for building resilience
Minnesota – US	• Minnesota offers a number of energy-efficiency rebates and programs for homeowners • Minnesota's Climate Action Framework includes action priorities to establish a standard to achieve 100% carbon-free electricity and 55% renewable electricity by 2040, while upgrading the electrical grid and facilitating greater access to renewable energy, and expanding the use of low-carbon heating sources
New York – US	• New York State (NYS) is increasing the use of cooling centres and supports outreach through the Be-a-Buddy Program to promote green infrastructure, reforestation, and reflective or "cool" roofs in order to moderate the urban heat island effect and reduce the severity and frequency of future projected extreme heat events • NYS has implemented adaptation strategies to address climate hazards, including developing Heat and Health profile reports that summarize extreme heat exposure and vulnerability, and revising thresholds for issuing heat advisories o NYS staff have also created a mapping application to track heat-stress hospitalization and emergency-department visits annually and display cooling centre stations across the state • The New York Health Department participates in multi-agency planning efforts that use policies and programs to make buildings, systems and infrastructure in the state more sustainable and resilient in order to protect public health from the impacts of climate change • The New York City Climate and Health Program (NYC CHP) focuses on the health impacts of current and future climate related hazards and prioritizes local communities for climate mitigation and adaption investments o One example of the program's work is the NYC Heat Vulnerability Index, which provides an assessment of how the risk of dying during a heat emergency varies across neighbourhoods

Table 3: Experiences in Canadian provinces and territories on adaptation interventions in built environments that reduce the risks to human health due to climate change (note that many of the points in this table are extracted from a complementary rapid evidence profile about the capacity of public-health systems to address climate change)

Province	Summary of experiences
Pan-Canadian	• The Canadian Centre for Climate Services was established by the Canadian Government to help Canadians increase their resilience to climate change by building local and regional capacity, and offering training and support to provinces and territories

	• The Government of Canada has funded the development of the Climate Change Toolkit for Health Professionals to support health professionals and students in healthcare to advocate for climate change mitigation policies and programs in their workplaces and communities
	• 10 projects at $300,000 each have been funded by the Climate Change and Health Adaptation Capacity Building Contribution Program to support efforts to increase climate resilience of the health system, such as assessments of climate change vulnerability and the development of adaptation plans and evaluation strategies
	• The Canada Greener Homes Grant provides up to $5,000 in grants to Canadian households to make energy-efficiency and climate resilience improvements to their homes
	  ○ Investments have also been made in recruitment and training of up to 2,000 new EnerGuide energy advisors to provide expert advice to homeowners on their climate resilience home improvements
	• The federal government has invested $4.4 billion to help landlords and homeowners complete deep home energy retrofits through the provision of interest-free loans, and committed $1.5 billion in projects for the Green and Inclusive Community Buildings program that retrofits, repairs, and upgrades new builds
	  ○ At least 10% of the funding being allocated to projects for the Green and Inclusive Community Buildings program serve First Nations, Inuit and Métis communities
	• Billions of dollars have also been invested in the development of zero-emission transit options in Ontario, Québec, British Columbia, and Alberta, and Canadians have been provided with up to a $5,000 reduction on their purchase of zero-emission vehicles to make purchases of these vehicles more affordable
	  ○ Investments have also been made in providing EV chargers and alternative refueling where and when needed, and building electric vehicles
	• A Natural Infrastructure Fund was established to support natural and hybrid infrastructure projects that aim to mitigate the impacts of natural events
	• The Smart Renewables and Electrification Pathway Program was launched to support projects that will invest in clean energy technologies, and Budget 2021 allocated funding towards supporting the planning of hydroelectricity and grid interconnection projects for northern communities and local sustainable energy projects for First Nations, Inuit, and Métis communities
	• The Agricultural Clean Technology Program was launched to provide farmers and agri-business with $165.7 million in funding so that they can develop and adopt clean technologies to reduce greenhouse emissions and enhance competitiveness
	• The Natural Climate Solutions Fund (NCSF) was created with an investment of $4 billion over 10 years towards planting two billion trees and restoring and conserving Canada's natural and managed ecosystems
	• The transition of Indigenous communities that are diesel-reliant onto clean energy is being supported through the Government's Indigenous Off-Diesel Initiative and by an investment of $220 million in clean energy projects for remote and rural communities

British Columbia	• Interior Health has produced 'Community Health and Climate Change' maps that show how different communities are exposed to climate change hazards ○ It is also stated that these maps can serve as a resource for those involved in decision-making regarding the built environment, for example by informing community amenities and increasing the quality of infrastructure

	○ The climate change hazards addressed by these maps include high temperatures, low temperatures, wildfire smoke, and flooding • The Community Social Planning Council has produced a backgrounder about 'Healthy and Safe Environment Metrics' ○ The backgrounder stresses the importance of developing and utilizing indicators that address the nexus between climate change, the built environment, and community safety, and that can inform adaptation interventions • The BC Climate Action Toolkit is a hub for communities to find out about best practices and new developments in local climate change mitigation and emission-reduction efforts, and the toolkit includes a section dedicated to land use and transportation ○ The land use and transportation section aims to inform local governments in decisions about land use, housing, open spaces, and transportation
Alberta	• *None identified*
Saskatchewan	• Prairie Resilience: A Made-in Saskatchewan Climate Change Strategy is a comprehensive strategic document published by the Government of Saskatchewan that aims to make the province more resilient with respect to the climatic, economic, and policy impacts of climate change. This strategy highlights the province's commitment to: ○ Improving energy efficiency and reducing the life cycle costs of new buildings ○ Raising the number of government buildings that operate through a sustainability certification ○ Engage key stakeholders and partners to improve the standards for climate resilience in building design ○ Incorporate an offset system that can help to raise carbon sequestration and reduce greenhouse gas emissions ○ Monitor highway systems to protect any impact on human health and property ○ Reassess the use of current government vehicles and further investigate new opportunities to incorporate lower-carbon technology • The Climate Resilience Measurement Framework highlights the province's climate resilience targets for natural systems and community preparedness, which include: ○ Maintaining a soil organic matter sequestration level of 5.6 M tonnes per year ○ Having 25% of the province's cropland under the 4R designation by 2025 ○ Having up to half of all electricity generated within the province from natural renewable energy sources ○ 100% of communities at-risk of flooding having completed floodplain mapping by 2030 ○ All communities at-risk of wildfires having operational safety pre-plans by 2036
Manitoba	• The Made-in-Manitoba Climate and Green Plan is a strategic document that helps guide the province's climate change response ○ With respect to housing, the province will be committing to the development of energy-efficient homes by offering expanded new home energy-efficiency programs as well as working with various partners to improve building standards • Within Manitoba's Climate Change and Green Economy Action Plan, the province is committed to working with the City of Winnipeg to transition towards zero-emission transit buses

Ontario	• The Public Health Agency of Canada, Ontario Region, Simcoe Muskoka District Health Unit, and Cambium Indigenous Professional Services collaborated to release a report in December 2020 on Indigenous perspectives in climate adaptation and the strategies to assist public authorities in doing so o The report discusses public-health adaptation interventions in health communications, health promotions, environmental adaptation policy, planning/decision-making surveillance, guidelines/frameworks, and alerts/advisories and warnings • The Ontario Ministry of Health developed the Ontario Climate Change and Health Toolkit report in August 2016 that includes health and vulnerability adaptation guidelines and climate change and health modelling to anticipate, address, and mitigate the impacts of climate change o The report describes vulnerabilities and capacities of the health system (e.g., estimate relationships between weather patterns and health outcomes, historical environmental trends, vulnerability of exposed communities and effectiveness of policies and programs to manage current vulnerabilities), projects future health risks, and prioritizes policies and programs to manage health risks • The city of Ottawa approved a new Climate Change Master Plan in January 2020 that identified eight priority actions for the next five years (2020 to 2025) that will be embedded into the city's business, including developing an energy transition strategy and a vulnerability assessment, exploring the feasibility of setting corporate carbon budgets, applying a climate lens to city projects, and encouraging private action through education, incentives, and advocacy • The Grey and Bruce Health Unit outlines key strategies to address, manage, and respond to the public-health effects of a changing climate by adapting existing programs, including education and capacity building (e.g., promoting the "Know your Neighbour" campaign to build community resiliency during extreme weather events), surveillance and monitoring (e.g., monitoring water quality), promotion of programs with health and environmental co-benefits (e.g., developing a campaign to encourage homeowners to regularly test their drinking water), advocacy for policies and program to support climate change mitigation, and support for multi-jurisdictional and multidisciplinary approaches • Through Ontario's Green Investment Fund, 40 Indigenous communities are collecting traditional ecological knowledge, leading the assessment of their communities' vulnerabilities to climate change, and developing adaptation plans o The funding will also create a Northern Ontario climate change impact study • The Eastern Ontario Health Unit implemented a Heat Event Response Program that aims to reduce the risks of exposure to extreme heat by educating and raising awareness about heat-related illness and alerting those at risk of heat-related illness that hot weather conditions are imminent or to take precautions • The City of Toronto is actively working to reduce health risks from climate change and contribute to greenhouse gas mitigation, and has far exceeded its initial target of a 6% reduction by 2012 o The estimated greenhouse gas emissions in 2012 were about 25% below 1990 levels o Examples of programs to mitigate public-health risks in Toronto include "A Commitment to Double the Tree Canopy", a project designed to provide shade and lessen the urban heat island effect, and "Building Green Roofs" to reduce the negative effects on the urban heat island effect of large flat roofs through its Green Roof Bylaw that requires the construction of a green roof on all new developments

	• Toronto's Heat Alert System is designed to protect the city's most vulnerable populations from climate change-related health risks such as extremes of heat and cold o The Toronto Medical Officer of Health issues a "Heat Alert" when the likelihood of excess weather-related mortality exceeds 65% and an "Extreme Health Alert" when the likelihood is 90% o Toronto Public Health is also developing a mapping tool to visualize human vulnerability to extreme heat to help TPH identify and prioritize geographic hot spots for delivering resources during a heat alert • The Harmonized Heat Warning and Information System (HWIS) was established in 2016 to reduce health vulnerability to heat and heat-related illnesses
Québec	• The government of Québec released a framework policy on electrification and green economy for 2030 o The government expanded the role for the Minister of the Environment, provided clear division of roles and responsibilities, and developed rigorous and transparent accountability o The target is 37.5% reduction in greenhouse gas emissions o The government aims for a major electrification of public transportation, subsidies for electric vehicles (e.g., prohibition of gasoline-powered light-duty vehicles), expansion of charging infrastructure, and other modes of transportation o It are also thinking about land use planning and remote working to reduce travel o Is aims to also decarbonize building heating by optimizing the use of electricity and natural gas o The plan also involves implementation considerations such as the emphasis of strong governance, increased innovative funding, agile implementation, and collaborating with Indigenous peoples o The plan has $6.7 billion in investments
New Brunswick	• In 2010, the province released a report called Capacity for Climate Change Adaptation in New Brunswick Municipalities, compiling feedback from municipalities about climate change adaptation o On the municipal level, passing by-laws and allocating staff to develop adaptation policies was the most critical priority, achieved through funding, open communication with municipalities, leadership by showing support for municipalities' plans, and working with the federal government to pass legislation that supports municipal plans o It was also recommended that the federal government become a leader in implementation by setting public policy mandates, providing funding for climate change adaptation development and enforcement, and providing accurate scientific information to the municipalities o Municipalities have also implemented training sessions for local communities, amendments to local statutes and zoning policies, they have improved conservation and developed strategic transportation and tourism plans
Nova Scotia	• The new 2021 Environmental Goals and Climate Change Reduction Act outlines long-term objectives for the Government of Nova Scotia with respect to climate change mitigation and adaptation and the reduction of greenhouse gas emissions, including: o Requiring any new build or major retrofit in government buildings, including schools and hospitals, that enters the planning stage after 2022 to be net-zero energy performance and climate resilient o To prioritize leased office accommodations in buildings that are climate resilient and meet net-zero energy performance starting in 2030

	• Nova Scotia is investing in a variety of energy-efficient programs, such as the HomeWarming program that covers energy-efficiency assessments and upgrades free of charge for low-income homes o The Clean Foundation and Efficiency Nova Scotia, in collaboration with Nova Scotia Power Inc., invested $60 million for upgrades in more than 8,000 homes since 2015 o In 2018, the Department of Energy and Mines partnered with Efficiency Nova Scotia and the Assembly of Nova Scotia Mi'kmaq Chiefs on a pilot program that provided energy-efficiency upgrades to 100 homes in all 13 Mi'kmaw communities across the province ▪ Due to the success of this pilot program, the provincial and federal governments are investing $14 million in the first four years of a 10-year Mi'kmaw Home Energy Efficiency Project
Prince Edward Island	• The government developed a 2040 Net Zero Framework which includes six pillars to achieve their goals o These goals include: transition to zero-emission vehicles and non-emitting fuel sources (e.g., active transportation routes, dependable public transit, car-sharing programs, transition to zero-emission vehicles sales by 2035, increased incentives for public zero-emission vehicle infrastructure), construct more efficient homes and buildings (e.g., land-use planning frameworks, pilot initiatives, reliable broadband internet, net zero-ready guidelines), accelerate use of advanced agricultural clean technologies, invest in early-stage carbon sequestration, develop clean industry and waste initiatives, and increase leadership capacity • The government has invested $25 million over five years to support sustainable transportation infrastructure as described in its Sustainable Transportation Action Plan such as urban and rural transit, vehicles and transportation, active transportation, and community design and infrastructure (e.g., new walking and bike paths, installing or widening paved shoulders, connecting existing trails, and other innovative ideas)
Newfoundland and Labrador	• Adaptation interventions that have been adopted in Newfoundland and Labrador include the construction of the Muskrat Falls hydroelectric generating facility that generates hydroelectric power from three dams to supply local communities with power, and the province's Home Energy Savings Program (HESP) that has been providing non-repayable grants up to $5,000 for energy-efficiency upgrades in electrically heated and fuel-oil homes, including insulation and air sealing
Yukon	• The Artic Institute of Community-Based Research (AICBR) has worked with communities in Yukon to understand the implications of changing environmental conditions on health and facilitate strategy developing for climate change adaptation and food security o Initiatives conducted by the AICBR include the Yukon Indigenous Community Climate Change Champions Project, which trained youth as champions for climate change adaptation in their communities, and the Linking a Changing Climate with Changing Traditional Diet, which is another project where the AICBR has developed two inventory maps of climate change and food-systems initiatives in the territory to help communities and policymakers find information about climate change adaptation • This report released by the territorial government in May 2019 outlines actions that could be taken in the province to reduce the health impact of climate change in Yukon, such as implementing the Fire Smarting (a program to make communities, buildings, and homes less prone to damage from wildland fires), flood proofing, having support networks, enhancing access to health services during climate change-related emergencies, and improving energy conservation

Northwest Territories	• In the 2030 NWT Climate Change Strategic Framework – 2019-2023 Action Plan, a few action areas include the province investing further in:
	  ○ Designing, building, and maintaining resilient infrastructure by constructing the "Tlicho All Season Road", "Great Bear River Bridge", and "Mount Gaudet All Season Road"
	  ○ Increasing local food security and food production

Nunavut	• Nunavut participates in the Northern Regional Adaptation Collaborative to facilitate planning and decision-making for a regional approach to climate change adaptation
	  ○ This collaborative brings together governments, communities and industry to develop adaptation strategies in Yukon, the Northwest Territories, and Nunavut which mainly focus on large-scale infrastructure planning
	• The Government of Nunavut's climate change adaptation *Upagiaqtavut* framework includes four focus areas for adaptation planning
	  ○ Partnership building
	  ○ Research and monitoring of impacts
	  ○ Education and outreach
	  ○ Government policy and planning
	• The Governments and Canada and Nunavut have secured funding to improve the reliability and resilience of the City of Iqaluit's water supply in light of the risk that climate change and extreme weather pose to the existing system

REFERENCES

1. Patterson B, Hilland J, Madden S, et al. 2021 Report on Health and Planning in Canada. Winnipeg: 2022.
2. Canada Government. Government of Canada announces funds for climate resilient infrastructure initiatives. 2022. https://www.canada.ca/en/office-infrastructure/news/2022/06/government-of-canada-announces-funds-for-climate-resilient-infrastructure-initiatives.html (accessed August 25, 2022 2022).
3. BC Centre for Disease Control. Healthy Built Environment Linkages Toolkit: making the links between design, planning and health. Vancouver, B.C.: Provincial Health Services Authority; 2018.
4. Huang C, Vaneckova P, Wang X, Fitzgerald G, Guo Y, Tong S. Constraints and barriers to public health adaptation to climate change: a review of the literature. *American Journal of Preventive Medicine* 2011; 40(2): 183-90.
5. Araos M, Austin SE, Berrang-Ford L, Ford JD. Public Health Adaptation to Climate Change in Large Cities: A Global Baseline. *Internatonal Journal of Health Services* 2016;46(1): 53-78.
6. Sharifi A, Pathak M, Joshi C, He B-J. A systematic review of the health co-benefits of urban climate change adaptation. *Sustainable Cities and Society* 2021; 74: 103190.
7. Dodman D, B. Hayward, M. Pelling, et al. Cities, Settlements and Key Infrastructure. In Pörtner H-O, Roberts DC, Tignor M, Poloczanska ES, Mintenbeck K, Alegría A, et al. (editors). Climate Change 2022: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, and New York, NY, USA: Cambridge University Press; 2022. p. 907-1040.
8. Sampson NR, Gronlund CJ, Buxton MA, et al. Staying cool in a changing climate: Reaching vulnerable populations during heat events. *Global Environmental Change* 2013; 23(2): 475-484.
9. Lesnikowski AC, Ford JD, Berrang-Ford L, et al. National-level factors affecting planned, public adaptation to health impacts of climate change. *Global Environmental Change* 2013; 23(5): 1153-1163.
10. Austin SE, Biesbroek R, Berrang-Ford L, Ford JD, Parker S, Fleury MD. Public Health Adaptation to Climate Change in OECD Countries. *International Journal of Environmental Research and Public Health* 2016; 13(9).
11. Meerow S, Keith L. Planning for Extreme Heat. *Journal of the American Planning Association* 2022; 88(3): 319-334.
12. Mees HLP, Driessen PPJ, Runhaar HAC. "Cool" governance of a "hot" climate issue: public and private responsibilities for the protection of vulnerable citizens against extreme heat. *Regional Environmental Change* 2015; 15(6): 1065-1079.
13. Paz S, Negev M, Clermont A, Green MS. Health Aspects of Climate Change in Cities with Mediterranean Climate, and Local Adaptation Plans. *International Journal of Environmental Research and Public Health* 2016; 13(4).
14. Park CY, Lee DK, Hyun JH. The Effects of Extreme Heat Adaptation Strategies under Different Climate Change Mitigation Scenarios in Seoul, Korea. *Sustainability* 2019; 11(14): 3801.
15. Monsalves-Gavilán P, Pincheira-Ulbrich J, Rojo Mendoza F. Climate change and its effects on urban spaces in Chile: A summary of research carried out in the period 2000-2012. *Atmósfera* 2013; 26(4): 547-566.
16. Rugel E. Green Space and Mental Health: Pathways, Impacts, and Gaps. Vancouver: 2015.

17. Salata F, Golasi I, Petitti D, de Lieto Vollaro E, Coppi M, de Lieto Vollaro A. Relating microclimate, human thermal comfort and health during heat waves: An analysis of heat island mitigation strategies through a case study in an urban outdoor environment. *Sustainable Cities and Society* 2017; 30(Complete): 79-96.

18. O'Neill MS, Jackman DK, Wyman M, et al. US local action on heat and health: are we prepared for climate change? *International Journal of Public Health* 2010; 55(2): 105-12.

19. Berisha V, Hondula D, Roach M, et al. Assessing Adaptation Strategies for Extreme Heat: A Public Health Evaluation of Cooling Centers in Maricopa County, Arizona. *Weather, Climate, and Society* 2017; 9(1): 71-80.

20. White-Newsome JL, McCormick S, Sampson N, et al. Strategies to reduce the harmful effects of extreme heat events: a four-city study. *International Journal of Environmental Research and Public Health* 2014; 11(2): 1960-88.

21. Mueller N, Rojas-Rueda D, Khreis H, et al. Changing the urban design of cities for health: The superblock model. *Environmment International* 2020; 134(105132): 9.

22. Lundgren Kownacki K, Gao C, Kuklane K, Wierzbicka A. Heat Stress in Indoor Environments of Scandinavian Urban Areas: A Literature Review. *International Journal of Environtal Research and Public Health* 2019; 16(4).

23. Alam M, Rajeev P, Sanjayan J, Zou PXW, Wilson J. Mitigation of heat stress risks through building energy efficiency upgrade: a case study of Melbourne, Australia. *Australian Journal of Civil Engineering* 2018; 16(1): 64-78.

24. Bélanger D, Abdous B, Gosselin P, Valois P. An adaptation index to high summer heat associated with adverse health impacts in deprived neighborhoods. *Climatic Change* 2015; 132(2): 279-293.

25. Macintyre HL, Heaviside C. Potential benefits of cool roofs in reducing heat-related mortality during heatwaves in a European city. *Environment International* 2019; 127: 430-441.

26. Porter JJ, Dessai S, Tompkins EL. What do we know about UK household adaptation to climate change? A systematic review. *Climatic Change* 2014; 127(2): 371-379.

27. Vellingiri S, Dutta P, Singh S, Sathish LM, Pingle S, Brahmbhatt B. Combating Climate Change-induced Heat Stress: Assessing Cool Roofs and Its Impact on the Indoor Ambient Temperature of the Households in the Urban Slums of Ahmedabad. *Indian Journal of Occupational and Environmental Medicine* 2020; 24(1): 25-29.

28. Shafique M, Luo X, Zuo J. Photovoltaic-green roofs: A review of benefits, limitations, and trends. *Solar Energy* 2020; 202: 485-497.

29. Sharma A, Woodruff S, Budhathoki M, Hamlet AF, Chen F, Fernando HJS. Role of green roofs in reducing heat stress in vulnerable urban communities—a multidisciplinary approach. *Environmental Research Letters* 2018; 13(9): 094011.

30. Teotónio I, Oliveira Cruz C, Matos Silva C, Morais J. Investing in Sustainable Built Environments: The Willingness to Pay for Green Roofs and Green Walls. *Sustainability* 2020; 12(8).

31. Madrigano J, Lane K, Petrovic N, Ahmed M, Blum M, Matte T. Awareness, Risk Perception, and Protective Behaviors for Extreme Heat and Climate Change in New York City. *International Journal of Environtal Research and Public Health* 2018; 15(7).

32. Burkart K, Meier F, Schneider A, et al. Modification of Heat-Related Mortality in an Elderly Urban Population by Vegetation (Urban Green) and Proximity to Water (Urban Blue): Evidence from Lisbon, Portugal. *Environmental Health Perspectives* 2016; 124(7): 927-34.

33. Keim ME. Building human resilience: the role of public health preparedness and response as an adaptation to climate change. *American Journal of Preventive Medicine* 2008; 35(5): 508-16.

34. Houghton A, Castillo-Salgado C. Health Co-Benefits of Green Building Design Strategies and Community Resilience to Urban Flooding: A Systematic Review of the Evidence. *International Journal of Environmental Research and Public Health* 2017; 14(12).

35. Owrangi AM, Lannigan R, Simonovic SP. Mapping climate change-caused health risk for integrated city resilience modeling. *Natural Hazards* 2015; 77(1): 67-88.

36. Mockrin MH, Fishler HK, Stewart SI. Does Wildfire Open a Policy Window? Local Government and Community Adaptation After Fire in the United States. *Environmental Management* 2018; 62(2): 210-228.

37. Banwell N, Rutherford S, Mackey B, Chu C. Towards Improved Linkage of Disaster Risk Reduction and Climate Change Adaptation in Health: A Review. *International Journal of Environmental Research and Public Health* 2018; 15(4).

APPENDICES

The following tables provide detailed information about the systematic reviews and primary studies identified in the rapid synthesis. The ensuing information was extracted from the following sources:

- systematic reviews - the focus of the review, key findings, last year the literature was searched, and the proportion of studies conducted in Canada; and
- primary studies - the focus of the study, methods used, study sample, jurisdiction studied, key features of the intervention and the study findings (based on the outcomes reported in the study).

For the appendix table providing details about the systematic reviews, the fourth column presents a rating of the overall quality of each review. The quality of each review has been assessed using AMSTAR (A MeaSurement Tool to Assess Reviews), which rates overall quality on a scale of 0 to 11, where 11/11 represents a review of the highest quality. It is important to note that the AMSTAR tool was developed to assess reviews focused on clinical interventions, so not all criteria apply to systematic reviews pertaining to delivery, financial or governance arrangements within health systems. Where the denominator is not 11, an aspect of the tool was considered not relevant by the raters. In comparing ratings, it is therefore important to keep both parts of the score (i.e., the numerator and denominator) in mind. For example, a review that scores 8/8 is generally of comparable quality to a review scoring 11/11; both ratings are considered "high scores." A high score signals that readers of the review can have a high level of confidence in its findings. A low score, on the other hand, does not mean that the review should be discarded, merely that less confidence can be placed in its findings and that the review needs to be examined closely to identify its limitations. (Lewin S, Oxman AD, Lavis JN, Fretheim A. SUPPORT Tools for evidence-informed health Policymaking (STP): 8. Deciding how much confidence to place in a systematic review. *Health Research Policy and Systems* 2009; 7 (Suppl1):S8).

All of the information provided in the appendix tables was taken into account by the authors in describing the findings in the rapid synthesis.

Appendix 1: Summary of findings from systematic reviews and other types of reviews about approaches to adapt health systems to climate change

Type of review	Focus of systematic review	Key findings	Year of last search/ publication date	AMSTAR (quality) rating	Proportion of studies that were conducted in Canada
Systematic reviews	Health co-benefits of urban climate change adaptation (6)	This study reviewed literature focused on the health co-benefits of urban climate change-adaptation measures. Health co-benefits of seven different categories of adaptation measures are discussed. • The reviewed literature covers various solutions ranging from the individual building scale (e.g., green roofs), to neighbourhood scale (neighbourhood parks, bicycle lanes), to city-wide networks of green and blue spaces • Nature-based solutions provide multiple health co-benefits such as enhancement of ecosystem services (e.g., clean air and water), reducing heat stress, and improving mental health • Urban planning and design measures that promote walkability and ensure outdoor thermal comfort can provide multiple benefits through enhancing physical activity, improving air quality, and creating environments conducive to mental health and well-being • Early warning systems for climate change events can improve well-being and reduce mortality, risk of disease or adverse health impacts • There is limited understanding among policymakers and the conventional siloed approach to urban planning and development does not lend itself easily to such integration • One prominent finding is that health co-benefits of some adaptation measures, such as those related to infrastructure, nature-based solutions, urban planning and design, and housing and building design, have received relatively more attention in the literature • In contrast, there is very limited quantitative evidence on the health co-benefits of adaptation measures associated with early warning systems, policy and governance, and knowledge and behaviour • Researchers and policymakers have always found it challenging to capture benefits associated with health and well-being due to their dispersed nature, temporality (as benefits accrue later), and the difficulty of putting an economic value on these • There is a need to develop methods to better understand costs and benefits in quantitative terms to aid decision-makers in prioritizing actions • Unless designed and implemented appropriately, some of the measures such as those related to nature-based solutions and urban planning/design may result in health trade-offs • Trade-offs related to air conditioning and poor design of green spaces has been documented in past studies	November 2019	4/10	Not reported
	Health co-benefits of green building design strategies and community	This systematic review considered evidence linking green building strategies in the Leadership in Energy and Environmental Design® (LEED) Rating System with the potential to reduce negative health outcomes following exposure to urban flooding	2008	2/9	Not reported

Type of review	Focus of systematic review	Key findings	Year of last search/ publication date	AMSTAR (quality) rating	Proportion of studies that were conducted in Canada
	resilience to urban flooding (34)	events. This review found evidence that certain green building strategies have the potential to reduce the risk of negative health outcomes following exposure to flooding. • Water quality, habitat loss and fragmentation, exposure to biodiversity, and percentage pervious cover in neighbourhoods with vulnerable populations were identified as key environmental determinants of health linking green building strategies and flooding events • The public-health co-benefits of these strategies include reducing the risk of waterborne diseases, flood-related morbidity and mortality, psychological harm, and interface between humans and wildlife. • Opportunities to Strengthen the LEED Rating Systems o The first step in this direction is the LEED pilot credits on resilient design, that provide the opportunity for project teams to: 1) perform a hazard assessment to identify the three natural hazards that pose the highest risk for the site; 2) incorporate design elements to protect building occupants from those hazards; and 3) incorporate design elements that will allow the building to continue functioning in the event of disruption to key utilities (i.e., design for passive survivability) • Flooding Resilience Policies o The U.S. Federal Emergency Management Agency (FEMA) offers an example of ways flooding resilience policies could be strengthened through input from research linking climate change with health outcomes and green building strategies o The 2014–2018 FEMA Strategic Plan includes an objective (4.2) to "incentivize and facilitate investment" in buildings and infrastructure that will reduce current and future economic losses related to disasters, particularly flooding-related risks • Community Planning o An example is the New York City plan, A Stronger, More Resilient New York, which was developed in response to the damage caused by Hurricane Sandy in 2012 o This plan and the recommendations of the related Building Resilience Task Force have focused on reducing the risk of wind damage and raising the first floor of occupied space and building equipment above the 100-year flood plain o Code recommendations also call for encouraging on-site backup power using renewable sources such as cogeneration and solar panels o The Building Resilience Task Force recommendations also encourage passive survivability (i.e., strategies that allow occupants to continue to use a building when the power and water are disconnected – for example, operable windows, water fixtures that can function when the power is out, and emergency lighting that functions for an extended period without electrical power • Transportation Planning			

Type of review	Focus of systematic review	Key findings	Year of last search/ publication date	AMSTAR (quality) rating	Proportion of studies that were conducted in Canada
		○ One of the key findings of the literature review is the link between flooding vulnerability and access to transportation to evacuate vulnerable areas before, during, and after flooding events ○ Cambridge, MA's climate change vulnerability assessment reflects these results, predicting that several subway and commuter rail hubs as well as three key bridges crossing the Charles River will represent priority vulnerabilities for the City by 2030			
	Cities, settlements, and key infrastructure (7)	This is chapter 6 in the intergovernmental report: "Climate Change 2022: Impacts, Adaptation and Vulnerability". This specific chapter addressed how urbanization processes generate vulnerability and exposure which combine with climate change hazards to increase urban risk and impacts. Globally, the most rapid growth in urban vulnerability and exposure has been in cities and settlements where adaptive capacity is limited, especially in unplanned and informal settlements in low- and middle-income nations and in smaller and medium-sized urban centres. Authors highlighted in this report that: • Globally, it is estimated that as much as US$94 trillion of investment is required between 2016 and 2040 to replace, upgrade and extend the world's physical infrastructure, much of which is aging and will require replacement. Given the typical lifespan of infrastructure, this is both an opportunity and an imperative to ensure this investment is low carbon and resilient to climate change risks • Regarding urban morphology and built form, authors found very limited research available to offer assessments of different urban-scale morphologies and urban-scale adaptation planning, including planning adaptation across supply chains and networked relationships with distant urban and rural places connected through trade and resource (financial, human and material) or waste flows • Interventions in the morphology and built form of cities can contribute to the reduction of the urban heat island effect and reduce the consequences of urban heatwaves. These can include installing air conditioning, establishing public cooling centres (i.e., for use during heatwaves), pavement watering and increasing surface albedo through 'cool roofs' (i.e., with high-reflectance materials) and walls • Air conditioning can significantly increase the local urban heat island and the choice of refrigerant has a significant impact on global warming potential • The relative efficiency of cool roofs compared with green roofs is variable, because while white roofs have similar potential to reduce the urban heat island, they can quickly turn grey due to dust and air pollution, losing their effectiveness, although these effects are now well studied and newer performance standards should account for aging and soiling effects on reflectivity • Aging of 'cool pavements' is more complex, which makes their long-term performance less reliable to predict	September 2021	3/10	Not reported

Type of review	Focus of systematic review	Key findings	Year of last search/ publication date	AMSTAR (quality) rating	Proportion of studies that were conducted in Canada
		• The cooling performance of green roofs is highly variable and depends on the actual water content of the green roof substrate, with dry vegetation performing poorly in terms of cooling • This holds true for regular vegetation and nature-based solutions (NBS) in general. For all built environment adaptations, changes are locked-in for a long time, and are likely to be expensive so that care is needed to avoid potential negative impacts on social equity and carbon-intensive construction • Architectural and urban design regulations at the single-building scale (building codes and guidelines) facilitate climate-responsive buildings that adapt to a changing climate and have the potential to collectively change user behaviour during extreme weather events. They include buildings that are adaptive to ensure user comfort during extremes of hot and cold as well as to floods (e.g., building on stilts and amphibian architecture). Changes to design standards can scale quickly and widely, but retrofit of existing buildings is expensive, so care must be taken to avoid potential negative impacts on social equity • Buildings can be adapted to the negative consequences of climate change by altering their characteristics, for example increasing the insulation values, increasing natural ventilation, preferably during the night, solar orientation of bedroom windows, applying high-albedo materials for the building envelope, altering the thermal mass, adding green roofs/facades to poorly insulated buildings and for water harvesting. In general, the most promising adaptation measures are a combination of solar shading with increased levels of insulation and ample possibilities to apply natural ventilation to cool down a building • However, it must be noted that the cooling potential of natural ventilation will decrease in the future because of increasing outdoor air temperatures. Increased insulation (including through green solutions) without shading and ventilation can also lead to adverse impacts through the lowering of night-time cooling. Similarly, air conditioning performance also decreases with increasing outdoor temperatures, in addition to being maladaptive where use increases anthropogenic heat emissions into the urban area, and global greenhouse gas emissions if powered by carbon-intensive energy systems • Passive cooling is a design-based, widely used strategy to create naturally ventilated buildings, making it an important alternative to address the urban heat island for residential and commercial buildings. Generally, passive cooling is achieved by controlling the interactions between the building envelope and the natural elements. Façade fixes such as overhangs, louvres and insulated walls are effective at shading buildings from solar radiation, while complex ones such as texture walls, diode roofs and roof ponds are effective at minimizing heat gains from solar radiation and ambient heat • Technological innovation can also be slow to embed itself in building norms and standards. Innovation also lies outside the formal sector and can include artisanal			

Type of review	Focus of systematic review	Key findings	Year of last search/ publication date	AMSTAR (quality) rating	Proportion of studies that were conducted in Canada
		building techniques that may have adaptive value. Examples from Latin America demonstrate how initiatives in informal settlement improvement associated with housing policy, guaranteeing access to land and decent housing, show the opportunity for overarching policies encompassing development, poverty reduction, disaster-risk reduction, climate change adaptation and climate change mitigation.			
	Pathways, impacts, and gaps of green space over mental health (16)	This review assessed scientific evidence regarding the relationship between green space and mental health, which was considered essential to inform the development of healthy, sustainable communities • Overall, the results of this evidence review indicate that exposure to green space has clear benefits for fundamental components of mental health, including overall mood and feelings of stress and anxiety • Green space also has potential as a complement to other forms of treatment (such as cognitive behavioural therapy) for individuals with mental health conditions, particularly those with mood and anxiety disorders • However, the weight of the evidence is relatively weak due to several common methodological flaws in this area of inquiry, including a reliance on small, convenience samples; a failure to properly account for confounding, particularly by socio-economic status; and a lack of longitudinal studies • Future research efforts should use clear, specific measures of green space to identify the characteristics and frequency of access to green space that are associated with longer-term benefits to mental health, and, in this way, support planners and policymakers in the design of healthier communities	January 2014	3/10	2/45
	U.K. household adaptation to climate change (26)	This review was conducted to understand what actions U.K. households have taken in response to, or in anticipation of, a changing climate, what drives or impedes these actions, and whether households will act autonomously. • Authors found that U.K. households struggle to build long-term adaptive capacity and are reliant upon traditional reactive coping responses • There is concern that these coping responses are less effective for some climate risks (e.g., flooding), cost more over the long term, and fail to create household capacity to adapt to other stresses • While low-cost, low-skill coping responses were already being implemented, the adoption of more permanent physical measures, behavioural changes, and acceptance of new responsibilities are unlikely to happen autonomously without further financial or government support • If public policy on household adaptation to climate change is to be better informed than more high-quality empirical research is urgently needed • Households are already undertaking low-cost, low-skill, coping responses to hot and cold weather by changing dietary intake, clothing, and routines	November 2012	5/10	0/14

Type of review	Focus of systematic review	Key findings	Year of last search/ publication date	AMSTAR (quality) rating	Proportion of studies that were conducted in Canada
		• Flood-proofing measures rolled out quickly and temporarily – door guards, toilet plugs, and airbrick covers – have also been implemented (five of the seven papers, agreed) • This suggests that low-level coping can occur without government intervention (four of the nine papers, strongly agreed) • More permanent measures – tiling floors, relocating electrical fittings, and removing impermeable surfaces – are expected to be adopted only if financial incentives are offered from government or insurers • Autonomous actions involving behavioural changes, acceptance of new responsibilities, or extensive-technical/resource-intensive actions • Those at risk of flooding tend to defer responsibility to government, believe the insurance safety-net will save them, and cite unfamiliarity with flood-proofing products as reasons for not acting (five of the seven papers strongly agreed) • While in relation to over-heating, a few households were found to have taken expensive adaptation decisions (e.g., installing air-conditioning units, interior redesign, and reflective roofs), despite the lack of public funds available to support these			
	Benefits, limitations, and trends of Photovoltaic-green roofs (28)	Photovoltaic (PV)-green roofs, a new development integrating the PV system with a green roof, provide additional benefits for renewable electricity production as compared to the green roof • This review identified the benefits and challenges associated with PV-green roofs in practice, and its future directions • A total of 145 published documents were reviewed, revealing that the PV-green roof is an effective strategy for producing clean energy on the building scale • There are still various challenges that hinder the large-scale implementation of PV-green roofs, including high initial costs, limited experimental data, and lack of awareness about the long-term benefits • These challenges can be overcome through the new cost-effective design of PV-green roofs and the adoption of the most appropriate materials, which can perform more effectively over a longer period • In addition, more real large-scale experimental studies are needed to evaluate the long-term performance of PV-green roofs in urban areas • Suggestions for further improvements include: providing the optimal design of PV-green roofs for each climatic region; improving laws and regulations; evaluating life-cycle assessment including social, environmental, and economic benefits over a longer period; and establishing interagency collaboration and cooperation tools for the wider adoption of PV-green roof projects	2019	3/10 (AMSTAR rating from McMaster Health Forum)	Not reported
	Climate change and its effects on urban spaces in Chile (15)	This study systematized the effects associated with climate change on urban spaces in Chile	2012	3/10	1/14

Type of review	Focus of systematic review	Key findings	Year of last search/ publication date	AMSTAR (quality) rating	Proportion of studies that were conducted in Canada
		• Only 14 research papers were found related to climate change in urban spaces, most of which were case studies focused on the capital, Santiago • The main effects on urban spaces were found in four areas: 1) increase in temperature (heat islands, heat waves); 2) health problems in vulnerable populations (cardiac complications, heat stroke, and respiratory diseases); 3) increased demand for water; and 4) damage to the urban infrastructure with resulting risk to the population • Considering the risks, authors identified the following measures needed: 1) effective incorporation of the potential impacts of climate change into territorial planning instruments; 2) increased green areas to mitigate the impact of heat waves; 3) limiting of housing or public services in areas at risk; 4) encouraging the design of adaptation plans by involving the vulnerable population; and 5) implementing water conservation measures			
	Public health adaptation to climate change in OECD countries (10)	This study aimed to examine how national-level public-health adaptation is occurring in Organisation for Economic Cooperation and Development (OECD) countries, as well as examine the roles national governments are taking in public-health adaptation, and critically appraise three key governance dimensions of national-level health adaptation – cross-sectoral collaboration, vertical coordination and national health adaptation planning – and identify practical examples suited to different contexts • Authors findings suggest national governments are primarily addressing infectious disease and heat-related risks posed by climate change, typically emphasizing capacity building or information-based groundwork initiatives • Following the adoption of the Paris Agreement and subsequent increased momentum for adaptation, research tracking adaptation is needed to define what health adaptation looks like in practice, reveal insights that can be taken up across states and sectors, and ensure policy-orientated learning • In this review, only Belgium reported adaptations on building and infrastructure; specifically, regulations for adaptation of buildings to ensure thermal comfort of buildings and their occupants (thermal insulation, solar protection shutters, ventilation)	March 2015	2/10	Not reported
	Heat Stress in Indoor Environments of Scandinavian Urban Areas (22)	This review aimed to describe how severe heat can occur and be identified in urban indoor environments, and what actions can be taken on the local scale • There is a connection between the outdoor and the indoor climate in buildings without air conditioning, but the pathways leading to the development of severe heat levels indoors are complex • This review shows that few studies have focused on the thermal environment indoors during heat waves, despite the fact that people commonly spend most of their time indoors and are likely to experience increased heat stress indoors in the future	Published in 2019	1/10	Not reported

Type of review	Focus of systematic review	Key findings	Year of last search/ publication date	AMSTAR (quality) rating	Proportion of studies that were conducted in Canada
		• Among reviewed studies, it was found that the indoor temperature can reach levels 50% higher than the outdoor temperature, which highlights the importance of assessment and remediation of heat indoors • Most Heat-Health Warning Systems (HHWS) are based on the outdoor climate only, which can lead to a misleading interpretation of the health effects and associated solutions • In order to identify severe heat, six factors need to be taken into account:air temperature, heat radiation, humidity, air movement and the physical activity and clothes worn by the individual • This paper highlights the need for the development of a heat index or the adjustment of current thresholds to apply specifically to indoor environments, its different uses, and vulnerable groups • There are several actions that can be taken to reduce heat indoors and thus improve the health and well-being of the population in urban areas • Examples of effective measures to reduce heat stress indoors include the use of shading devices such as blinds and vegetation as well as personal cooling techniques such as the use of fans and cooling vests • The integration of innovative Phase Change Materials (PCM) into facades, roofs, floors, and windows can be a promising alternative once no negative health and environmental effects of PCM can be ensured			
	Constraints and Barriers to Public-Health Adaptation to Climate Change (4)	This review shows that public-health adaptation essentially can operate at two levels, namely, adaptive-capacity building and implementation of adaptation actions • However, there are constraints and barriers to public-health adaptation arising from uncertainties of future climate and socio-economic conditions, as well as financial, technologic, institutional, social capital, and individual cognitive limits • Climate change is prompting a rethinking of consumption patterns, energy choices, and lifestyles • This presents an important opportunity for public health, as many actions to combat climate change also could bring substantial health co-benefits; for example, appropriate GHG-mitigation strategies in transport, household energy, food and agriculture, and power generation all can have substantial net benefits for health	2010	1/10	Not reported

Type of review	Focus of systematic review	Key findings	Year of last search/ publication date	AMSTAR (quality) rating	Proportion of studies that were conducted in Canada
Other types of reviews (e.g., scoping, integrative, narrative)	Public-Health Adaptation to Climate Change in Large Cities: A Global Baseline (5)	• Local governments are positioned to protect populations from climate health risks, but it is unclear whether municipalities are producing climate adaptive policies • In this study, authors developed and applied systematic methods to assess the state of public health adaptation in 401 urban areas globally with more than 1 million people, creating the first global baseline for urban public-health adaptation • Authors found that only 10% of the sampled urban areas report any public-health adaptation initiatives, and those initiatives most frequently addressed risks posed by extreme weather events and involve direct changes in management or behaviour rather than capacity building, research, or long-term investments in infrastructure • The key finding is that a large majority of municipalities sampled (90%) are not reporting implementation of any public-health adaptation initiatives • Extreme heat, floods, storms, and other unspecified disasters are the most addressed health risks of climate change in municipalities; however, there remains a large adaptation gap because studies have found that several cities reported recognition of risk from extreme heat (88 cities) and more frequent storms (43 cities), suggesting a time lag between cities' self-reported recognition of risk and the formation of actual plans • Most heat-related initiatives found in this study aim to reduce the long-term effects of the urban heat island through green infrastructure projects, and those projects included expanding the urban tree canopy and converting rooftops into vegetable gardens Green urban design can promote active lifestyles through the production of a more appealing urban environment, thus improving public health	March 2014	N/A	11/41
	Improved linkage of disaster risk reduction and climate change adaptation in health (37)	Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) are essential for addressing the ever present, complex and increasing risk. There is a need to clearly articulate why linking DRR and CCA is important in health; however, little is known about how DRR and CCA should be linked in health • This review presents the current state of knowledge of linking DRR and CCA in health • This includes the potential for maximizing conceptual synergies such as building resilience, and reducing vulnerability and risk • Technical and operational synergies are identified to link DRR and CCA in health, including policy, Early Warning Systems, vulnerability and risk assessment, health-systems strengthening, infrastructure resilience, disaster preparedness and response, and health-impact pathways • Public-health actors have a central role in building these links due to their expertise, work functions, and experience in addressing complex health risks The review concludes with recommendations for future research, including how to better link DRR and CCA in health, and the opportunities, challenges and enablers to build and sustain these links	Published in 2018	NA	Not reported

Appendix 2: Summary of findings from primary studies about approaches to adapt health systems to climate change

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
Local adaptation plans in cities with Mediterranean-type climate (13)	*Publication date*: April 2016 *Jurisdictions studied:* Adelaide, Australia Barcelona, Spain Cape Town, South Africa Los Angeles, the U.S. Santiago, Chile *Methods used:* Documentary analysis	Survey of municipal climate plans that were published online between two to eight years ago by municipalities Focus on different cities (<20,000 population < 4,000,000) with a Mediterranean climate that have climate action plans	Not applicable	Cities with a Mediterranean-type climate (Med-cities) are particularly susceptible to health risks from climate change since they are in biogeographical hot-spots. Authors identified five Med-cities with a climate change adaptation plan: Adelaide, Barcelona, Cape Town, Los Angeles and Santiago. Rising Temperatures: Heat Waves, Heat Stress, Heat Island Effect Identified as a local risk by all five cities Adelaide, Australia: • Water sensitive urban design; increase vegetation in capital works projects • Urban Design strategies and approaches incorporating urban heat island mitigation measures (network of greenways, tree-lined streets, open spaces) Barcelona, Spain: • Include adaptation criteria (to heat island effect risks) in drafting new urban development plans; reform existing ones • Convert fleet of buses to hybrid/electrical as measure to combat heat island effect Cape Town, South Africa: • "Heat-Health" action plans, including plans in respect of emergency medical services • Nation-wide climate change and atmosphere monitoring systems/networks: Climate Change Response Monitoring and Evaluation System Los Angeles, United States: • Million Trees Initiative to increase tree canopy throughout the city Santiago, Chile: • Green standards in new development projects; protection of ventilation corridors • More green spaces to reduce heat island effect Heavy rainfall and flooding identified as a local risk by all five cities Adelaide, Australia:

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
				• Design public spaces to assist in adapting to climate change; incorporation of green infrastructure into the renewal of the city • Adaptation measures and protection from predicted sea-level rise in development plans Barcelona, Spain: • Flood management through risk mapping, prevention plan, emergency plan, action plan for flood zones Cape Town, South Africa: • Flood management through a Climate Adaptation Plan of Action (CAPA): sea-level rise risk assessment and economic modelling; coastal protection • Zone by-law; stormwater management responses to more intense rainfall, sea-level rise and storm surges Los Angeles, United States: • Climate forecasting, sea-level rise; vulnerability and risk assessments Santiago, Chile: • Flood management through monitoring system WebGIS • Revitalizing existing water flow networks (river irrigation channels); permeable pavements • More green spaces to reduce flooding exposure
The effects of extreme-heat adaptation strategies under different climate change mitigation scenarios (14)	*Publication date:* July 2019 *Jurisdiction studied:* Seoul, Korea *Methods used:* Modelling using parameters related to mortality as the criteria for the extreme-heat assessment and the Mean Radiant Temperature (MRT)	Not applicable	The study site is Jangwee-ro, which is a street (length: 755 m, width: 7 m) running east–west, located in the northern part of Seoul, Korea. The road is bordered by buildings 2.6–18.6 metres in height. This study site has two characteristics. First, none of the adaptation strategies evaluated in this study are currently implemented. The street	In this study, authors aimed to determine the effect of adaptation strategies to reduce the mortality risk under two climate change-mitigation scenarios, using Representative Concentration Pathways (RCP) 2.6 and 8.5. Authors selected four street-level adaptation strategies: green walls, sidewalk greenways, reduced-albedo sidewalks and street trees. As an extreme heat-assessment criterion, authors used a pedestrian mean radiant temperature threshold, which was strongly related to heat mortality. The results, projected to the 2050s, showed that green walls, greenways, and reduced-albedo sidewalks could adequately reduce the extreme heat impacts under RCP2.6; however, only street trees could reduce the extreme heat impacts under RCP8.5 in the 2050s. This implies that required adaptation strategies can vary depending on the targeted scenario.

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
			consists of old asphalt and sidewalk pavement, which reflects heat directly onto pedestrians. There is also no tree cover that could lower the incident radiation. Second, this street consists of low-rise buildings, which have low thermal comfort. For these characteristics, the study site has low vulnerability to extreme-heat events.	Authors found that extreme heat, especially the frequency, slightly increased under RCP2.6, but dramatically increased under RCP8.5 by the 2050s. All four investigated adaptation strategies (green walls, sidewalk greenways, reduced-albedo sidewalks and street trees) could alleviate the increase in extreme heat under RCP2.6 to reduce the EHD (Extreme Heat Days) to below 10 days and the AMRT (Average Mean Radiant Temperature) to below 55.88 C by the 2050s. However, under RCP8.5, green walls, sidewalk greenways, and reduced-albedo sidewalks could not provide any adequate adaptation effects by the 2050s, and only street trees offered sufficient reductions in the impacts for the entire investigated timespan. This study focused on a specific site in Seoul, and the projected climate impacts and the calculated adaptation effects may differ according to the target site. Thus, further research on the methodology used in this study is warranted to better translate it into a decision-making support tool.
The Superblock model as design for healthy cities (21)	*Publication date:* January 2020 *Jurisdiction studied:* Barcelona, Spain *Methods used:* Health impact assessment	Barcelona residents ≥20 years (N = 1,301,827) on the projected Superblock area level (N = 503), following the comparative risk assessment methodology. Authors estimated expected changes in (a) transport-related physical activity, (b) air pollution (NO2), (c) road traffic noise, (d) green space, and (e) reduction of the urban heat island (UHI) effect through heat reductions. Additionally, authors scaled available risk estimates and calculated attributable health-impact fractions. Estimated endpoints were preventable premature mortality, changes	There are 503 Superblocks designed in Barcelona, which have been developed by the Urban Ecology Agency (BCNEcologia). Superblocks are constructed cells that connect neighbourhoods with a mixed land use, and high potential for social capital. The Superblocks are a new innovative model in urban and transport planning that reframe the current mobility paradigm and places people and well-being at the centre.	The Barcelona Superblock model is an innovative urban and transport planning strategy that aims to reclaim public space for people, reduce motorized transport, promote sustainable mobility and active lifestyles, provide urban greening and mitigate effects of climate change. In this study, authors estimated that 667 premature deaths (95% CI: 235-1,098) could be prevented annually through implementing the 503 Superblocks. The greatest number of preventable deaths could be attributed to reductions in NO2 (291, 95% PI: 0-838), followed by noise (163, 95% CI: 83-246), heat (117, 95% CI: 101-137), and green space development (60, 95% CI: 0-119). Increased physical activity for an estimated 65,000 persons shifting car/motorcycle trips to public and active transport resulted in 36 preventable deaths (95% CI: 26-50); authors also found that Superblock promotes physical activity in children given they facilitate safe and independent child play. The Superblocks were estimated to result in an average increase in life expectancy for the Barcelona adult population of almost 200 days (95% CI: 99-297), and result in an annual economic impact of 1.7 billion euros (95% CI: 0.6-2.8).

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
		in life expectancy and economic impacts.		It was estimated that with the implementation of the 503 planned Superblocks, 667 premature deaths could be prevented annually in Barcelona, translating into a substantial economic impact of 1.7 billion euros and considerable average gains in life expectancy of almost 200 days due to reductions in harmful environmental exposures. Further gains in life expectancy are expected with green space development and uptake of public and active transport. The present study is the first study to comprehensively estimate the health impacts of this proposed real-life innovative intervention, holistically considering the expected changes in the multiple urban and transport planning-related exposures. By far the strongest mortality impacts for the Superblocks resulted from air pollution reductions (291 deaths), under the assumption that the association between NO2 and mortality is causal. This finding is linked to the assumption of reduction of traffic volume and decline in congestion that reduces NO2 concentrations substantially. Estimated road traffic noise and heat mitigation effects were of considerable magnitude (163 and 117 deaths, respectively), emphasizing the importance of these understudied environmental exposures in urban environments. Further, green space development in the Eixample neighbourhood alone resulted in a considerable number of preventable deaths (60), underlining the epidemiological significance of vegetation in cities in times of increasing population densities, general space scarcity and climate change.
A public-health evaluation of cooling centres (19)	*Publication date:* January 2017 *Jurisdiction studied:* Maricopa County, Arizona, U.S. *Methods used:* Mixed methods (observational surveys, interviews and visitors' surveys)	The field evaluation teams conducted observational surveys at 53 facilities and interviewed 52 managers. The visitor surveys were completed by 658 participants from 22 cooling centres	Most cooling centres operated in facilities that already provided health or human services for the community. The facilities tended to operate the cooling centre during their normal weekday hours of operation. The cooling centres in Maricopa County were	With nearly 4 million residents, Maricopa County (MC) is one of the largest metropolitan centres in the U.S. Southwest. It is home to Glendale, Mesa, Phoenix, Scottsdale, and other cities. The region experiences temperatures of more than 108F from May through October; on average, temperatures reach a maximum of 108F 26 days a year. The objective of this project was to evaluate Maricopa County cooling centres and gain insight into their capacity to provide relief for the public during extreme-heat events. The evaluation team estimated that up to 2000 individuals used the cooling centres each day. The cooling centres appear to reach some of the region's most vulnerable populations. Many visitors were unemployed, lacked a permanent residence, had no reliable

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
			often housed within community, senior, or religious centres, which offered various services for at least 1,500 individuals daily.	access to home air conditioning, and/or had a chronic medical condition. Cooling centre use might be improved if signs were present or more visible to attract potential visitors. In addition, knowledge and use of cooling centres might improve by promoting cooling centre services through distributing current information and accurate maps of cooling centre locations. Authors concluded that the cooling centres provide a valuable service and reach some of the region's most vulnerable populations.
Potential benefits of cool roofs in reducing heat-related mortality during heatwaves (25)	*Publication date:* June 2019 *Jurisdiction studied:* West Midlands, U.K. *Methods used:* Modelling	Not applicable	Potential effect of reflective 'cool' roofs – to reduce local ambient temperatures, and the subsequent impact on heat-related mortality in the West Midlands, U.K., with analysis undertaken for the summer of 2006, as well as two shorter heatwave periods in 2006 and 2003.	In built up areas, temperatures are commonly observed to be higher than those in surrounding rural areas, due to the Urban Heat Island (UHI) effect. Building and city scale interventions have the potential to reduce health risks due to UHI. Reflective 'cool' roofs have a higher albedo (i.e., reflectivity) compared with ordinary roofs, which increases the amount of reflected solar radiation. Authors found that the UHI contributes up to 40% of heat-related mortality over the summer period and that cool roofs implemented across the whole city could potentially offset 18% of seasonal heat-related mortality associated with the UHI (corresponding to 7% of total heat-related mortality). Cool roofs reduced average UHI intensity by ~23%, and reduced heat-related mortality associated with the UHI by ~25% during a heatwave. Cool roofs were most effective at reducing peak temperatures during the daytime, and therefore have the potential to limit dangerous extreme temperatures during heatwaves. Cool roofs have the greatest effect on mean near-surface air temperatures when used on buildings one to two storeys high, and while the effect was negligible on buildings taller than four storeys, a tall building downwind could counteract this by mixing cooled air down to street level. For cool roofs, the adjacent top floor rooms will benefit the most, which is also where the greatest hazard is (indoor temperatures are generally higher for the top floor of buildings). However, this effect is diminished if the building is very well insulated. Temperature reductions were dependent on the category of buildings where cool roofs were applied; targeting only commercial and industrial type buildings contributed more than

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
				half of the reduction for heatwave periods. This modelling suggested that modifying half of all industrial/ commercial urban buildings could have the same impact as modifying all high-intensity residential buildings in the West Midlands.
Mitigation of heat-stress risks through building energy-efficiency upgrade (23)	*Publication date:* May 2018 *Jurisdiction studied:* Melbourne, Australia *Methods used:* Modelling	The city of Melbourne in Australia was selected for this study because heatwaves appeared to affect mortality more in Melbourne than any other cities in Australia. Distributions of different energy-rated houses and the percentage of people living in those houses were calculated. Indoor heat-stress conditions of the different energy-rated houses were calculated using building simulation software EnergyPlus and two well-established heat stress indices: wet bulb globe temperature and discomfort index. Two types of Melbourne dwellings, a duplex and single-storey houses, were used in this study.	In Australia, the Nationwide House Energy Rating Scheme (NatHERS) is used to assess the thermal performance of buildings, and rates the building on a scale of 0–10 stars depending on the heating and cooling energy requirements of a house for the comfortable indoor environment (NatHERS 2014). The higher the energy star rating, the lower is the requirement for artificial heating and cooling to maintain occupant thermal comfort.	People spend most of their time indoors during a heatwave period, and such assessment of indoor heat stress is an important issue for public-health care. In this study, the impact of building energy efficiency in mitigating the risks of experiencing heat stress by the occupants' different energy-rated dwellings was investigated under the 2009 Melbourne heatwave scenario. Authors found that residents of 0.9 energy star-rated houses are approximately 50% more vulnerable to experiencing heat stress during a heatwave compared to the residents of 5.4 energy star-rated houses. It was revealed that upgrading energy efficiency of existing dwellings could be one of the most effective heatwave mitigation measures. If the entire lower energy-rated houses can be upgraded to 5.4-star, the percentage of people that are at risk of being exposed to extreme heat stress conditions for six hours could be reduced from 50% to only 4%.
Modification of heat-related mortality in an elderly urban population by vegetation and proximity to water (32)	*Publication date:* July 2016 *Jurisdiction studied:* Lisbon, Portugal *Methods used:* Risk assessment and modelling	Not applicable	Urban green (urban vegetation) and urban blue (water bodies) impacts on heat-related excess mortality in the elderly > 65 years old, from 1998 to 2008.	Heat-related mortality shows intra-urban variations that are likely due to differences in urban characteristics and socio-economic status. Authors found an association between mortality and a 1°C increase in universal thermal climate index (UTCI) above the 99th percentile (24.8°C), which was stronger for areas in the lowest Normalized Difference Vegetation Index (NDVI) quartile (14.7% higher; 95% CI: 1.9, 17.5%) than for areas in the highest quartile (3.0%; 95% CI: 2.0, 4.0%). In areas > 4 km from water, a 1°C increase in UTCI above the 99th percentile was associated with a 7.1% increase in mortality (95% CI: 6.2, 8.1%), whereas in areas ≤ 4 km from water, the estimated increase in mortality was only

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
				2.1% (95% CI: 1.2, 3.0%). Authors concluded that urban green and blue appeared to have a mitigating effect on heat-related mortality in the elderly population in Lisbon. Increasing the amount of vegetation may be a good strategy to counteract the adverse effects of heat in urban areas. Authors findings also suggest potential benefits of urban blue that may be present several kilometers from a body of water.
Local government and community adaptation to wildfires (36)	*Publication date:* May 2018 *Jurisdiction studied:* U.S. *Methods used:* Case study	Eight locations in the United States that were affected by wildfires, selected to represent different regions and periods of time	Not applicable	Experience with wildfire and other natural hazards suggests that disasters may open a "window of opportunity" leading to local government policy changes. Authors examined how destructive wildfires affected progress toward becoming fire adapted in eight locations in the United States. Authors found that across diverse settings, communities consistently used the most common tools and actions for wildfire mitigation and planning. Nearly all sites reported changes in wildfire suppression, emergency response, and hazard planning documents. Expansion in voluntary education and outreach programs to increase defensible space was also common, occurring in half of our sites, but land-use planning and regulations remained largely unchanged. Across diverse settings, authors found that destructive fires did not change the tools and actions typically used for wildfire mitigation and planning, and that local and state governments alike declined to take larger action on land-use planning or building standards in response to these wildfires. Across diverse sites, the most common response to wildfire experience was to invest in suppression and emergency response. Improvements in suppression are a common tactic in response to wildfire threats, and typically garner community support. For example, authors described that residents in rural Oklahoma (Loco-Healdton, OK) passed a public safety tax to improve firefighter resources. At the national level as well, improving fire suppression remains a key area of policy emphasis and attention. Authors also found consistent investment in vegetation mitigation on public lands was another commonly used tool to reduce wildfire risk.
Analysis of urban heat island mitigation strategies	*Publication date:* April 2017	Not applicable	The impact of cool roofs, urban vegetation, cool pavement, and a	This study examined different mitigation strategies of the urban microclimate by taking into consideration the campus of the Sapienza University of Rome. Authors found that combining cool

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
on microclimate, human thermal comfort and health during heat waves (17)	*Jurisdiction studied:* Rome, Italy *Methods used:* Case study		combination of them on Mediterranean Outdoor Comfort Index (MOCI) compared with the present configuration of the site and a configuration with a ground surface characterized by asphalt only in total absence of vegetation	roofs, urban vegetation and cool pavement leads to a decrease in the MOCI with respect to the present configuration of the site which in some areas was of −3.37 units and a mean decrease of the air temperature of 1.49°C. What affects this result the most is the shielding effect and the evapo-transpiration phenomenon of the plants together with, in absence of direct shortwave radiation, the highest albedo of the ground surface. On the other hand, a small contribution is given by the cool roofs: if used as a unique mitigation strategy, they can determine a decrease in the mean MOCI of almost 0.01 units. However, the height of the buildings characterizing the site must be taken into consideration, distancing the roofs' tops from the human height level. Then an important factor was the deterioration of the conditions that would happen if only asphalt was used for the site and all the vegetation was removed. As a matter of fact, in this case a mean and maximum increase in the MOCI of 0.19 and 3.05 units respectively was noticed. For what concerns the thermal balance of the pedestrians, the increase in the mean radiant temperature also was important, being in some points of about 40°C.
Awareness, risk perception, and protective behaviours for extreme heat and climate change (31)	*Publication date:* July 2018 *Jurisdiction studied:* Ne.w York City, US. *Methods used:* Cross-sectional	A random digit dial telephone survey of 801 NYC adults aged 18 and older was conducted from 22 September to 1 October, 2015	Not applicable	Authors explored the drivers of socio-economic disparities in heat-related vulnerability in New York City, the perceived risk of heat exposure and climate change, and barriers to protective behaviours. Authors found that 28% of New Yorkers did not have access to a functioning AC or used it less than half the time or not at all during very hot weather. The findings indicate that racial and socio-economic disparities in heat illness and death are partially explained by AC access. Non-Hispanic blacks and individuals with a household income of less than $30,000 per year, were both independently less likely to possess AC than those of other races/ethnicities and those with higher household incomes. The most frequently reported reasons for lack of AC or lack of AC use were financial barriers, and additionally, for AC use, a desire to conserve energy (which may also indicate a financial barrier). In adjusted models, odds of not possessing AC were greater for non-Hispanic blacks compared with other races/ethnicities, odds ratio (OR) = 2.0 (95% CI: 1.1, 3.5), and for those with low annual household income, OR = 3.1 (95% CI: 1.8, 5.5). Only 12% reported going to a public place with AC if they could not keep cool at home. While low-income individuals were

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
				less likely to be aware of heat warnings, they were more likely to be concerned that heat could make them ill and that climate change would affect their health than participants with a higher household income, OR = 1.6 (95% CI: 1.0, 2.3).
Public and private responsibilities for the protection of vulnerable citizens against extreme heat (12)	*Publication date:* September 2014 *Jurisdiction studied:* Arnhem and Rotterdam, the Netherlands *Methods used:* Qualitative study (two multi-stakeholder workshops and one focus group)	Not applicable	Not applicable	In cities in temperate climate zones, the elderly, disabled and socially deprived are most vulnerable to extreme heat, as witnessed by increased mortality rates during heat waves in Europe and North America. This study explored potential governance arrangements between public and private actors by analysing the perceived responsibilities and their underlying considerations of public and private actors. Furthermore, the study looks into what can be learned from 10 foreign cities where a heat-stress policy has been implemented. Authors concluded that "cool" governance suggests extensive public responsibilities throughout the policy process, but that policy implementation needs public–private networks tailored to these differentiated approaches. Some of the responsibilities of the public sector are to install or subsidize air conditioners for low-income vulnerable elderly people, turning public buildings into cooling centres during a heat wave in districts with high concentrations of vulnerable citizens, and risk communication.
An adaptation index to high summer heat associated with adverse health impacts in deprived neighbourhoods (24)	*Publication date:* May 2015 *Jurisdiction studied:* Quebec, Canada *Methods used:* Cross-sectional	Most deprived areas in nine cities of 100,000 or more inhabitants in Quebec, in total, 3,485 people were interviewed at home	Not applicable	This study adapted an index to high summer heat whose validity was tested by correlating it with self-reported adverse health impacts to heat. An index of various behavioural adaptations was developed using a Multiple Correspondence Analysis. This individual-level adaptation index summarizes a range of 14 easy-to-use and energy-efficient solutions for cooling off or protecting oneself against the sun, both at home and in other places, whether indoors or out. In addition, it shows that adaptation to heat goes beyond air conditioning in the home. People who experience adverse effects of heat on their health tend to adopt more of the behaviours measured by the index than those perceiving little or none, regardless of their age group or presence of air conditioning at home. Among the 14 variables, two were related to infrastructure or buildings: using the balcony or the backyard to cool off in the evening, and frequenting places other than home for air conditioning to cool off.

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
Reaching vulnerable populations during heat events (8)	*Publication date:* April 2013 *Jurisdiction studied:* Phoenix, Detroit, New York City, and Philadelphia, U.S. *Methods used:* Multiple case study	173 community members and organizational leaders during 2009–2010	Not applicable	Current literature indicates that emergency preparedness plans, heat-health warning systems, and related interventions may not be reaching or supporting behaviour change among those most vulnerable in heat events. In this study, four U.S. cities with documented racial/ethnic and socio-economic disparities and diverse heat preparedness strategies were studied. Authors found that decision-making related to commonly promoted behaviours such as air conditioner use and cooling centre attendance is complex, and these resources are often inaccessible financially, physically, or culturally. Low-income populations may be less likely to participate in help-seeking behaviours during heat events, such as making health-related calls; the most vulnerable populations, including the elderly, low-income, and homeless, are frequently not perceiving themselves as vulnerable or changing their daily practices during heat events. As described by community members in all case study cities, strategies for staying cool during heat events included use of air conditioners and fans, going to cooler locations, taking cold showers, drinking water, adjusting schedules to avoid travelling during the hottest parts of the day, opening windows, sitting in the shade, and wearing lighter clothes. In this study, many of those with air conditioners appeared to use them, but financial cost was the barrier cited by most of these community members. Participants noted utility bills as an obstacle to staying cool in the summer. Going to cooler locations, including public pools, libraries, malls, movie theatres, homeless shelters, parks, senior centres, and churches, and many described barriers related to these places. Usage was inconsistent and residents faced barriers to accessing some cooling areas. Those who were homeless or worked with homeless individuals explained exclusionary policies in parks and libraries and noted that some homeless shelters are not air-conditioned. Barriers to using cooling centres included concerns about culturally appropriate food, accommodations or care for pets, safe and affordable transportation to and from the centres, distrust in the entities offering services at the centres or transportation to them.

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
Strategies to reduce the harmful effects of extreme heat events (20)	*Publication date:* February 2014 *Jurisdictions studied:* Phoenix, Detroit, New York City, and Philadelphia, U.S. *Methods used:* Multiple case study	73 semi-structured interviews with government and non-governmental organization leaders representing public health, general social services, emergency management, meteorology, and the environmental planning sectors	Not applicable	In this study, authors identified activities that leaders used to reduce the harmful effects of heat for residents in four cities of the U.S. Authors found that cooling centres are possibly the most commonly used heat preparedness strategy in cities across the nation for protecting health during heat events, yet many barriers to their use exist. These include: stigma, hygiene, health and safety, access, and the difficulty with evacuating one's home. Some interviewees spoke of the misconception that cooling centres are only for seniors or homeless individuals, deterring people from going to them. Additionally, cooling centres are intended to prevent heat-related health problems, but they may create a host of new health concerns. For instance, one social-service provider described concerns with hygiene in a New York cooling centre, leading staff to keep a supply of extra clothes and, in the past, sending clients to the park to shower in fountains before returning. Further, access to centres may be difficult. While many cities have paratransit or public transportation, cooling centres are not always on the direct route of these services.
Planning for extreme heat (11)	*Publication date:* December 2021 *Jurisdiction studied:* U.S. *Methods used:* Cross-sectional	The first sample aimed to be representative of how diverse cities across the United States are planning for extreme heat. The second sample captured the perspectives of planning professionals more broadly, but especially those with an interest in heat and climate planning. A final list of 69 cities were surveyed.	Not applicable	Existing literature on heat planning focuses on heat island mapping and modelling, whereas few studies delve into heat planning and governance processes. Authors surveyed planning professionals from diverse cities across the United States to establish critical baseline information for a growing area of planning practice and scholarship. Authors found numerous strategies that have been proposed for enhancing resilience to extreme heat, but no clear evidence of effectiveness. These strategies fall into two main categories: heat mitigation and heat management. Heat-mitigation strategies are design and planning interventions aimed at reducing the built environment's contribution to extreme heat. These include land-use policies, urban design, urban greening, and waste heat. Heat-management strategies are efforts to prepare for and respond to extreme heat and include strategies related to energy, personal exposure, public health, and emergency preparedness. Urban design strategies refer to site-level elements that mitigate heat, such as building and street orientation to maximize shade, constructed shade structures, and the use of "cool" or more reflective pavements. Whether through urban forestry, green

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
				stormwater infrastructure, green roofs, or parks, increasing vegetation is a commonly cited heat resilience strategy. Reducing waste heat can also mitigate heat, for example, through reduced air-conditioning and vehicle use, weatherization programs, and increasing the reflectivity of roofs and other surfaces. Heat management includes energy-related strategies, such as enhancing energy grid resilience to avoid power outages during heat events and policies to make energy, and thereby cooling, more accessible and affordable. Reducing personal exposure involves changes to how infrastructure, facilities, and workers operate to minimize human exposure to extreme heat. Public-health interventions for extreme heat include public education and information campaigns, emergency preparedness strategies focus on warning systems for extreme heat, planning and coordinating responses to heat emergencies, and establishing cooling centres (e.g., libraries, churches) where people can seek shelter and assistance.
Role of green roofs in reducing heat stress in vulnerable urban communities (29)	*Publication date:* September 2018 *Jurisdiction* studied: Chicago, U.S. *Methods used:* Modelling	Not applicable	Not applicable	This study discussed strategies to identify vulnerable neighbourhoods in the City of Chicago, where green roofs could achieve multiple goals to mitigate urban heat-related challenges. This modelling approach integrated information from multiple sources: social vulnerability indices, high-resolution temperature simulations over the urban area, and observed electricity (air conditioning) consumption data. Authors identified many census tracts in south and west Chicago, along with isolated tracts throughout the city that would strongly benefit from green-roof implementation. Authors suggest that even though green roofs reduce temperatures in general, they will have a limited effect on temperatures in the most vulnerable neighbourhoods. The greatest temperature reductions were realized in the hottest areas of the city. AC consumption showed inverse relationship with vulnerability and a positive relationship with roof surface temperatures, although in both cases, the relationship was weak. Downtown Chicago and affluent neighbourhoods with high roof temperatures in Northern Chicago were consuming the most electricity.

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
				Authors also found common challenges with siting green roofs. For example, reducing electricity consumption or addressing heat vulnerability may be conflicting objectives.
The willingness to pay for green roofs and green walls (30)	*Publication date:* April 2020 *Jurisdiction studied:* Portugal *Methods used:* Economic evaluation	Non probabilistic sampling for convenience	Not applicable	Green infrastructure, such as green roofs/walls, plays a key role in addressing urban problems. This study evaluated the willingness-to-pay of owner/tenants for green roofs/walls in residential buildings and determine the influence of multiple factors. The willingness-to-pay was measured as an increase in the monthly housing expenses, like renter banking payments. The results show that willingness-to-pay for green roofs/walls in Portugal is relatively low. The average willingness-to-pay reported by respondents is similar for green roofs and walls, of 3% and 2.13%, respectively. Summary statistics indicate that the benefit of recreation is at the forefront of individuals' concerns, even more than esthetics. Users highly value the accessibility of green roofs, and significant differences are found in the willingness-to-pay for accessible and inaccessible green roofs, varying from 4% and 2%, respectively. Greater knowledge about the benefits of green roofs and walls leads to greater willingness-to-pay values. The amount that users are willing to invest increases with increasing monthly incomes. Lastly, residents who are responsible for the expenses have a different perception of the value of money and are more likely to make lower investments.
National-level factors affecting planned, public adaptation to health impacts of climate change (9)	*Publication date:* October 2013 *Jurisdiction studied:* Global *Methods used*: Cross-sectional with calculation of two indices build on action-level data on adaptation	Not applicable	Not applicable	This study provides preliminary indication that countries with strong institutional frameworks for environmental governance and/or incentives structures are also likely to be higher adaptors to climate change. This research indicates no evidence of commitment to mitigation and commitment to adaptation being significantly correlated. The study determined that GDP is significantly related to health adaptation, but at the same time weaker performance among some of the world's wealthiest countries indicates that resource availability alone may be insufficient to provoke high levels of adaptation in the absence of policy commitments. This suggests that barriers to adaptation exist within high-income countries that limit how much adaptive capacity is being translated into health-adaptation action. Longitudinal research is needed to more fully understand what leads to more or less health adaptation.

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
Assessing cool roofs and its impact on the indoor ambient temperature (27)	*Publication date:* March 2020 *Jurisdiction studied:* Ahmedabad, India *Methods used:* Cross-sectional (measuring the indoor ambient temperature and humidity, as well as applying a questionnaire-based survey)	Not applicable	Cool roof interventions were compared with the non-intervention roof types (tin, asbestos/cement sheet, and concrete)	This study aimed to identify the efficient cool roof technologies that reduce indoor temperature of the households and improve the heat resilience of dwellings located in the urban slums of Ahmedabad. The results revealed that selected cool roof technologies including Thermocol insulation, solar reflective white paint on the outer surface of the roof, and Modroof are effectively reducing the indoor temperature as compared to the non-intervention roofing. Validated cool roof technologies can be promoted as these structures do not require legal sanctions and are easily dismantled and installed in multiple places, and safeguards the investment of urban poor.
Local action on heat and health (18)	*Publication date:* April 2010 *Jurisdiction studied:* U.S. *Methods used:* Cross-sectional	Cities were sampled (n=101) on the basis of being large in size and having data available for a planned epidemiologic study of heat and hospital admissions among elderly people	Not applicable	This study aimed to establish baseline information on local efforts to reduce heat vulnerability, including public advisories, minimizing greenhouse gas emissions, and mitigating urban heat islands. Authors got information from 70 respondents, and their results suggest that many U.S. communities are not adequately prepared to prevent the effects of hot weather on the health of residents, and several are not undertaking activities, either individual measures or a comprehensive set, to reduce heat exposure and emissions of the greenhouse gases that contribute to global climate change. Cool paving materials and vegetated roofs were common heat-mitigation strategies.
Mapping climate change-caused health risk for integrated city resilience modelling (35)	*Publication date:* January 2015 *Jurisdiction studied:* Manila (The Philippines), Bangkok (Thailand), Lagos (Nigeria) and Vancouver (Canada) *Methods used:* Data analytics and mapping	Not applicable	Not applicable	The Coastal Cities at Risk (CCaR) project is a multidisciplinary team project involving four large coastal cities: Manila (The Philippines), Bangkok (Thailand), Lagos (Nigeria) and Vancouver (Canada). One of the project objectives includes development of a system dynamics simulation model to assess the resilience of the participating cities to climate change caused by sea-level rise and riverine flooding. The resilience model is designed to integrate physical, economic, health, social and organizational impacts of climate change. This study presented the methodology for providing spatial and temporal information on climate change health impacts for use in the resilience simulator.

Focus of study	Study characteristics	Sample description	Key features of the intervention(s)	Key findings
				The final maps indicate that the Richmond and Delta regions of Metro Vancouver are more vulnerable to climate change caused by sea-level rise and flooding compared to other municipalities. The paper demonstrated how composite health-impact maps can be used both as an input for resilience modelling, as well as a "stand-alone" product for the assessment and development of mitigation and adaptive strategies for coastal cities.

McMaster University | HEALTH FORUM

>> Contact us

1280 Main St. West, MML-417
Hamilton, ON, Canada L8S 4L6
+1.905.525.9140 x 22121
forum@mcmaster.ca

>> Find and follow us

mcmasterforum.org
healthsystemsevidence.org
socialsystemsevidence.org
mcmasteroptimalaging.org
mcmasterforum